Article

Quantifying the Spatial Fragmentation Pattern and Its Influencing Factors of Urban Land Use: A Case Study of Pingdingshan City, China

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Abstract: In the context of rapid urbanization, the phenomenon of spatial fragmentation in Chinese inland central cities is significant. The scientific measurement and evaluation of urban spatial fragmentation are conducive to its transformation, advancement, and sustainable development. Based on the fractal dimension index and Shannon index, this study measures urban spatial fragmentation in terms of form and function, respectively. In addition, multi-scale geographic weighted regression (MGWR) is used to study the influencing factors of spatial fragmentation. The conclusions are as follows: ① the measurement results of spatial form fragmentation and functional fragmentation of urban built-up areas are consistent. The fragmentation degree of the new urban area (new urban district and high-tech district) is higher than that of the old urban areas, and the urban space fragmentation degree around railways and rivers is high. The urban space fragmentation degree of coal resource concentrated distribution areas in the north is lower. The cold spot area of the fragmentation phenomenon appears in the old urban area, and the hot spot area is in the new urban area and along the railway. ② The positive influencing factors of urban spatial fragmentation in Pingdingshan city are the NDVI and the distance from CBD. The negative influencing factor is the number of bus stops per unit area. The DEM and population density have no significant impact on urban fragmentation in Pingdingshan city. ③ Among the variables with significance, its influence has a certain spatial heterogeneity. The spatial scale from small to large is the number of bus stops per unit area, NDVI, and the distance from CBD. The degree of urban fragmentation is very sensitive to the number of bus stops per unit area and the impact scale is quite small. The spatial impacts of the NDVI and the distance from CBD are relatively stable. This study provides a reference and basis for the spatial development of built-up areas of inland central cities and promotes the transformation, advancement, and sustainable development of inland central cities.

Keywords: spatial fragmentation; fractal dimension index; shannon index; MGWR

1. Introduction

In recent years, with the rapid development of the global economy, cities are also experiencing rapid urbanization, which leads to the structural reorganization of urban built-up areas and the establishment of marginal new urban areas. Moreover, this produces a series of urban development problems, such as resource depletion, ecological destruction, separation of work and residence, mismatch of functions, fragmentation of urban space, and so on, which seriously hinders the sustainable development of a city [1,2]. There are some differences in spatial geometric structure and organization between new and old urban areas [3]. In the process of rapid urbanization, gated communities and upscale communities have caused a differentiation between urban residents. The rapid development of highways and railways has also divided the urban space to a certain extent [4,5]. The fragmentation...
land and closure of urban spatial structures leads to the weakening, blocking, and interruption of urban people flow, logistics, and information flow, which leads to the low overall operation efficiency of the city, and thus it affects the sustainable development of the city and the improvement of the quality of life of urban residents [6].

Initially, fragmentation was mainly studied in natural science, focusing on landscape fragmentation [7], forest fragmentation [8], land use fragmentation [9], and so on. Afterwards, scholars of Social Sciences combined fragmentation with social culture, cities, and commerce [10,11], which enriched the meaning of fragmentation [12]. This includes the study of urban spatial fragmentation. This paper will discuss the spatial fragmentation of built-up areas of inland cities in combination with the development status of Chinese cities. At present, there is no unified definition of urban space fragmentation. Different scholars at home and abroad have described the definition of urban space fragmentation. Generally speaking, urban space fragmentation refers to a non-integrated state of urban space. It is a kind of “fragmented” state and formation process, which is characterized by the separation of space, function, and society [13–15].

Most existing studies focus on large cities and pay less attention to small and medium-sized cities and special types of cities [16–18]. The development of inland cities in China is slower than that of coastal cities, and there are few development opportunities; however, in recent years, the development opportunities of inland central cities have increased, and urbanization has developed rapidly. With this development, there are also problems such as environmental pollution, ecological damage, and the decline of land carrying capacity. The extension of urban scale and the promotion of functional connotation are very important in the process of urban transformation and sustainable development; therefore, this study chooses Pingdingshan, a Chinese inland central city, to study the form and functional pattern of urban spatial fragmentation.

Many scholars believe that urban spatial fragmentation is characteristic of most developing countries, which is different from the urban pattern of cities in developed countries. Balbo said in his book that the city of the third world is a mosaic from an aerial perspective [19]. The initial research mainly focused on the urban territorial spread and urban expansion [20] and did not realize the problem of urban space fragmentation in the process of urban expansion and spread.

Relevant papers on urban space fragmentation mainly include research on closed communities [21], business districts, retail industries [22], housing and housing prices [23,24], social spaces [25,26], social systems [27], and industrial spaces [28]. Pessoa and other scholars explored the relationship between spatial fragmentation and self-organization [20], and Jimmy used questionnaires and other data to study the combination of housing fragmentation and residents’ quality of life [21]. Falahat studied the spatial structure and spatial form of Safavid Isfahan’s old texture and new extensions [3].

The measurement research of urban spatial fragmentation mainly includes morphological fragmentation, functional fragmentation, connection fragmentation, risk fragmentation, and so on. The fragmentation measurement method includes a single index method and a comprehensive index combined with multiple fragmentation indexes. The single index method includes a landscape fragmentation index [22], boundary density index [23], aggregation index [24], a density index of aggregates [25], and so on. Bentley and Kallenberg used the comprehensive index method of multiple indexes to discuss the spatial fragmentation in northwestern Portugal and Santiago, the capital of Chile [26,27]. In addition, Fan and other scholars compared the application of spatial autocorrelation index and landscape index in fragmentation measurement [28]. Urban suburbs are generally agricultural planting areas or urban–rural fringe areas, and their land fragmentation is also significant. Some scholars analyze land use in the suburbs, and use the methods of the analytical hierarchy process and a weighted linear combination procedure to conduct factor analysis, so as to quantify the current situation of land use and the sharp conflict area of land use [29]. Due to the increase in built-up areas and the acceleration of urbanization, the phenomenon of space fragmentation is more significant. Based on this, some scholars use the Urban
Fragmentation Index (UFI) and index of landscape compactness (LCI) construction formula to measure the current situation of urban and suburban space fragmentation [30].

Urban space fragmentation is caused by social, economic, natural, and other factors. The widening gap between the rich and the poor among urban residents caused by economic development and social structure changes will promote the formation and development of urban space fragmentation [31]. In the context of rapid urbanization, urban sprawl, expansion strategies, and development models also have a certain impact on urban fragmentation [32]. At present, there are few scholars to analyze and study the influencing factors of urban spatial fragmentation in combination with spatial scale. This paper mainly uses the MGWR model to calculate the influencing factors of urban spatial fragmentation. It integrates spatial heterogeneity and spatial scale into the model, which can better analyze the impact mechanism of urban spatial fragmentation.

The research steps of this paper are as follows: firstly, we review the relevant literature. Secondly, we use the Fractal dimension index and the Shannon index to measure the fragmentation of urban spatial form and function, and then we calculate the comprehensive fragmentation index. We also visualized the distribution pattern of fragmentation for analysis. Thirdly, based on the MGWR model, this paper explores the influencing factors of urban space fragmentation and discusses the mechanism of urban spatial fragmentation. The last part is the discussion and conclusion. We analyze some of the flaws and inadequacies of this research and summarize the main findings of this study.

The scientific problems raised in this paper will be solved by: ① exploring the types and characteristics of spatial fragmentation in inland central cities; ② studying the causes and mechanisms of fragmentation of inland central cities to provide constructive suggestions or a basis for decision-making for future urban development.

2. Research Areas and Methods

2.1. Study Area

Pingdingshan city is located in the inland area of China. It is a typical inland city, with the Funiu Mountain in the west and Huanghuai Plain in the east. The area of study in this paper is the built-up area of Pingdingshan city, including Xinhua District, Weidong District, and Zhanhe District, as well as the new high-tech District and Xincheng District. The built-up area is about 1.3 million square kilometers, with a population of about 1.1 million. As shown in Figure 1, Pingdingshan is an important energy and heavy industry base in the Central Plains Economic Zone. It is a typical resource-based industrial city. It is famous for its unique coal resources.

The urban spatial form is consistent with the terrain and resource distribution. Indeed, it includes mountains and rivers, showing a banded development in the east–west direction. Railways and rivers pass through the old urban area, which leads to the fragmentation of urban land function, causing the overall land planning and layout of the system to become more difficult. Since 2002, the new urban area adjacent to the Baiguishan Reservoir has been developed in the west of the city, focusing on the common development of ecology and economy. The new urban area has been constructed by adopting the group construction and development mode of the administrative area, scientific research and education area, as well as the high-tech industrial zone. The land use form is also banded, but the progress of development and construction is relatively slow. The function realization of the planned land is poor, the attraction is low, and the population density is low. The planned development needs to be implemented; therefore, it is necessary to study the current situation of urban spatial fragmentation in the new and old urban areas of Pingdingshan city.
The data used in the fragmentation measure are the road enclosure patch data and POI data. The patch data of the road enclosure are based on the remote sensing image of Pingdingshan city from Google Earth (scale 1:15,000) and the scope of the built-up area. All roads (except the roads inside the community) are depicted by CAD. After that, the street data map was imported into ArcGIS 10.8 for geographic registration and projection setting. Then, we used the tools in Arctoolbox to convert the lines to polygons to obtain the area data of the main urban area, which are the road closure patch data. POIs data were obtained by crawling based on the Gaode map. After cleaning, deletion, and correction, POIs outside the study area, and the duplicate POIs, were removed by various methods. For example, the original POIs data included the north gate of the Jinhuayuan community and the South Gate of the Jinhuayuan community. In this study, we regard it as a functional element, therefore, we deleted the redundant data, and left only one point to ensure the smooth progress of subsequent data processing. In the analysis of influencing factors, population data (https://www.worldpop.org/, accessed on 16 February 2022) and NDVI data are 30 m resolution data, and DEM is 12.5 m resolution data (https://search.asf.alaska.edu/#/, accessed on 16 February 2022). The bus station data comes from the Pingdingshan Gaode API from 2019. In addition, all maps in this paper are made with ArcGIS 10.8.
2.3. Methodology

2.3.1. Fractal Dimension Index

The fractal dimension index in landscape ecology is used to measure the spatial fragmentation of urban built-up areas. The formula of fractal dimension index is as follows:

$$FD = \frac{2 \ln \left( \frac{p}{4} \right)}{\ln A}$$

where $p$ is the perimeter of the road patch and $A$ is the area. The value of the fractal dimension index field is $[1, 2]$. The fractal dimension index can be used to quantitatively describe the size of the core area of street-enclosed patches and the tortuosity of their boundary lines. The larger the fractal dimension index, the higher the degree of fragmentation in the built-up area, and the smaller the value, the smaller the degree of fragmentation. As the fractal dimension approaches 1, the patch has a smaller core area and larger boundary tortuosity, and the patch geometry tends to be more regular. On the contrary, when the fractal dimension is closer to 2, the patch has a larger core area and smaller boundary tortuosity, and the patch geometry tends to be irregular. The fractal dimension index mainly reflects the effectiveness of space occupied by complex bodies, and it is a measure of the irregularity of complex bodies [33,34]; therefore, this paper chooses the fractal dimension index to measure the fragmentation of urban space morphologically.

2.3.2. Shannon Index

Entropy is applied in many fields. Shannon proposed information entropy based on the concept of entropy. He defined the average amount of information excluding redundant information as “information entropy”. In other words, the more ordered the system is, the smaller the information entropy is; on the contrary, the more chaotic the system, the greater the information entropy. Therefore, information entropy can measure the distribution uniformity of POI in urban space and the degree of functional fragmentation of urban space [35].

$$H = - \sum_{i=1}^{n} P_i \ln P_i$$

where $H$ is the information entropy and $P_i$ is the probability of random event $i$.

2.3.3. Cold/Hot Spot Analysis

Hot spot analysis uses a Z-score and $p$-value to determine the spatial clustering distribution areas of high and low values. The larger the positive Z-score, the smaller the $p$-value, indicating that there is a high-value spatial agglomeration. The smaller the negative Z-score, the smaller the $p$-value, indicating that there is low-value spatial agglomeration. In this study, ArcGis10.2 is used to analyze the cold/hot spots of urban spatial fragmentation [36].

2.3.4. MGWR Model

The Multiscale Geographically Weighted Regression (MGWR) model is the latest improvement to the Geographically Weighted Regression (GWR) model, which makes up for the defect of the bandwidth of all independent variables in GWR being the same. The MGWR model can consider different bandwidths for different independent variables. Each independent variable has a unique appropriate bandwidth, which is a more robust fitting model than the GWR [37]; therefore, we use the MGWR model in this paper to study the spatial variation characteristics of the influencing factors of urban spatial fragmentation.

The equation of the MGWR model is as follows:

$$y_i = \sum_{j=1}^{k} \hat{\beta}_{buj}(u_i, v_i) x_{ij} + \epsilon_i$$
where \( bw_j \) represents the bandwidth of the \( j \)-th variable, \( \beta_{bw_j} \) represents the \( j \)-th regression coefficient, \( x_{ij} \) is the \( j \)-th predictor variable, \( y_i \) is the dependent variable, and \( \epsilon_i \) denotes the random error term. The selection of the kernel function and bandwidth of the MGWR still continues the classical selection criterion of the GWR. To calculate the optimal bandwidth, the bisquare kernel function and AICc criterion are selected [38–41].

3. Results and Analysis

3.1. Fragmentation Pattern of Spatial Form

Based on patch density, total patch area, minimum patch, maximum patch, and fractal dimension index, this paper describes the spatial fragmentation of built-up area in Pingdingshan city. According to the data statistics, as shown in Table 1, the number of patches in the built-up area of Pingdingshan city is 2667, and the patch density is 19.5 patches per square kilometer. Overall, there are many patches with a high density.

| Study Area                | Number of Patches | Total Patch Area (km\(^2\)) | Patch Density (Block/km\(^2\)) | Minimum Patch Area (km\(^2\)) | Maximum Patch Area (km\(^2\)) | Fractal Dimension Index |
|---------------------------|-------------------|----------------------------|-------------------------------|-------------------------------|-------------------------------|------------------------|
| Pingdingshan built-up area| 2667              | 136.7                      | 19.5                          | 0.000016                      | 0.97                          | 1.029                  |

The fractal dimension index is a quantitative description of the “irregular” degree of objective things, which fully reflects people’s ability to transform space and fill space form. By calculating the fractal dimension index of road-enclosed patches, the fractal dimension index of each patch in the built-up area of Pingdingshan city is visually expressed according to the natural breaking point method. As shown in Figure 2, the fractal dimension index in the central area of the city is low, and the high value of fractal dimension is mainly distributed on both sides of the two railways in the south and north, as well as in the northwest and the eastern new area. The degree of fragmentation in other areas is not obvious. The planning in the old urban area is relatively advanced, and the degree of fragmentation is relatively low. Although the fractal dimension index of the new area is high, the fragmentation of the new area is serious, and there are a large number of fragmentation areas. This shows that the planning and construction of the new area have not reached the standard and development is slow. After investigation, it was found that there are numerous urban villages, cultivated land, and planning areas under construction in the new area, which are less advanced compared with the old urban area. Railways and railway stations have a significant impact on the urban spatial pattern. The spatial fragmentation on both sides of the southern and northern railways is relatively high, and the spatial fragmentation on both sides of the southern railway is higher than that in the north. As most coal mines are distributed on the northern railway, coal mining and transportation are required, so the planning is relatively better, and the degree of fragmentation is relatively lower than that on both sides of the southern railway.

To further identify the spatial differentiation characteristics of fragmentation in the built-up area, in this paper, the fractal dimension index value is analyzed and expressed visually based on ArcGIS, as shown in Figure 3. The hot spots of the fractal dimension index are in the northwest of the built-up area, both sides of the northwest section of the southern railway, and around the east station, and the cold spots are mainly distributed in the center of the Xinhua District, Zhanhe District, and high-tech district. Therefore, the characteristics of urban form fragmentation in Pingdingshan city are as follows: (1) high-value areas of spatial fragmentation form in the new urban area: contrary to the neat planning of general new areas, the new urban area of Pingdingshan city has an obvious phenomenon of villages in the city, poor development in terms of architectural planning, and serious spatial form fragmentation due to the slow implementation process of planning and construction. (2) High-value areas of spatial fragmentation form along the Southern
Railway and Pingdingshan east station: the railway and station have greatly changed and impacted the urban spatial form, and the fragmentation is serious due to the division of urban space. (3) Low-value areas of spatial fragmentation form in Zhanhe District, Xinhua District: as the center of the old urban area, the economy has developed well. As the establishment of Pingdingshan city is related to the rich coal resources, urban development is late and unnatural. There is certain national government planning, building rules, and reasonable road planning, but the spatial fragmentation of the city is not significant.

![Figure 2. Fractal dimension index spatial visualization of road enclosure patches in Pingdingshan city.](image1)

![Figure 3. Fractal dimension index hot spot analysis of road enclosure patches in Pingdingshan city.](image2)

3.2. Fragmentation Pattern of Spatial Function

The diversity of POI types of road enclosed patches in Pingdingshan city was calculated by the Shannon index. Shannon index information entropy has a negative correlation with the degree of urban spatial fragmentation. According to the agglomeration character-
istics of the tertiary industry in the built-up area of Pingdingshan city, this paper mainly selects six types of POIs data with the most obvious urban space occupation for Shannon index analysis. They are residential areas, commercial services (catering facilities, shopping places, and leisure and entertainment places), and public service facilities (hospitals and schools). At the same time, to better reflect the spatial fragmentation characteristics of urban functions, ArcGIS is used to visualize the Shannon index results, as shown in Figure 4. The Shannon index values in different regions vary greatly. The areas with a high Shannon index include Zhanhe District, Xinhua District, the central area of Weidong District, around the government of the new urban area, and near Pingdingshan University. All kinds of POIs in these areas are evenly distributed and in large quantities, with dense population distribution, good economic development, and high urban spatial vitality. The areas with a low Shannon index include the marginal built-up areas and most new urban areas and high-tech zones. These areas have relatively singular urban functions, incomplete supporting facilities for residents' lives, and insufficient urban vitality.

![Figure 4. Visualization of the Shannon index based on POI data of road enclosure patches in Pingdingshan city.](image)

3.3. Comprehensive Fragmentation

The results of morphological fragmentation and functional fragmentation are standardized and then added according to the method of equal weight. Finally, the comprehensive fragmentation value of the built-up area space of Pingdingshan city is obtained, as shown in Figure 5. The spatial differentiation of the degree of spatial comprehensive fragmentation in the built-up area of Pingdingshan city is significant. The low-value areas of comprehensive fragmentation include the old urban area, near Pingdingshan University, and around the east railway station. Most areas on the fringe of the built-up zone, new urban areas, and high-tech zones are space fragmentation high-value areas. Overall, the fragmentation degree of the old urban area is lower than that of the new area, indicating that the planning and construction of the new area in Pingdingshan city is slow, the land use is unreasonable, and the spatial vitality is low.
4. Analysis on Influencing Factors of Space Fragmentation

The spatial differentiation of urban spatial fragmentation is affected by many factors. Referring to the existing literature, it has been found that there are natural factors, construction factors, policy factors, market factors, and so on. As the research area and scale of this paper are small, and the analysis of influencing factors is based on the drawn road enclosure patches, there are certain data limitations in the selection of influencing factor indicators. This paper mainly selects DEM and NDVI for natural factors, and population density, bus stations, and distance from CBD (Central Business District) for socio-economic factors, which are shown in Table 2.

Table 2. Influencing factors of urban spatial fragmentation and its meaning.

| Variable               | Meaning                                           |
|------------------------|---------------------------------------------------|
| DEM                    | Digital Elevation Model (m)                       |
| Population density (pop) | Population per unit land area (Person/km²)       |
| NDVI                   | Surface vegetation coverage                       |
| Distance from CBD (cbd) | Euclidean distance to downtown (km)               |
| Number of bus stops (bus) | Number of bus stops per unit area                |

Natural geographical factors have an important impact on urban spatial development and urban construction. In this paper, the DEM and NDVI are selected. The DEM will have a certain impact on urban construction, urban land use, and urban development direction. The NDVI is the surface vegetation coverage, which can reflect people’s impact and transformation on the natural environment. Compared with natural factors, socioeconomic factors play a leading role in urban spatial construction and urban development. Urban development is not only affected by government planning, but also the market itself. Among the socioeconomic factors, three indicators are selected: population density, Euclidean distance from CBD (commercial building in Xinhua District, Pingdingshan city), and the number of bus stops per unit area. Population density is the population per unit of land area. As the main driving force of urban development, population can not only reflect the level of urban economic development, but also promote urban construction and development. The distance to the downtown CBD can effectively reflect economic development and urban development. The distribution of bus stops can reflect the convenience of urban transportation and the current situation of urban planning and development.

After researching the influencing factors of spatial fragmentation in the built-up area of Pingdingshan city, this paper constructs three regression models, including the OLS model, GWR model, and MGWR model. MGWR software is used to calculate the model.
To begin with, the collinearity test between the independent variables of the influencing factors is carried out. Through the test, it has been found that the variance expansion factor is less than 7, and there is no collinearity between the respective variables; thus, regression analysis can be carried out. By analyzing the results of the three models, it has been found that the minimum values of AICc and $R^2$ appeared in the MGWR model, the fitting effect is the best, the fitting effect of the GWR Model is the second best, and the fitting effect of the OLS model is the worst. Secondly, there are different bandwidth choices for different influencing factors in the MGWR model, so the MGWR model is more suitable to research the influencing factors of urban spatial fragmentation.

Firstly, this paper analyzes the overall effect of variables under the MGWR regression model. Through the estimation results (Table 3), we can see that the DEM and population density have no significant impact on the spatial fragmentation of the Pingdingshan urban built-up area. The NDVI, in terms of natural factors, and distance from CBD, in terms of economic factors, have a positive impact on urban spatial fragmentation. The closer to CBD, the more prosperous the economic development, the lower the degree of spatial fragmentation; the farther from CBD, the more economic development regresses, and the higher the degree of urban spatial fragmentation. Moreover, the degree of spatial fragmentation is also high in areas with a high NDVI. The number of bus stops has a negative impact on urban spatial fragmentation. The areas with more bus stops have slow degree of spatial fragmentation, whereas areas with fewer bus stops have high degrees of spatial fragmentation.

Secondly, the regression coefficients of significant important variables are visually analyzed by ArcGIS, as shown in Figure 6. It can be seen that there are significant spatial differences between the impacts of different variables on spatial fragmentation. The impact of NDVI on urban spatial fragmentation in high-value areas is seen in the old urban area of the urban central area, the Zhanhe District, Xinhua District, and Weidong District, and high-value areas show a double center phenomenon in the old urban area. The low-value areas of influence are in the new urban area and high-tech district, and in the fringe areas on the east and west sides of the city. High-value areas are also located in the old urban area of the urban center, and most of the low-value areas are in the new areas on the east and west sides, which demonstrates the impact of distance from CBD on urban spatial fragmentation. However, in the high-value areas of the old urban area, the south area is higher than the north area, and the new urban area in the west is lower than the high-tech zone in the east. The number of bus stops has a negative correlation with the degree of urban spatial fragmentation. The higher negative value mainly shows the phenomenon of double centers in the old urban area, where the governments of the Zhanhe District, Xinhua District, and Weidong District are located. Secondly, the higher negative value also exists in the government of the new urban area.

Table 3. Model results of OLS, GWR, and MGWR.

| Variables | Model1: OLS | Model2: GWR | Model3: MGWR |
|-----------|-------------|-------------|--------------|
|           | $\beta$     | $T$         | $\beta$      | $T$         | Bandwidth | $\beta$ | $T$         | Bandwidth |
| intercept | 0           | 0           | 0.909563124 ** | 2.625133 | 177        | 0.808246096 | 8.36379 | 43        |
| DEM       | $-0.074 ***$ | $-4.087$    | $-0.22335$ | 0.2164 | 177        | $-0.069925622$ | 1.6365 | 1672      |
| pop       | $-0.041 **$  | $-2.165$    | $-1.43368$ | 0.71453 | 177        | $-0.00741654$ | 2.98809 | 1605      |
| NDVI      | 0.154 ***    | 8.607       | 0.144686 | 0.977292 | 177        | 0.075891598 ** | 2.131271 | 762       |
| CBD       | 0.337 ***    | 16.853      | 0.792347 | 1.289819 | 177        | 1.22245201 *** | 4.139189 | 1429      |
| bus       | $-0.17 ***$  | $-9.763$    | $-0.680588228 **$ | 2.02741 | 177        | $-0.169607141 **$ | 2.32578 | 180       |
| bs        | 2667         | 2667        | 2667        | 2667        | 2667        | 2667        | 2667        | 2667        |
| AICc       | 6971.06      | 6186.975    | 5998.129    | 5998.129    | 5998.129    | 5998.129    | 5998.129    | 5998.129    |
| $R^2$     | 0.2049       | 0.488       | 0.539       | 0.539       | 0.539       | 0.539       | 0.539       | 0.539       |
| Adj.$R^2$ | 0.2034       | 0.449       | 0.497       | 0.497       | 0.497       | 0.497       | 0.497       | 0.497       |

$\beta$ represents the average estimates of variables. $T$ represents the average t values of variables. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.
spatial fragmentation. However, in the high-value areas of the old urban area, the south area is higher than the north area, and the new urban area in the west is lower than the high-tech zone in the east. The number of bus stops has a negative correlation with the degree of urban spatial fragmentation. The higher negative value mainly shows the phenomenon of double centers in the old urban area, where the government of the Zhanhe District, Xinhua District, and Weidong District are located. Secondly, the higher negative value also exists in the government of the new urban area.

Figure 6. Spatial patterns of estimators of variables.

Finally, in the MGWR model, different variables are allowed to have their own appropriate bandwidth, which explains the multi-scale effect. The bandwidth results of the model are shown in Figure 7. Next, the spatial scales of different variables will be discussed, which reflects the spatial change degree of influencing factors of urban spatial fragmentation. The spatial scale from small to large is the number of bus stops, NDVI, and the distance from CBD. The influence scale of distance from CBD is large, at 1429, accounting for 53.58% of the total sample size, which shows that the spatial difference of the degree of economic development is relatively small, the coefficient is relatively stable in the space, and the spatial heterogeneity exists but is not significant; the NDVI has a moderate bandwidth of 762, accounting for 28.57% of the total sample size. Relatively speaking, spatial heterogeneity is significant. The action scale of the number of bus stops is small, at 180, accounting for 6.74% of the total sample size, indicating that the spatial heterogeneity is large, the degree of urban spatial fragmentation is more sensitive to the number of bus stops, and the coefficient is spatially non-stationary. The T statistics of the DEM and population density are not significant, so the analysis of the bandwidth scale is no longer carried out.
5. Discussion

Spatial fragmentation is an inevitable phenomenon in the process of urban development. With the completion of expressways, railways, and closed communities, various dividing lines have been formed for urban form and urban space. This leads to the fragmentation of urban spatial form and function. This also warns the government to pay attention to the integrity of the city and the improvement of the quality of urban construction, and make reasonable planning, construction, and development decisions for urban development. After analyzing the spatial fragmentation pattern of Pingdingshan city, this paper finds that the old urban area of the city has perfect planning and complete supportive facilities due to the long construction time; therefore, the degree of fragmentation of urban form and function is lower than that of new urban district and high-tech district. The results show that the railway has a significant impact on the fragmentation of urban spatial form. The degree of fragmentation of urban spatial form on both sides of the railway is relatively high. This paper shows from the data that the segmentation of the railway has a significant impact on the fragmentation of urban form, but it has no significant effect on the fragmentation of urban function.

The new urban district has been under construction for 20 years; however, from the current research results, the implementation of urban construction planning in the new urban area is not perfect, and the development is still relatively backward. Secondly, the supporting infrastructure is not perfect, which is inconsistent with the expected results of urban construction in the new district. As a new urban district, to relieve the pressure of population, transportation, and employment in the old urban area of the city, it has not achieved its real expected effect. In the future development of the new urban district, it still needs the detailed planning, construction, and guidance of relevant government departments, so as to promote the implementation of the new town construction plan and truly alleviate the problems of population, traffic congestion, and housing tension in the old urban area.

There are many factors leading to urban space fragmentation. This study selects social, economic, natural, and other factors for analysis based on MGWR. It can be found that the distance from CBD and the NDVI have a positive impact on the degree of fragmentation. The number of bus stops per unit area not only has a negative impact on the degree of fragmentation but also has a relatively small spatial scale, indicating that urban spatial fragmentation is more sensitive to its impact. In future urban planning and development, the government should pay attention to the rational planning of urban traffic roads and related configurations to promote the sustainable development of the city. The DEM and population density have no significant effect on urban fragmentation in Pingdingshan city, which is not completely consistent with the research of some scholars. In some studies [42],

![Figure 7. Bandwidths for explanatory variables in MGWR.](image-url)
population density and the DEM have a certain influence on urban spatial fragmentation; however, there are many factors affecting urban spatial fragmentation, such as land price, policy factors, and so on. Due to reasons concerning data acquisition, it is impossible to include them all; therefore, the research of this paper has certain limitations. For future research, more comprehensive factor indicators should be included to detect and provide targeted suggestions for urban sustainable development.

The policy implications of this article are as follows. To some extent, this paper reveals the current situation of the spatial distribution pattern of spatial fragmentation in built-up areas of Pingdingshan city and analyzes the factors affecting urban spatial fragmentation. According to the analysis results, the development speed of the new urban area of Pingdingshan city is slow, the planned land function has not been fully realized, the mixing degree of land function is low, the attraction is insufficient, there is a separation between one’s job and residence, and the posts provided are insufficient. In the old urban area, the function of urban land is fragmented due to the division of urban space by railways. In the future, Pingdingshan city can carry out planning and construction using different aspects of new and old urban areas, such as accelerating the construction progress of new urban areas, carrying out the construction of transportation infrastructure, commercial infrastructure, and housing, promoting the adjustment and integration of land use functions of old urban areas, truly realizing the optimization of urban space, improving urban operation efficiency, and promoting the construction and sustainable development of the whole city.

6. Conclusions

In terms of the distribution pattern and the degree of spatial fragmentation, the results of morphological fragmentation and functional fragmentation are relatively consistent. The comprehensive spatial fragmentation degree of Pingdingshan city shows that the old urban area in the center is lower than the new urban area on the edge, which is consistent with the conclusions of many other articles. In addition, the degree of spatial fragmentation along the railway and river is higher than that in the surrounding areas, and the spatial fragmentation in the areas with dense coal resources in the north is lower than that in the surrounding areas. Based on the results of MGWR, the DEM and population density have no significant impact on the urban fragmentation of Pingdingshan city. Among the other significant factors, the positive impact factor is the NDVI and the distance from CBD, and the negative impact factor is the number of bus stops per unit area. The spatial scale of significant influencing factors from small to large is the number of bus stops per unit area, NDVI, and the distance from CBD. Among them, the degree of urban spatial fragmentation is very sensitive to the number of buses per unit area, and the influencing scale is only 180 m. The spatial impacts of the NDVI and the distance from CBD are relatively stable. In the future, in terms of urban planning and layout, the government needs to pay attention to the impact of traffic layout, make reasonable planning adjustments, and promote urban sustainable development.

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