Study On Land Use Aggregation Pattern Of Luohe City Based On Spatial Heterogeneity

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Abstract

The spatial layout of land use can reflect the health of urban development and inform the construction of green infrastructure. Many layout measurements have been proposed for lands in homogeneous spaces. Researchers and planners have used them to describe the urban structure and identify current problems in pursuit of problem-oriented optimizations. Now, with the urban expansion and accessibility development, the urban space has gradually changed from homogeneous to heterogeneous. However, the study of land use layout based on heterogeneous space is insufficient. Different land use types are expected to be allocated more scientifically, so providing more objective evidence on the urban land layout is necessary. Among them, the Aggregation-Diffusion status of each type of land is the most basic and vital information. In this paper, the spectral, index, and inversion data of Landsat 8 and Sentinel2 were collected, combined with NPP/VIIRS, and the Weka-EM clustering method was used to determine the boundary of build-up area in Luohe City (China) to obtain our study area. Then, we improve the traditional RAD by measuring roads 'Efficiency value' using Space Syntax: the homogeneous space is weighted to describe the effect of spatial heterogeneity for each land type. Therefore, by comparing the differences in the aggregation-diffusion land layout of these two spaces, the results are as follows: first of all, RAD shows that there is a dense core in Luohe City, in which priority development of ecological land can achieve a multiplier effect with half the effort. Secondly, in AAD, the basic unit based on efficiency value shows apparent spatial heterogeneity in Luohe urban space, represented by the contour line. The benefits of the greenway will be more fully realized where the contours are dense. Thirdly, comparing the description of the Aggregation-Diffusion situation of each land type by RAD and AAD, it can be found that: each land type has a different sensitivity to spatial heterogeneity, and AAD is a more accurate way of spatial description; Both AAD and RAD indicate a significant radial differentiation of land use in Luohe, which means that the significance of greenway construction in this religion is further enhanced. In addition to the greenway's fundamental ecological implications, it also plays a vital role in facilitating the material-energy flow as well as promoting integration and equitable urban development.

Introduction

Modern urban planning hopes for an "Organized Complexity" like the life sciences (Peiru Yang 2010). Researchers no longer see the city as an engineered artifact but as a "complex giant system". In Chinese cities with high-intensity construction, urban planning gradually shifts from rigid blueprint-style control planning to consciously using the city's self-organization to guide the resilient urban development based on critical factors. In these plannings, various quantitative indexes are undoubtedly important windows to understand the urban status. However, as the cities expand, some traditional linear indicators can no longer accurately describe the situation. Then, it is logical to introduce morphology, graph theory, and topology theory to optimize various indicators. Among them, fractal dimension calculation based on urban morphology is widely used in many fields, such as discussing multi-system coupling (Li et al. 2022) and land aggregation relationships (Chen and Feng 2012). It can help planners understand the layout structure of artificial or natural surfaces more accurately than traditional indices.

Background and Literature Review

The essential characteristic of the fractal is self-similarity, which enables the quantitative portrayal of irregular shapes (Batty and Longley 1986). In terms of empirical studies, fractal measures of several essential world cities have emerged successively since birth (Benguigui et al. 2000). Then, the RAD (Radius Aggregation Dimension) index was widely used to study the land use Aggregation-Diffusion and later extended to China.

Now, most traditional land use fractal research focuses on 2D space. Some scholars propose considering elevation, which is very informative (Liu and Chen 2022). Usually, whether in 2D or 3D, the measuring units of the fractal are usually evenly distributed in space, which determines that the results are based on homogeneous space. However, the TOD (Transit-Oriented-Development) points out that urban space is not homogeneous in all directions (Calthorpe 1993) because accessibility/land aggregation will gradually destroy the homogeneity. This dramatically affects the accurate description of homogeneity or linear index for the city's current state. Therefore, many scholars have started to explore the morphological index changes in heterogeneous space, and the AAD (Accessibility Aggregation Dimension) based on road network has been proposed (Pavón-Domínguez et al. 2017). This paper aims to reveal the impact of heterogeneity change on land use layout through AAD and understand the land use layout of Luohe City to support land use planning such as urban greenway planning.

Methods and Data

The study city, Luohe (113°27′-114°16′E, 33°24′-33°59′N), is in the south-central part of Henan Province in central China, with a plain topography and the Shali River going through it (Figure 1). There is still a large amount of agricultural and unused land within the urban planning area. The RAD remains essentially a local index, which means that the selection of the region will influence its calculation. Hence, the built-up area in the main urban area needs to be screened firstly to remove the above interference.

The traditional method based on the nightlight threshold tends to lose factories and low-light areas within the boundaries when determining the built-up area boundaries. It is also susceptible to water reflections and road lights. Therefore, the 2021 NDBI (Normalized Difference Built-up Index)/ MNDWI (Modified Normalized Difference Water Index)/ LST_{mean} (Winter Mean Land Surface Temperature) calculated by Sentinel 2 and Landsat 8 (https://earthexplorer.usgs.gov/) was included for EM clustering. After morphological optimization, finally, the study area (113°56'15''-114°10'12''E, 33°31'01''-33°38'32''N) is shown in Figure 1 (205.16km^2).

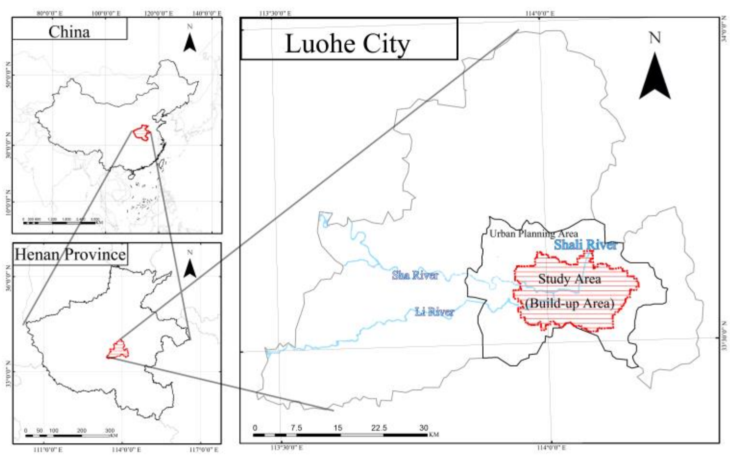


Figure 1. Location Map

Land use data based on the reclassification of urban construction land (Table 1) are mainly derived from fieldwork, combined with the POI (https://lbs.amap.com/api/) and CB04 (http://36.112.130.153:7777/#/home/). The roads are derived from fieldwork and calibrated based on multiple sources such as OSM (https://www.openstreetmap.org/). The study excludes transport land to avoid distortion of the dimensional fit results due to multicollinearity between transport land and accessibility.

Table 1. The Reclassification of Urban Construction Land

Code	A	B	W	R	O
Name	Public Administration-Service Land	Commercial Land	Warehousing and Industrial Land	Residential Land	Under Construction Land

This paper first determines the built-up area boundary of Luohe City in 2021 based on EM clustering. According to the traditional fractal index (RAD), concentric circles are the basic unit to explore the aggregation of construction land. Subsequently, road accessibility is calculated by space syntax. According to the modified fractal index (AAD), the non-uniform iso-accessibility service areas are the basic unit representing spatial heterogeneity.

(1) EM Clustering.

The identity of the built-up area is essentially the determination of mutation points of the aggregation degree of construction land, which is a type of curvilinear clustering. Compared to traditional clustering methods such as K-means/Gaussian Mixture, this algorithm is more suitable for the problem with unknown thresholds in multiple datasets.

(2) Space Syntax.

It is a theory that can deeply analyze the spatial structure and explain the human social system. In this paper, the line segment diagram is chosen to measure the accessibility of roads by the composite variable "*Efficiency*" (based on *Choice* and *Global Depth*), which also indicates that "*Efficiency*" is the primary cause of spatial heterogeneity.

(3) RAD Index.

The index reflects the Aggregation-Diffusion of the land use in the plane space by constructing construct basic units, concentric circles, in units of 500m, denoted by the number i. The linear change of the construction land area S_i covered by the concentric circles indicates spatial homogenization. The slope of the fit of $Ln(S_i)$ to $Ln(i)$ is the RAD index, denoted by D_{ra}. According to the Smeed model, the change of land density $\gamma(i)$ is called the scale behavior curve. When $D_{ra} < 2$, the density of construction land decreases from the center to the periphery; when $D_{ra} = 2$, the construction land is evenly distributed from the center to the periphery; when $D_{ra} > 2$, the density of construction land increases from the center to the periphery.

(4) AAD Index.

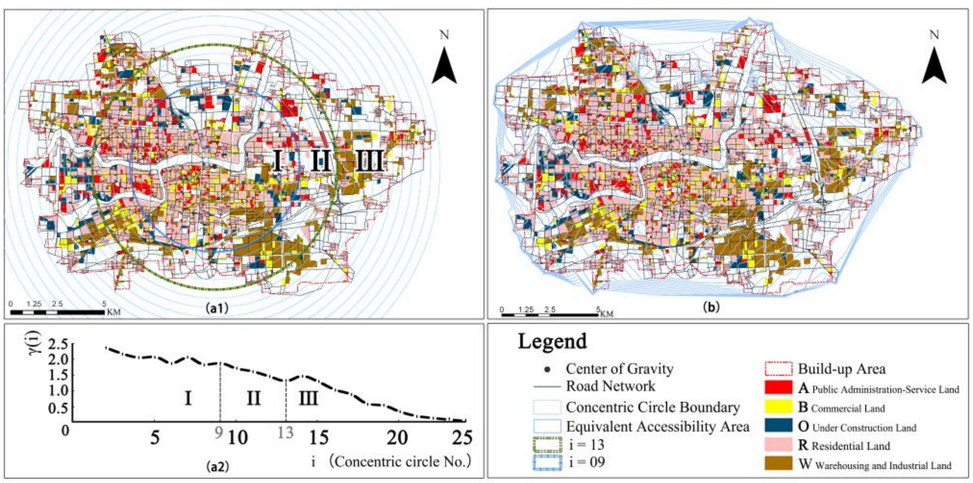
Based on the RAD, we calculate the multi-dimensional basic unit derived from "basic unit + road efficiency", equivalent to the uneven shrinkage of the accompanying accessibility in linear space. AAD is the aggregation of land projections on fold space. Measurement process: An equivalent spatial service area with a difference of 500 m (the area is M_i) is a basic unit, and another measurement process is the same as the calculation for RAD. The slope of the fit of $Ln(S_i')$ to $Ln(i)$ is the AAD index, denoted by D_{aa}. For the AAD, it is known that its Aggregation-Diffusion cut-off point is different from the RAD's, and the two cannot be directly compared. Therefore, a secondary projection of the folded space is required. D_{ai} is the fitted slope of the service area for the same no-scale region as D_{aa}, and D_{ma} is the adjusted value AAD. It can be expressed as:

$$D_{ma} = \frac{2}{D_{ai}} \cdot D_{aa} \qquad ①$$

Results

Because the center of gravity of the region is close to the Shali River, and the change in the aggregation dimension of construction land based on this point can reflect the beneficial impact of the river on alleviating the flow barriers of urban material and energy, it was chosen as the central point. Moreover, this choice is consistent with the spreading situation of Luohe City with the river as the development axis.

The study area is divided into three zones according to Scaling Behaviour Curve (Figure 2(a1-a2)): Interval I, *i*= (1,9], the value of *γ(i)* is stable at about 2. This interval corresponds to the dense core of the city. However, between *i*= [2,5], the Shali River and its surrounding green parks begin to effectively dilute the construction land, which makes *γ(i)* decrease temporarily. Interval II, *i*= (9,13], where the land density is lower than the dense urban core, and *γ(i)* shows a rapidly decreasing trend in the extended radial direction. This interval corresponds to the ring-shaped interval II in figure 2(a2), which is relatively better than interval I in terms of environmental quality because it has been separated from the dense core. The ecological land is richer in quantity. Interval III, *i*=(13,24], the value of *γ(i)* shows a decreasing trend. However, due to the enclave-like urban development, there is a wave at *i*=14.



(a1) Circle and land use variation in RAD; (a2) Scaling Behaviour Curve in the RAD;
(b) Circle and land use variation in AAD

Figure 2. Two Space Types, Radial Land Change and Scaling Behaviour Curve

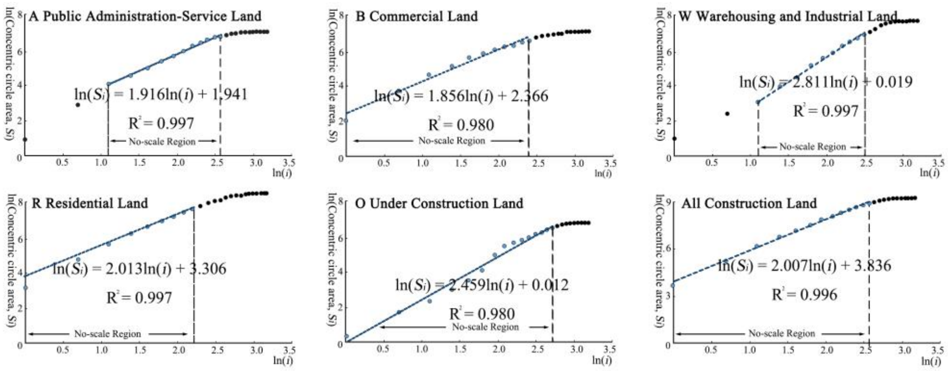


Figure 3. RAD Fit Measurements

Table 2. The Dimensional Measurement Values Under Homogeneous Space

Name	No-scale Region	R^2	D_{ra}
A Public Administration-Service Land	3-13	0.997	1.916
B Commercial Land	1-11	0.980	1.856
W Warehousing and Industrial Land	3-12	0.997	2.811
R Residential Land	1-9	0.997	2.013
O Under Construction Land	1-15	0.980	2.459
All-Construction Land	1-13	0.996	2.007

In homogeneous space, Benguigui took R^2>0.996 as a criterion to determine whether the city has strict fractal characteristics. However, for Commercial/Under Construction Land, the R^2 can be reduced to 0.980 according to previous studies. The two types usually exist in a mixed form. For example, Under Construction Land is more about the state than use and usually includes multiple land use types. The RAD index D_{ra} presents Commercial Land< Public Administration-Service Land< 2< All-Construction Land< Residential Land< Under Construction Land< Warehouse and Industrial Land (Table 2, Figure 3).

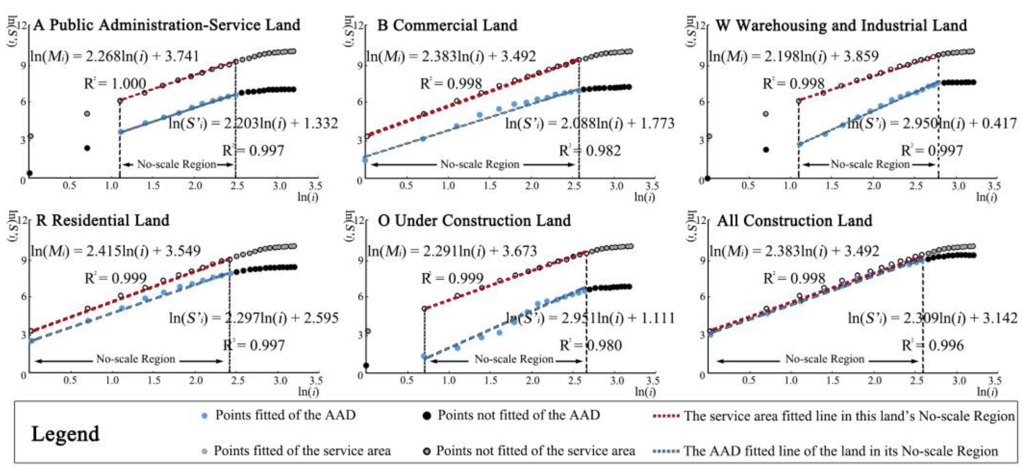


Figure 4. AAD Fit Measurements and Their Adjustment

Table 3. The Dimensional Measurement Values Under Heterogeneous Space

Name	No-scale Region	D_{aa}-R^2	D_{aa}	D_{ai}-R^2	D_{ai}	D_{ma}
A Public Administration-Service Land	3-12	0.997	2.203	1.000	2.268	1.943
B Commercial Land	1-13	0.982	2.088	0.998	2.383	1.752
W Warehousing and Industrial Land	3-16	0.997	2.950	0.998	2.198	2.683
R Residential Land	1-11	0.997	2.297	0.999	2.415	1.902
O Under Construction Land	2-14	0.980	2.951	0.999	2.291	2.576
All-Construction Land	1-13	0.996	2.309	0.998	2.383	1.937

In heterogeneous space, D_{ai} is calculated as $R^2 \geq 0.998$, indicating that irregular geometry has stricter self-similarity than land use systems. The adjusted AAD index D_{ma} presents Commercial Land < Residential Land < Public Administration-Service Land < All-Construction Land < 2 < Under Construction Land < Storage and Industrial Land (Table 3, Figure 4). Obviously, this is a different description and order than the RAD.

Discussion and conclusion

This paper identified the aggregation-dispersion pattern of construction land in Luohe City based on the spatial situation measured by RAD and AAD. After data analysis, firstly, according to the traditional RAD, the dense core of Luohe is identified. It also shows that All-Construction Land density is raised from the center to the periphery and describes the radial distribution of each land use type. Secondly, according to the adjusted AAD, Luohe's urban space shows significant heterogeneity, affecting the aggregation of urban construction land.

The RAD and adjusted AAD indexes demonstrate different urban land use layouts. The RAD shows that the All-Construction Land is diffuse. We can interpret the results as, with the help of the concept of the UCI (Urban Expansion Core Index), Urban expansion tendency is weaker. However, this interpretation is still worth discussing (Dietzel et al. 2005). The Residential Land diffusion is higher than All-Construction Land and Public Administration-Service Land. This stratification of each type of land use layout means that the city has gotten rid of the traditional construction model of "government units + supporting family homes" and entered a new urban form. The land use functions in various spheres of urban space have been highly differentiated. The adjusted AAD shows a high concentration of Commercial Land, and it is surrounded by a circle of Residential Land intermixed with Public Administration-Services Land. There is a marked expansion tendency for the All-Construction Land, and the urban core area consisting of the above three elements will continue to grow in the future. The whole urban space follows the traditional "government units + supporting family homes" pattern. Compared to the RAD results, this indicates a lower rate of inside urban renewal. Subsequently, the edges of the built-up area are actively developed, and Under Construction Land and Warehousing and Industrial Land are scattered further out. These two types are the main driving force behind the outward spreading of built-up area in Luohe's urban development. So, the land use stratification in the city has already started to appear, regardless of the AAD or RAD.

In fact, solving the mixing of residential problem compounds with other types of land use has been an important task in China's city renovation. The residential land layout has been considered closely related to the overall level of urban development (Levinson 1998). Further sorting of residential land use may be necessary for the current situation in Luohe. This makes the linking role of urban greenways not only limited to ecological patches. Based on ensuring the relative functional independence of each type of land use, it can also link different city circles and provides more opportunities for the mutual material and energy exchange between these urban subsystems.

The RAD and AAD measurements can also provide more detailed recommendations for constructing ecological land, such as greenways. For example, RAD shows the dense core is 4500m around the center, where the construction density is the highest, and the ecological conditions are harsher compared to other areas. Several studies have argued that urban sprawl reduces ecological resources and environmental space (Grimm et al. 2008). And the process of sprawl is usually accompanied by uncontrolled and intense construction. The compactness of the layout in the urban form has influenced eco-efficiency (Liu, Song, and Arp 2012). The overly dense nature of the core area cuts off material-energy exchange with the outside, and the development of ecological land here, especially the construction of a greenway, will be more effective. Greece researchers in this field have realized that planting sections in urban centers can be a good way to help restore species diversity in cities (Liordos et al. 2021). Furthermore, some researchers also have introduced greenways to connect green patches to help restore nature in cities. In parallel, coupled with the result of AAD, the basic unit calculated based on space syntax-Efficiency can be seen as a “contour” of spatial efficiency, which can better guide the construction of urban greenways and provide an adequate construction basis. It can be argued that where the lines are dense, the spatial efficiency value is high, and the greenways that run through more "contour" per unit length can produce more full benefits — whether landscape, cultural or ecological. On the one hand, this is an exploitation of heterogeneity. On the other hand, greenways can bridge the fragmentation of urban development through "integration" (Kowarik 2019).

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Acknowledgements

This research is financed by China Scholarship Council (CSC) and the Stipendium Hungaricum (SH) scholarship programme.