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Spatial Correlation Analysis of Urban Air Quality in Henan Province

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ABSTRACT

Aiming at the impact relationship between urban air qualities, this paper uses correlation analysis methods to study the spatial correlation distribution characteristics of urban air quality and its relationship with topography, and uses the partial correlation and multiple correlation analysis to explore the impact degree between cities in the strong correlation region, as well as the city atmosphere type. The results show that: (1) There is a significant correlation between urban air quality in Henan province, the correlation is linear with distance, and propagation ability is inverse proportional with terrain elevation; (2)The province's air quality presents three independent systems and four relevance belt, the cities in the northern area have north-south correlation characteristics, and the cities in the central area have northwest-southeast correlation characteristics; (3)The cities whose air quality is greatly affected by neighboring cities in the topography are distributed along the 250m elevation belt, Luohe, Zhengzhou and Anyang are air pollution radiation cities, which greatly affect the air quality of Xuchang, Zhumadian, Xinxiang and Hebi.

Keywords: Urban air qualities; Correlation analysis; Partial correlation analysis; Multiple correlation analysis; Spatial relationship; Henan province

INTRODUCTION

The rapid growth of China's economy and the rapid advancement of urbanization have greatly promoted the accumulation of material wealth, and the improvement of people's living standards. Inefficient resource utilization and rapid population agglomeration have also caused serious ecological and environmental problems in many urbanized regions, especially atmospheric environmental problems in the meantime. It has also caused serious ecological and environmental problems, especially atmospheric environmental problems. Air pollution has seriously been affecting the atmospheric environment and public health in and around urban areas, hindering regional sustainable development. Air quality issues have been receiving more and more attentions.

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. In fact, although the amount of atmospheric pollutant emissions is the main factor determining urban air quality, the regional topographic conditions, wind direction, wind speed, precipitation and temperature very serious impacts on the spread of the pollutants, regional transmission and transport is one of the important features of air pollution, the air quality of a region is affected by the pollution conditions of its adjacent regions, and there is a certain correlation between regions.

Air Quality Index (AQI) is a quantitative data describing the short-term air quality situation and changing trend of a region. Based on the impact of various pollutants on human health, ecology and environment, according to the Environmental Air Quality Standard, AQI simplifies the monitored main air pollutant concentrations, as PM10, PM2.5, SO_2, NO_2, O_3, CO and so on, into a single conceptual index, classifies air quality as 0~500, the larger the index, the more serious the pollution situation and the greater harm to the human body.

Based on the daily average data of urban AQI from 2015.1 to 2018.12 in Henan province, this paper utilizes correlation analysis methods to study the spatial distribution characteristics of urban air quality and its relationship with topography, to explore its spatial distribution characteristics and evolution mechanism, in order to provide some scientific references for the provincial air pollution joint defense.

DATA AND RESEARCH METHODS

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, 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. The data used in the study mainly include 30m×30m DEM provided by Computer Network Information Center (http:// www.gscloud.cn); 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).

2. Correlation Test Model

2.1 Correlation Analysis

The correlation coefficient is a statistical indicator used to reflect the correlation degree between urban AQI, by the sum of multiplied deviations of standardized two urban AQI.

Suppose x_i and y_i, $i=1,2,3\cdots n$ respectively are the AQI of city X and Y, the correlation coefficient between them is defined as

$$r=(\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y}))/\sqrt{D(X)D(Y)} \quad (1)$$

Where $\bar{x}$ and $\bar{y}$ respectively are the AQI means of city X and Y; $D(X)$ and $D(Y)$ respectively are the AQI standard deviations of city X and Y; r belongs to $[-1,1]$, the larger $|r|$ means the stronger relevance between X and Y, $|r|=1$ means the AQIs of city X and Y are linearly dependent, $r=0$ means the AQIs of city X and Y are independent. Using the statistic $t=r\sqrt{(n-2)}/\sqrt{1-r^2}\sim t(n-2)$ as the significant basis for judging relevance between X and Y, when t greater than the standard value t_α of the significance level $\alpha=0.05$, the relevance between X and Y is significant.

2.2 Partial Correlation Analysis

Correlation coefficient reflects the correlation degree of the AQIs between the two cities as a whole. Urban air quality is the result of the combination of urban air pollutant emissions and surrounding cities, partial correlation analysis refers to controlling the influence of other cities in a specific urban agglomeration analyze the correlation degree of the AQIs between two cities, defined as:

$$Pr_{12(3,\cdots q)}^{2}=(R_{1(2,3,\cdots q)}^{2}-R_{1(3,4,\cdots q)}^{2})/(1-R_{1(3,4,\cdots q)}^{2}) \quad (2)$$

Where $R_{1(2,3,\cdots q)}^{2}$ is the proportion of the total variance of the AQI of the city X_1 that is linearly interpreted by the AQIs of $X_2, X_3, \cdots X_q$.

Pr belongs to $[0,1]$, the larger Pr means the stronger relevance between X_1 and X_2 when controlling the influence of cities $X_3, X_4, \cdots X_q$, $Pr=1$ means the AQI relevance between city X_1 and X_2 is only relevant to these two cities, $Pr=0$ means the AQI relevance between city X_1 and X_2 is obtained by conduction in neighboring cities. Using the statistic $t=(Pr\sqrt{(n-q-2)})/\sqrt{1-Pr^2}\sim t(\mathrm{n}-q-2)$ as the significant basis for judging relevance between X_1 and X_2, when t greater than the standard value t_α of the significance level $\alpha=0.05$, the relevance between X_1 and X_2 is significant.

2.3 Multiple Correlation Analysis

Multiple correlation coefficient reveals the relevance of AQI between two cities in different aspects with partial correlation coefficient, describes the comprehensive relevance characteristics between the AQI of one city with the AQIs of all adjacent cities in a specific urban agglomeration $\Theta=\{X_i, i=1,2,\cdots q\}$, defined as:

$$Mr_i=\sqrt{\sum(\hat{x}_i-\bar{x})^2/\sum(x_i-\bar{x})^2} \quad (3)$$

where $\hat{x}_i$ the regression estimate of the AQI of city X_i, with the regression equation $x_i=\alpha_0+\alpha_1 x_1+\cdots+\alpha_j x_j+\cdots\alpha_q x_q (i\neq j)$. Mr belongs to $[0,1]$, the larger Mr means the stronger relevance of city X_i with the rest cities in the urban agglomeration Θ. $Mr=1$ means the AQI of city X_i has a linear relation with the rest cities, in other words, the air pollution in city X_i mainly comes from the spread of these cities. $Mr=0$ means the AQI of city X_i is independent with the rest cities, in other words, the air pollution in city X_i mainly comes from its own air pollutant emissions. Using the statistic $F=Mr^2(n-q-1)/(1-Mr^2)q\sim F(q,n\text{-}q\text{-}1)$ as the significant basis for judging relevance between X_1 and the rest cities, when t greater than the standard value t_α of the significance level $\alpha=0.05$, the relevance between X_1 and the rest cities is significant.

SPATIAL CORRELATION ANALYSIS OF URBAN AIR QUALITY IN HENAN

1. Analysis of Urban Spatial Distribution Characteristics in Henan

Figure 1a and Figure 1b are the elevation DEM and the 250m contours Interval interpolation results. The topography of the province is characterized by west high east low, middle low south and north high. According to the classification criteria of mountain scales, the province's topography could be divided into three elevation zones as below half one standard mountain(the elevation=<250m), half one standard mountain(250<the elevation=<500m) and above one mountain(the elevation>500m). These three elevation zones distributes from east to west by the obvious boundary. The first is the plain area, distributed in the east of 113°30'E including Anyang, Hebi, Fuyang, Xinxiang, Kaifeng, Shangqiu, Zhoukou, Xuchang, Weihe and Zhumadian. The second is the middle altitude area, located from 112°30'E to 113°30'E, including Jiaozuo, Luoyang, Zhengzhou, Pingdingshan, Nanyang and Xinyang; there are mountain regions with the elevation higher than 2 standard mountain elevation in the straight line connection between Zhengzhou and Pingdingshan, Luoyang and Pingdingshan and Luoyang and Nanyang. The third is the high altitude area, only containing a city of Sanmenxia, and there are mountainous regions of higher than 2.5 standard mountain elevation between Luoyang and Nanyang of the second elevation zone.

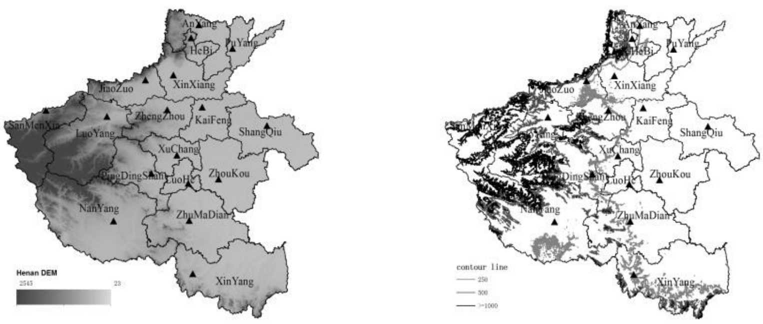

Figure 1. The topographic distribution in Henan

2. Correlation Analysis of Urban Air Quality Index in Henan

Based on the 1365 days urban AQIs between 2015.1-2018.9, using the Equation 1 calculating the correlation coefficient between cities the correlation coefficient between cities, the results are listed in Table 1, all of them are significant under the confidence level of 99.99% with the test of $t \sim t(1363)$.

There is a strong relevance between the cities in Henan, the mean value of the correlation coefficient is of 0.72, the maximum value is of 0.93 appearing in Zhumadian-Luohe and Anyang-Hebi, the minimum value is of 0.53 between Hebi and Xinyang. The relevance is linear with the distance(100 km) between cities the confidence level of 99.99%. The linear regression equation is $r = -0.0969d + 0.9586$, the correlation coefficient decrease 0.0969 per 100 km. The linear regression equation very different in first two elevation zones, which respectively are $r = -0.0995d + 0.9682$ and $r = -0.1169d + 0.9845$, the decrease rate in the second elevation zone is higher than the first elevation zone with 20 percentage points.

Table 1: The correlation coefficient between cities

	AY	HB	JZ	KF	LY	LH	NY	PDS	PY	SMX	SQ	XX	XY	XC	ZZ	ZK	ZMD
AY		93	82	84	76	72	66	73	88	69	68	88	56	78	86	69	67
HB	93		84	83	78	72	61	71	85	69	67	90	53	77	84	67	68
JZ	82	84		79	87	74	66	79	75	74	66	88	59	79	89	67	70
KF	84	83	79		75	83	71	77	88	66	77	85	64	89	89	81	76
LY	76	78	87	75		76	73	83	70	84	62	79	63	79	85	68	73
LH	72	72	74	83	76		84	88	75	69	80	77	81	92	81	90	93
NY	66	61	66	71	73	84		84	65	70	70	66	81	82	73	81	85
PDS	73	71	79	77	83	88	84		70	75	70	77	74	91	85	78	86
PY	88	85	75	88	70	75	65	70		64	76	86	56	79	84	74	68
SMX	69	69	74	66	84	69	70	75	64		60	70	61	71	75	64	68
SQ	68	67	66	77	62	80	70	70	76	60		72	69	78	70	84	77
XX	88	90	88	85	79	77	66	77	86	70	72		59	82	91	74	72
XY	56	53	59	64	63	81	81	74	56	61	69	59		73	64	81	89
XC	78	77	79	89	79	92	82	91	79	71	78	82	73		89	86	87
ZZ	86	84	89	89	85	81	73	85	84	75	70	91	64	89		76	76
ZK	69	67	67	81	68	90	81	78	74	64	84	74	81	86	76		90

ZMD	67	68	70	76	73	93	85	86	68	68	77	72	89	87	76	90

In order to analyze the spatial distribution of the relevance, the following research divides these correlation degree into three levels according to the correlation coefficient, namely weak relevance ($C \le 0.75$), relevance ($0.75 < C \le 0.85$) and strong relevance ($0.85 < C \le 0.95$).

In terms of spatial distribution, Shangqiu, Nanyang and Sanmenxia, located in three different elevation zones, form three independent atmospheric systems, and their correlation with other cities in the province is weak. There is a strong relevance between cities with topological adjacency in the same elevation zone, which is significantly higher than the topological adjacency cities in different elevation zones, and the relevance distribution are significantly different in the different elevation zones.

On the first elevation zone, a strong relevance region is formed in the city north of the Yellow River, and the dependence relation shows a north-south trend, for example, the correlation coefficient between Puyang and Kaifeng is 0.88, but they are not topological adjacent; The rest cities form the other strong relevance region, the dependence relation shows a northwest and southeast trend. On the second elevation zone, Jiaozuo is strong relevant with Luoyang and Zhengzhou. Between the first and second elevation zones, there are strong relevance between Jiaozuo and its adjacent Xinxiang, Zhengzhou and its adjacent Xinxiang as well as its northern cities, Pingdingshan and its adjacent Xuchang and Luohe.

In general, the urban air quality in the province presents three independent systems and four relevance belts, as shown in Figure 2. The first relevance belt is located on the first elevation zone, along Zhumadian-Zhoukou-Kaifeng-Puyang; The second relevance belt go across the 1st and 2nd elevation zones along Zhengzhou-Xinxiang-Hebi-Anyang; the 3rd relevance belt is located in the 2nd elevation zone, along Luoyang-Jiaozuo; the 4th relevance belt spans the 1st and 2nd elevation zones, along Pingdingshan - Luohe - Zhumadian.

3. Partial correlation analysis of Urban air quality index in Henan

For studying the correlation degree of urban AQIs in the strong relevance regions, using formula (2) to calculate the partial correlation coefficient between cities, under the 99.99% confidence level 99.99% , passing the hypothesis test $t \sim t(1363-q)$ (q is the total number of cities in the region), The results are shown in Table 2($Pr \times 100$). In the table NC means non-significant, Pr_{ij} is the partial correlation coefficient controlling the impacts of other cities in its the city in the strong relevance regions.

There are some differences between the partial correlation coefficient and the correlation coefficient of some cities in their strong relevance region. The most obvious difference is Luoyang in Jiaozuo's strong correlation region, Puyang in Kaifeng's strong correlation region, Kaifeng in Puyang's strong correlation region, Pingdingshan in Xuchang's strong correlation region, Jiaozuo in Zhengzhou's strong correlation region, Xinyang in Zhumadian's strong correlation region, where their correlation coefficients are inversely proportional to their partial correlation coefficients. Xinxiang's partial correlation coefficients with Anyang's is non-significant in Anyang's strong correlation region, this thing also appears on Kaifeng in Puyang's strong correlation region, Puyang in Kaifeng's strong related region, Xuchang in Zhumadian's strong related region, which shows that the air quality relationships between them are transmitted through other cities in the strong related region.

Table 2: The partial correlation coefficient between cities

	AY	HB	JZ	KF	LY	LH	PDS	PY	XX	XY	XC	ZZ	ZK	ZMD
AY		60						38	NC			20		
HB	66								46					
JZ					46				36			22		
KF								48	NC		42	21		
LY			37											
LH							15				39		27	46
PDS						8					51			20
PY	41			46					18					
XX	NC	32	23	NC				25				37		
XY														54
XC				35		32	41					18	14	
ZZ	10		37	20					32		38			
ZK						25					17			35
ZMD						41	18			57	NC		23	

For the area of a city is different with the area of the other city in its strong correlation region in calculating, the partial correlation coefficients do not have symmetry. Defining the impact degree β_{ij} as the proportion of Pr_{ij} in the strong correlation region of city j,

$$\beta_{ij} = \frac{Pr_{ij}}{\sum_j Pr_{ij}} \tag{4}$$

$\beta_{ij} > \beta_{ji}$ means the impact of city j on city i is greater than i on city j.

Using formula (4) and Table 2 to calculating the impact degree of all cities, the results are showed in Figure 3. The spatial distribution of the impact degree shows three impact centers, as Anyang, Zhengzhou and Luohe, which have great impacts on the air quality of their adjacent cities.

4. Multiple correlation analysis of urban air quality index in Henan

The partial correlation coefficient studies the correlation degree of urban AQIs between two cities in the strong relevance regions through controlling the impact of other cities in the strong correlation region.

Figure 2. Correlation Belt

Figure 3. Impact Relationship

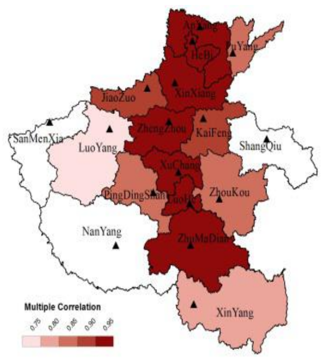

Figure 4 Multiple Correlation

In order to study the correlation degree of a city with all cities in its strong correlation region, the multiple correlation coefficients are calculated by formula (3), under the 99.99% confidence level 99.99%, passing the hypothesis test $F \sim F(q, 1364 - q)$ (q is the total number of cities in its strong correlation region), The results are shown in Figure 4.

Among the cities with strong correlation regions, the cities with large air quality relations(greater than 0.90), with adjacent cities are Xuchang, Luohe, Zhumadian, Zhengzhou, Xinxiang, Anyang and Hebi. All of them are distributed from north-south along the dividing line between the first and second elevation zone (Figure 4). Considering with their partial correlation coefficient distribution characteristics (Figure 3), it can be found that

Luohe, Zhengzhou and Anyang are air pollution radiation cities, which greatly affect the air quality of Xuchang, Zhumadian, Xinxiang and Hebi.

CONCLUSIONS

This paper uses correlation analysis methods to study the spatial correlation distribution characteristics of urban air quality and its relationship with topography, and uses the partial correlation and multiple correlation analysis to explore the impact degree between cities in the strong correlation region, as well as the city atmosphere type. The results show that:

(1) There is a significant correlation between urban air quality in Henan province, the correlation is linear with distance, and propagation ability is inverse proportional with terrain elevation.

(2)The province's air quality presents three independent systems and four relevance belt, the cities in the northern area have north-south correlation characteristics, and the cities in the central area have northwest-southeast correlation characteristics.

(3)The cities whose air quality is greatly affected by neighboring cities in the topography are distributed along the 250m elevation belt, Luohe, Zhengzhou and Anyang are air pollution radiation cities, which greatly affect the air quality of Xuchang, Zhumadian, Xinxiang and Hebi.

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