Spatiotemporal Variation of AOD and Geographical Detection of Influencing Factors in the Beijing-Tianjin-Hebei Region: Postprint

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Abstract

Based on MODIS 3 km AOD remote sensing data, this study employs spatial autocorrelation models and the Geographical Detector to investigate the spatiotemporal variation characteristics of AOD and its influencing factors in the Beijing-Tianjin-Hebei region from 2010 to 2016. The results indicate: (1) The annual average AOD value in the Beijing-Tianjin-Hebei region from 2010 to 2016 was 0.83, with Tianjin exhibiting the highest annual average AOD value in the study area, followed by Hebei Province, and Beijing showing the lowest. The 7-year variation trend of AOD in the study area and its sub-regions was generally consistent, showing a pattern of initial decrease, followed by increase, and then small fluctuations. (2) Spatial autocorrelation analysis reveals that the spatial distribution of AOD in the Beijing-Tianjin-Hebei region exhibits significant positive correlation. Local high-high clustering areas are mainly concentrated in southeastern Beijing, southern Tianjin, and central-southern Hebei Province, while low-low clustering areas are distributed in the northwestern mountainous regions. The areas of both high-high and low-low clustering zones in the study area show a decreasing trend, while non-significant areas exhibit an expanding trend. (3) Geographical Detector results demonstrate that the dominant influencing factors vary across different regions. For Beijing, the primary influencing factor is NDVI, followed by population density, with significant interaction effects between the two. For Tianjin, the dominant factor is wind speed, while anthropogenic factors such as population density and secondary industry GDP also exert substantial influence, with strong interaction effects between wind speed and these factors. For Hebei Province, the dominant factor is population density, followed by GDP and secondary industry GDP, with overall weaker interaction effects. Analyzing the influence mechanism of AOD spatial differentiation in the Beijing-Tianjin-Hebei region through the Geographical Detector holds significant importance for air pollution control in China.

Full Text

Preamble

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Abstract:
The Beijing-Tianjin-Hebei region, located in the Bohai Rim, is the most economically developed region in northern China and also one of the most polluted. Aerosol Optical Depth (AOD) can effectively reflect the degree of air pollution. This study analyzed MODIS 3km AOD remote sensing data, with results of great significance to understanding air pollution in China. Firstly, the temporal variation characteristics and spatial autocorrelation of AOD in the Beijing-Tianjin-Hebei region from 2010 to 2016 were analyzed. Factors including precipitation, wind speed, relative humidity, Normalized Difference Vegetation Index (NDVI), Gross Domestic Product (GDP), secondary industry GDP, and population density were selected as influencing factors of AOD. Geographical detection was used to analyze the trend of the factors' contribution ratio and its dominant affecting factors in different regions and times within the Beijing-Tianjin-Hebei region. The results showed: (1) The annual average AOD of the Beijing-Tianjin-Hebei region was 0.83 from 2010 to 2016. Tianjin had the highest annual average AOD, followed by Hebei and Beijing. The annual variation trend of AOD showed an overall pattern of decline followed by rise and then small fluctuations, with similar patterns in each local region. (2) Spatial autocorrelation analysis indicated significant positive correlation among the spatial distribution of AOD in the Beijing-Tianjin-Hebei region. Local high-accumulation areas were mainly concentrated in the southeastern part of Beijing, southern Tianjin, and central-southern Hebei Province. Low-accumulation areas were concentrated in the northwestern mountains. The areas of high and low accumulation in the Beijing-Tianjin-Hebei region showed decreasing trends, while non-significant areas showed increasing trends. (3) Geographical detection analysis indicated that the primary influencing factor was NDVI in Beijing, followed by population density, and their interaction was significant. The dominant factor was wind speed in Tianjin. Human factors such as population density and secondary industry GDP were also important, with significant interaction effects between wind speed and other factors. The dominant factor was population density in Hebei Province, followed by GDP and secondary industry GDP, with relatively weak overall interaction. In the past, correlation analysis of influencing factors was based on linear relationships across the entire area, while geographical detection not only has no wireless assumptions but also

reveals linear, nonlinear, and spatial relationships of driving factors. From this perspective, geographical detection is more reliable for studying influencing factors. This study applied geographical detection to analyze the impacting factors of AOD in the Beijing-Tianjin-Hebei region, proving its feasibility in this field and region. Meanwhile, the results also have important reference value for air pollution prevention, industrial and agricultural layout, and urban construction in the Beijing-Tianjin-Hebei region.

Keywords: Aerosol Optical Depth (AOD); spatiotemporal variations; geographical detection; influencing factors; Beijing-Tianjin-Hebei region

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1 Data and Methods

1.1 Data Sources

(1) AOD Data: Terra MOD04_3km AOD products from 2010 to 2016 were obtained from NASA' s LAADS Web (https://ladsweb.nascom.nasa.gov/). The data had a spatial resolution of 3 km, temporal resolution of 1 day, and wavelength of 550 nm at level 2. After removing 11 days of missing data, 2,547 days of data were retained. AOD data were processed using ENVI IDL and the MCTK toolkit for batch processing, including format conversion, projection transformation, and extraction.

(2) Influencing Factors Data: Meteorological data including precipitation, wind speed, and relative humidity were obtained from the China Meteorological Administration (http://data.cma.cn/). NDVI data, GDP, secondary industry GDP, and population density data were also collected. All data were resampled to 3 km resolution to match the AOD data.

1.2 Methods

Geographical Detection: Geographical detection is a statistical method for analyzing spatial stratified heterogeneity. It includes factor detection, interaction detection, risk detection, and ecological detection. This study used factor detection and interaction detection to analyze the influencing factors of AOD. The factor detection formula is:

where q measures the explanatory power of factor X on Y. Interaction detection identifies whether two factors have independent, enhanced, or weakened effects on Y.

Spatial Autocorrelation Analysis: Moran' s I was used to analyze spatial autocorrelation of AOD. Moran' s $I > 0$ indicates positive spatial correlation, Moran's $I < 0$ indicates negative spatial correlation, and Moran's $I = 0$ indicates random distribution.

2 Results

2.1 Spatial Distribution of AOD and Influencing Factors

The 7-year average distribution of AOD and its influencing factors in the Beijing-Tianjin-Hebei region showed significant spatial heterogeneity [Figure 1: see original paper]. High AOD values were concentrated in the southeastern part of Beijing, southern Tianjin, and central-southern Hebei, while low values were found in the northwestern mountainous areas.

2.2 Temporal Variation Characteristics

From 2010 to 2016, the annual average AOD in the Beijing-Tianjin-Hebei region was 0.83. Tianjin had the highest AOD (0.90), followed by Hebei (0.79) and Beijing (0.79). The annual variation showed a decreasing trend from 2010 (0.88) to 2012 (0.79), then a slight increase and fluctuation.

2.3 Factor Contribution Analysis

Contribution Rates: The contribution rates of influencing factors varied by region and year [Figure 5: see original paper]. Population density had the highest average contribution rate (25.38%), followed by GDP (23.47%), secondary industry GDP (21.75%), wind speed (13.57%), precipitation (6.56%), NDVI (4.77%), and relative humidity (4.50%).

Dominant Factors: The dominant factors differed across regions: - **Beijing:** NDVI was primary, followed by population density - **Tianjin:** Wind speed was dominant, with significant interactions - **Hebei:** Population density was dominant, followed by GDP and secondary industry GDP

Interaction Effects: Interaction between factors enhanced their individual effects. The interaction between wind speed and other factors was particularly significant, with q-values often exceeding 0.5.

2.4 Spatial Autocorrelation

Moran' s I values for AOD were consistently positive (0.72 in 2010, 0.83 in 2016), indicating strong spatial clustering. High-high clusters were found in urban areas, while low-low clusters were in mountainous regions.

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Note: Figure translations are in progress. See original paper for figures.