Agglomerate Fog Early Warning Method based on GWR Model

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Abstract

In order to realize the early warning of Agglomerate fog-prone sections, reduce accidents and ensure the safety of personal and property. Taking Shandong Province as an example, according to the statistics of the time and location of the roads where the agglomerate fog occurs and the number of occurrences in 2018, the time and space analysis of the agglomerate fog occurrence is carried out, and combined with the analysis of the correlation between the frequent occurrence of agglomerate fog and the elevation of Shandong Province, river density, and Normalized Difference Vegetation Index (NDVI), construction of Geographically Weighted Regression (GWR) model to study the geographical environment conditions of highways prone to foggy weather, the influence of regional altitude, river density analysis and NDVI on the occurrence of agglomerated fog. The research results show that the number of agglomerate fog occurrences in different regions has a strong spatial correlation, that is, the environment of different regions has a greater impact on the number of agglomerate fog occurrences. The agglomerate fog early warning model built with regional river density, elevation difference and NDVI as independent variables can effectively predict agglomerate fog-prone areas. The prediction result shows that more than 98% of the area is within the allowable range of error.

1 Introduction

In order to increase the traffic speed more effectively, strengthen the connectivity between various cities. Expressway construction is developing rapidly. According to the data released by the Ministry of Transport in May 2020, the total mileage of expressways has reached 149,600 kilometers, and the density of expressway networks has further increased, brings great convenience to daily travel, and getting closer and closer to the goal of becoming a transportation power. However, with the rapid development of high-speed, traffic safety has also become the focus of social attention. In particular, traffic accidents caused by special severe weather such as agglomerate fog have greatly hindered and threatened the improvement of high-speed traffic safety. As a "mobile killer" of traffic safety, agglomerate fog has the characteristics of rapid occurrence, strong regionality, and difficulty in forecasting and forecasting. It will cause a sudden decrease in visibility, a decrease in road adhesion coefficient and an increase in the psychological burden of drivers, and it is extremely prone to vehicle skidding and rear-end collision. Such phenomena are extremely harmful to highway traffic safety and are likely to cause major traffic accidents. According to statistics from the Traffic Management Bureau of the Ministry of Public Security, there are 3188 areas where there are frequent agglomerate fog on the expressway, and the number is increasing every year. The monitoring and early warning of agglomerate fog has become an important problem that needs to be solved urgently in traffic safety ^[1].

The hazards caused by agglomerate fog have attracted the attention of the transportation industry, and many scholars have conducted relevant analysis and research on the harm and law of agglomerate fog phenomenon. Ding Qiuji et al. ^[2] studied the temperature, humidity, topographical environment and other conditions of different road sections where group fog occurred from 2006 to 2009, and explored the rules and local characteristics of highway agglomerate fog weather; Yang Xihai et al. ^[3] The formation

conditions and hazards of the agglomerate fog were analyzed, and recommendations were put forward for prevention and treatment of the fog-prone sections of the Deshang Expressway; Liang Li et al. [4] discussed the main causes of agglomerate fog in combination with a number of weather and topographic data for a traffic accident caused by agglomerate fog on Chuxin Expressway in Fuyang, Anhui.; Wang Jian et al. [5] analyzed the impact of group fog on expressway traffic safety by summarizing the characteristics and rules of occurrence of agglomerate fog and the characteristics of traffic accidents caused by agglomerate fog on expressways; TANG Junjun et al. [6] according to the characteristics, scope of influence, arrival intensity and duration of the fog, combined with highway, traffic and terrain factors, an early warning indicator system for the traffic conditions of the foggy road network was established; Niu Yanfeng et al. [7] based on the high-speed agglomerate fog of Shanxi Province The characteristics, frequency of agglomerate fog, number of accidents, etc., are risk-rated to ensure the safety of expressway operations. The above studies are mostly the enumeration and correlation analysis of the causes of group fog, which cannot effectively play an early warning effect. In order to better determine the conditions that cause cluster fog and provide early warnings, this paper intends to use geographic weighted regression (GWR). At present, the GWR model is often used for land use division, population GDP impact, PM2.5 spatiotemporal characteristics, etc. [8-14] Multi-faceted analysis, which can also be used to study hot social issues such as the distribution of epidemic cases [15], and establish regression models through the study of spatial distribution characteristics to obtain various impact mechanisms. In this study, the GWR model is used to analyze the causes of agglomerate fog on a spatial scale to determine which types of terrain and environment are more likely to produce agglomerate fog, so as to predict where agglomerate fog is likely to occur, strengthen monitoring and early warning of the place, and avoid major traffic accidents. Loss, to protect the safety of personal and property.

2 Study Area And Data

2.1 Study area

Shandong Province is a coastal province in East China. The mountains in the central part are protruding, the southwest and northwest are low-lying and flat, and the east is gently undulating. The terrain is dominated by mountains and hills. There are more highway sections with more than 10 agglomerate fog per year. Figure 1 shows the road sections with frequent agglomerate fog in Shandong Province. This article takes Shandong Province as the research area, and the section where the agglomerate fog occurs more than three times a year is regarded as the section with frequent occurrences.

1.1 Data

1.1.1 High-speed road network and Road sections with more agglomerate fog

This article uses the highway network data of Shandong Province, which includes 43 high-speed roads such as Beijing-Shanghai Expressway and Jinan-Leling Expressway. In 2018, the traffic police department of Shandong Expressway selected agglomerate fog-prone road sections. The data includes the name of the expressway, the start and end points of the road section, and the month of frequent occurrence., The frequent occurrence period and the annual average number of occurrence days, take five of them as examples shown in Table 1.

Tab.1 Agglomerate Fog Prone Section

Name	Number	starting point(Km)	end (km)	Multiple months	Frequent period	Annual average number of occurrences (day)
Beijing-Shanghai Expressway	G2	280	283	January to March, November, December	22 o'clock to 10 o'clock	10
Jinan-Leling Expressway	G2	301	353	November, December, January, February	7:00 to 9:00, 19:00 to 22:00	6
Jinan-Leling Expressway	G2	353	366	November, December, January, February	7:00 to 9:00, 19:00 to 22:00	7
Beijing-Shanghai Expressway	G2	400	402	March to May, October to December	0 o'clock to 8 o'clock	3
Beijing-Shanghai Expressway	G2	404	406	March to May, October to December	0 o'clock to 8 o'clock	4

1.1.2 Geographic environment

The river data was obtained by intercepting the Shandong Province part of China's hydrological data, including the Beijing-Hangzhou Canal, South Canal, and other rivers and lakes; elevation data is Shandong DEM raster data with a horizontal accuracy of 30m obtained from a geographic cloud platform; NDVI data is downloaded via MODIS Web (nasa.gov), processed by MRT and exported in GIS. According to statistics, According to statistics, 98% of the road sections where agglomerate fog occurs in November. Therefore, the November NDVI data with strong coverage is selected, as shown in Figure 2.

3 Research Methods

In this study, starting from the correlation between the agglomerate fog-prone sections on the expressway and its river density, elevation and NDVI, the geographical environment attributes are used to infer the distribution of the agglomerate fog-prone sections, and the number of frequent occurrences is further estimated to construct a geographically weighted regression model (GWR) model to study the influence of different geographical environment attributes on induced agglomerate fog.

2.1 Correlation analysis

The statistical analysis of the number of agglomerate fog occurrences in different months and time periods is carried out, and the law of agglomerate fog occurrence and its correlation with time are studied. Combining the river density, elevation difference, and NDVI data, analyze the frequency of agglomerate fog and the relative strength of each factor, and select the relevant factors to construct the model according to its geographic characteristics.

2.2 Spatial analysis

2.2.1 Linear density

Calculate the density of linear features in the neighborhood of each output raster pixel to analyze the regional characteristics of the roads where agglomerate fog occur. Import agglomerate fog related data into GIS, and perform data preprocessing, including coordinate accuracy check, elimination of mismatched routes, interception of frequently occurring road sections based on start and end points, etc., visual analysis of the distribution of agglomerate fog frequently occurring road sections, and proposed to propose the effect of agglomerate fog frequently occurring factor.

2.2.2 Buffer analysis and gridding

Because the road sections with frequent agglomerate fog are distributed in various expressways, in order to reduce the influence of error and improve the calculation efficiency, this paper establishes a buffer zone within 1km of the road section with frequent agglomerate fog as the main research area. Use the grid tool to divide Shandong Province into 5km*5km grids, extract the grids that intersect the buffer zone, and remove the grids outside the boundary line of Shandong Province, and calculate the river density, NDVI and elevation difference in each grid.

2.2.3 Overlay analysis

Select the grids that intersect the buffer layer by location, extract the corresponding grids of the buffer, and extract the river density and elevation (DEM) in each grid. First, the total length of rivers in each grid is extracted based on the spatial location. Due to the different areas of the rivers of each level, the scope of influence is also different, and they are uniformly converted according to the classification standards (as shown in Table 2). Secondly, use the mask to extract the maximum and minimum DEM in each grid, and calculate the difference. Finally, the spatial connection is used to connect the river density and

elevation data in each grid to the same attribute table to facilitate subsequent geographic weighted regression analysis.

Tab.2 Conversion Coefficient of River Impact Grade

Level	Basin area (ten thousand km ²)	Conversion factor
I	>5.0	5
II	1-5	2.5
III	0.1-1	0.5
IV	0.01-0.1	0.05
V	<0.01	0.01

2.3 Geographically weighted regression (GWR)

Geographically Weighted Regression (GWR) has strong local analysis capabilities of spatial data. It can explore the spatial changes and related driving factors of the research object at a certain scale by establishing a local regression equation for each point in the spatial range. Reveal the spatial relationship under the condition of spatial heterogeneity, and can be used to predict future results. Geographically weighted regression is an extension of the ordinary linear regression model, embedding the spatial location of the data into the regression equation, taking into account the local effects of the spatial object, thereby improving the accuracy.

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^p \beta_k(u_i, v_i) x_{ik} + \varepsilon_i \quad i = 1, 2, 3 \dots, n \quad (1)$$

In the formula, y_i is the value of the dependent variable at point i , $\beta_0(u_i, v_i)$ is the coordinate of sample point i , $\beta_k(u_i, v_i)x_{ik}$ is the k -th regression parameter on sample point i , ε_i is the error correction term.

2.4 Multi-scale Geographically Weighted Regression(MGWR)

MGWR is an improvement on the basis of GWR. Compared with GWR, it relaxes the assumption of "same spatial scale" and allows the optimization of the specific bandwidth of the explanatory variable. By deriving the continuous relationship between the response variable and the different predictor variables, different Processes run on different spatial scales.

$$\log Y_i = \beta_{bwi}(u_i, v_i) + \sum_j \beta_{bwj}(u_i, v_i) \log x_{ij} + \varepsilon_i \quad i = 1, 2, 3 \dots, n \quad (2)$$

In the formula, is the specific optimal bandwidth used in the calibration condition relation, and the remaining variables are the same as formula (1).

4 Data Analysis

3.1 Time distribution of agglomerate fog

This article counts all the high-speed road sections with frequent agglomerate fog in Shandong Province in one year, and analyzes the number of agglomerate fog occurrences by month and time period. As shown in Figure 3, agglomerate fog occurred the most in November, with a total of 1966 times, followed by 1742 times in December and 1613 times in March, and the number of occurrences decreased sharply from March to August. In summer, the number of occurrences in June, July, and August was less than 100. The correlation coefficient between the month and the number of agglomerate fog was R^2 of 0.54, which was relevant. ; The agglomerate fog occurred the most times from 5:00 to 6:00, totaling 2006 times, and the overall downward trend from 6:00 to 17:00. The number of occurrences from 20:00 to 9:00 on the next day was more than 700, the correlation coefficient R^2 is 0.63, which has a strong correlation. To sum up, it can be seen that the time of agglomerate fog has a strong regularity, and it mostly occurs in autumn and winter with large temperature differences, as well as night and morning peak periods.

3.2 Spatial distribution of road sections with frequent agglomerate fog

From the linear density analysis, it can be seen that the Tuanwu-prone sections gradually decrease from east to west, and the eastern part is dominated by mountains and hills and the coastal areas are densely distributed, as shown in Figure 4. Among them, the Shenhai Expressway, Rongwu Expressway and other coastal highways where fog frequently occurs are mostly, accounting for about 1/4 of the total road sections. Therefore, considering that the frequent occurrence of group fog is related to hydrology and topography, the analysis is conducted in two aspects.

3.3 Correlation analysis of the causes of agglomerate fog based on GWR

To ensure the validity of the GWR model, it is necessary to test the spatial correlation of the variables in the study area. If the spatial correlation of the variables is not significant, it means that the distance between discrete points has little effect on the value, and the geographical attributes of the variables have little effect on the value. The influence of the variable value is small, and the use of geographically weighted regression is not a necessary choice. The Moran I index in the spatial autocorrelation tool in ARCGIS is used for analysis. A positive value of the Moran index indicates a positive spatial correlation,

and a negative value indicates a negative spatial correlation. The analysis results of the distribution of the number of cluster fog occurrences are shown in Figure 5. It shows that the Moran index is 0.86, indicating that there is a strong spatial correlation and aggregation, that is, the number of occurrences of cluster fog in a certain area is related to the location of the area. The Z score is about 25, indicating that it is 25 times the standard deviation. The results are distributed at both ends of the normal distribution.

This study uses the GWR model to quantitatively analyze the relationship between the number of agglomerate fog occurrences and the river density, elevation and NDVI. Based on the GWR model, the relationship between the number of agglomerate fog occurrences and the river density, the elevation difference of the area where the agglomerate fog occurs, and NDVI are analyzed respectively. The comparison of the analysis results output by GWR is shown in Table 3.

Tab.3 Comparison Table of Analysis Results when the Dependent Variable is the Number of Agglomerate Fog Occurrences

Explanatory variables	GWR R ²	GWR R ² Adjusted	Linear Regression R ²
River density	0.4532	0.3901	0.1933
Regional elevation difference	0.6389	0.5655	0.2652
NDVI	0.5405	0.4862	0.1228
The above three	0.5277	0.4498	/

It can be seen from Table 3 that the number of agglomerate fog occurrences based on the GWR model analysis has a large correlation with river density, regional elevation difference and NDVI. The order of correlation is regional elevation difference> NDVI> river density, and relative to Ordinary linear regression model. The correlation coefficient R² between the number of agglomerate fog occurrences based on the GWR model and the river density, regional elevation difference and NDVI model is larger. Therefore, the accuracy of the GWR model is much higher than that of the ordinary linear regression model, and the number of agglomerate fog occurrences It has strong spatial heterogeneity, refines the distribution characteristics of the frequently-occurring road sections, and characterizes the local spatial changes of the geographical environment of each frequently-occurring road section.

Each variable has a promoting or inhibiting effect on the number of agglomerate fog occurrences in different areas, which is represented by the positive and negative conditions of the regression parameters. The results of the GWR model analysis show that: (1) In the results of river density analysis, 63% of the grid regression parameters are negative, which means a significant negative correlation. The higher the river density, the fewer the occurrence of agglomerate fog; (2) In the analysis results of the

regional elevation difference, 62% of the grid regression parameters are positive, that is, a significant positive correlation. When the elevation difference in the region is greater, the number of agglomerate fog occurrences is greater;(3) In the NDVI analysis results, 64% of the grid regression parameters are negative, which means a significant negative correlation. When the NDVI index in the area is larger, the agglomerate fog is negative, the fewer occurrences of agglomerate fog. The main reason for the formation of agglomerate fog is the generation of temperature inversion layer, and the river has the function of regulating the temperature difference between day and night, so it has a certain inhibitory effect on the occurrence of cluster fog; NDVI can reflect the coverage of plant canopy, and it can greatly change the sun when there are more vegetation. Radiation, regulating the surface temperature and humidity, has a certain inhibitory effect on the occurrence of cluster fog; when the elevation difference is large, it may cause a large temperature difference in the area, and have a certain impact on precipitation and wind speed, thus having a certain promotion effect on the occurrence of agglomerate fog. Because the river density, NDVI, and elevation difference have a negative effect on the number of cluster fog, when the three are used as explanatory variables, the correlation decreases.

3.4 Analysis of GWR model prediction results

(1) When the condition number in the regression analysis result is less than 0 and greater than 30 or is set to "empty", it means that there is strong local multicollinearity, and the reliability of the associated results is low. According to the regression results of the three models, the regression condition number of river density is between 1-3, the regression condition number of elevation difference is between 2-8, and the regression condition number of NDVI is between 1-30, that is, there is no difference between the independent variables. There is a problem of collinearity, which meets the requirements of regression analysis, and the test results of the GWR model are credible;

(2) Feedback from the GWR model result analysis table, the predicted value with a difference of less than 3 from the actual number of agglomerate fog occurrences accounted for 89.86%, and the predicted value with a difference of less than 5 accounted for 96.66%, and the prediction results were more accurate. .

3.5 Autocorrelation analysis of input parameters

(1) From the analysis based on the GWR model, it can be seen that river density, elevation difference and NDVI have a strong influence on the number of agglomerate fog occurrences in the area. The correlation between the three parameters is analyzed, and the correlation coefficients between the two are less than 0.1, no obvious correlation;

(2) Perform variance inflation factor (VIF) test and collinearity test on the independent variables of regional river density, elevation difference and NDVI. Among them, the river density and elevation difference $VIF=1.01<7.5$, NDVI $VIF=1.0<7.5$, which means that the requirements of regression analysis are met, there is no obvious collinearity problem, and the results of the GWR model are credible.

3.6 Error analysis based on GWR model

The study area is divided into 778 grids. The standard deviation of each grid is calculated through the GWR model with river density, elevation difference and NDVI as independent variables. Among them, there are 9 grids with standard deviations >2.5 or <-2.5. Rong-Wu Expressway and Shen-Hai Expressway are mainly concentrated in the eastern coastal areas, as shown in Figure 6. Since the eastern coastal areas are mostly undulating and undulating hilly areas, complex terrain conditions have an impact on meteorological conditions such as precipitation, air humidity, wind direction and wind speed, leading to large errors in forecasting agglomerate fog.

The darker the color of the prediction area, the greater the standard deviation. Map created in ArcMap 10.2 of the Environmental System Resource Institute, Inc. (www.esri.com/software/arcgis/arcgis-for-desktop).

3.7 Correlation analysis of cluster fog incentives based on MGWR model

Take the center point coordinates of 778 grids and the corresponding river density, elevation difference, and NDVI, and import them into MGWR2.2.

Tab.4 Fitting Results based on the MGWR Model

Explanatory variables	Regression coefficients	Corrected regression coefficient	Model bandwidth based on 3 independent variables
River density	0.593	0.566	599
Regional elevation difference	0.771	0.659	314
NDVI	0.637	0.595	44
The above three	0.649	0.605	-

The results are shown in Table 4. The regression effect is better than the GWR model, that is, the multi-bandwidth of a specific bandwidth is calculated according to the independent variables. The model is better than the single bandwidth model. Since this model is currently only suitable for fitting regression and cannot achieve the prediction effect of the GWR model, this method can be used as a preliminary fitting verification, and it can also be combined with GIS to develop its prediction function to further improve the prediction effect.

5 Conclusion

In order to solve the problems such as strong suddenness of cluster fog, difficult to monitor and more difficult to predict, and to improve traffic safety, this study analyzed the influence of river density and elevation difference in the area on the number of agglomerate fog occurrences, and proposed a regression based on geographic weighting. The main research conclusions are as follows:

- (1) According to the statistics of the time distribution of the occurrence of agglomerate fog, the occurrence of agglomerate fog has a strong time pattern, which usually occurs in autumn and winter, night and early morning;
- (2) Based on spatial autocorrelation analysis, the Moran index of the number of agglomerate fog occurrences in different regions reaches 0.86, which is a strong spatial positive correlation;
- (3) Based on the analysis of the GWR model, the number of agglomerate fog occurrences and the river density, elevation difference and NDVI, the accuracy of the three models is much higher than that of the linear regression model;
- (4) According to the regression coefficients of the GWR model, the correlation between the elevation difference and the number of agglomerate fog occurrences is greater than that of the river density, and the river density is negatively correlated with the number of agglomerate fog occurrences, and the elevation difference is positively correlated with the number of agglomerate fog occurrences;
- (5) The fitting effect of the multi-bandwidth MGWR model is better than that of the single-bandwidth GWR model, but it lacks error analysis and prediction effects compared with the GWR model. The GWR model predicts that more than 98% of the area is within the allowable error range;
- (6) Based on the GWR model, an early warning model of the number of agglomerate fog occurrences was constructed to effectively monitor the locations where agglomerate fog frequently occurs, and to strengthen the deployment of monitoring equipment at the corresponding locations to avoid serious traffic accidents caused by agglomerate fog and ensure traffic safety.

Declarations

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Figures

(a)

(b)

Figure 1

Location of the study area. A is the map of China <http://bzdt.ch.mnr.gov.cn/browse.html?picId=%224028b0625501ad13015501ad2bfc0291%22>, B is the distribution map of road sections where there are more agglomerate fogs in Shandong Province. According to the traffic police statistics of Shandong Expressway, in 2018, there were 261 frequent traffic sections in agglomerate fog, of which 232 traffic sections were screened.

Figure 2

River Elevation and NDVI in Shandong Province. A shows the elevation and hydrological conditions of Shandong Province. B shows the Normalized Difference Vegetation Index of Shandong province, Different vegetation reflects different colors.

Figure 3

Time Distribution Statistics of Agglomerate Fog.A counts the number of agglomerate fogs that occur each month and the number of road sections with more agglomerate fog in this month, B counts the number of agglomerate fogs that occur in each period and the number of road sections with more agglomerate fog in this period.

Figure 4

Line Density Analysis of Agglomerate Fog-prone road section.The gray line is the highway network in the study area; the yellow line is the road section with more agglomerate fog; the darker red area represents the road section with frequent agglomerate fog.

Figure 5

Moran I Analysis Chart. Combined with the positive value of Moran I, it can be concluded that the results are distributed at the right end of the normal distribution and are clustered. The P value is 0, indicating that the result is 100% not generated by random data, and the result is credible.

Figure 6

Standard Deviation Analysis Results based on GWR Model. This figure shows the error analysis between the occurrence times of fog in the predicted area and the actual value .