Scale Effect Analysis of Urban Compactness Measurement Index Based On Grid

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Abstract. Scale effect is one of the basic aspects of urban compactness. This paper takes the use of urban construction land as the breakthrough point, continuity degree and Gini coefficient as the indexes to analyse the scale effect of grid from the calculation through the different scales grid analysis of urban construction land extracted by ERDAS and ARCGIS respectively. The result showed that the selected indicators quantitively indicate the features of research area land, different scale effects of two indexes, big difference in continuity degree influenced by scale, and slight impact on Gini coefficient influenced by scale.

1. Introduction
As one of the key issues in the research of sustainable development, the sustainable development of cities has been paid much attention by governments and academia. Compact city is the concept based on urban sustainable development which aims at solving the problem of unordered city expansion. The concept of compact city first appeared in Holland and later was written in the urban development policy in England and America, and eventually become a widely accepted urban development strategy [1]. However, city is not more compact, the merrier. The form of compact city is under the great influence of population and building density. There will be problems in the aspects of urban communications, infrastructure and environmental capacity, if it is too much compact. And urban ecosystem and the quality of life of residents will be adversely affected [2]. The rationality of city compactness directly affects the efficiency of relevant strategies, therefore, the research of urban compactness has become a hotspot issue in the fields of geography and planning.

In this paper, the continuity degree and Gini coefficients are selected as the representative indicators of urban compactness taking Nanjing city of Jiangsu Province as an example. First, it extracts the building lot map of Nanjing from remote sensing images by using remote sensing software, then sets a certain scale gradient difference grid and calculates the index of urban compactness under different scale by using the method of grid analysis. The index of recognition of urban compactness is under the influence of grid scale through the comparison of two indexes analysis under different grid scale, which provides useful reference and powerful technical support for the research of urban compactness and city development plan.

2. Analysis method

2.1. Selection of structure index
There are different levels and aspects research about urban compactness. The measurement of urban compactness can be divided into five types, shape, scale, density, function and structure. And the index of structure is measured by the spatial distance and the internal relation of urban elements. There are two research areas. Firstly, the equilibrium degree of spatial distribution of urban elements, Gini coefficient can be selected. Secondly, the fragmentation degree of different components in city. It is different from shape, which emphasizes the overall situation of internal composition of research objects. There are some frequently-used indexes, splitting degree, effective grid size and urban layout continuity [3].

Therefore, this paper selects two compact indexes based on the land use structure, which are continuity degree and Gini coefficient to consider the degree of fragmentation and equilibrium degree of urban land respectively.

2.2. Calculation method of measure index

2.2.1. Gini Coefficient The Gini coefficient is derived from the measurement of the difference of income distribution in economics, and has been applied to measure the degree of urban development focusing on a small number of plots. Considering the global distribution of the whole building land, the Gini coefficient can effectively measure the equilibrium degree of urban construction land. The formula is as follows:

$$Gini = 0.5 \sum_{i=1}^{N} |Y_i - Y|$$  

In the formula: $X_i$ is the plot unit, $i$ is construction land for the proportion of total construction land, $Y_i$ is the plot unit, $i$ is area accounted for the proportion of the overall plot, $N$ is the standard small plot of total number of $i$. The index is used to measure the density distribution of urban land, the greater the value, the greater the degree of imbalance.

2.2.2. Continuity Degree In order to measure the city development of continuous high density, some scholars choose residence or employment density as the threshold; set a proportion as the standard. If the functional land reaches the standard, it will be the continuous use, if it doesn’t any continuous use. Marjo (2006) selects 80% as the boundary to distinguish between continuous and discontinuous city land, when he does the analysis of development mode of land use in 15 European cities. And this threshold conforms to our country city land use situation of heterogeneity after verification, which plays an important role in instructing the definition of city development mode [3]. Based on this research, the level of contiguous land unit construction can be calculated by the proportion of city construction land.

$$Continuity = \frac{\sum_{i=1}^{N} (if \ D_i > 80\%, \ M = 1; otherwise \ M = 0)}{N}$$

In the formula: $D_i$ is the proportion of construction land in the plot unit $i$. $M=1$, when $D_i>80\%$, in other cases, $M=0$. $N$ is the total number of standard small plots of $i$. The value Continuity is between 0 and 1. The higher the level of city construction contiguous land is, if the value tends to 1, the small the relative degree of fragmentation.

2.3. Scale Effect of Grid
Spatial scale is to measure the space to carry out research and the scale effect is defined as changing of unit size, shape and direction, when spatial data polymerizes in geography [4]. This paper takes the continuity and Gini coefficient as the indexes by the calculation of grid analysis. In the process of grid
analysis, it inevitably involves the grid size. Therefore, in the grid analysis, the scale effect on the implementation of what size of grid cell is able to express the specific geographical phenomenon. In the study of compact degree of city land use by the method of the grid analysis, not only can help select the appropriate grid size, but also can provide an important reference for the different indicators to screen effectiveness and adaptability [5].

This paper adopts the square grid size to partition the entire study area taking each unit block as a grid to calculate the proportion of construction land and compactness index. If the calculated results show that the size of grid computing and grid results are closely related, it can explain the measurement index with spatial scale effect. In addition, the characteristic difference between each index can be observed at different scales with selection of grid units of different sizes for the construction of compact measure, which, meanwhile, has specific impacts on each index of the grid scale. Therefore, the use of simple grid partition can effectively identify the effects of spatial scale and its influence.

3. Scale Effect Analysis of Compactness Measurement Index: a Case Study of Nanjing

3.1. Study area and data

Nanjing belongs to the "Yangtze River Delta" economic developed areas with superior natural conditions and dense population, which is in a rapid urban growth. Over the past 30 years, the scale of urban construction land has expanded more than 10 times in an average annual growth rate of 10%. The structure of urban land use in Nanjing is characterized by the relative concentration [6]. Meanwhile, Jiangning district, Pukou district and Liuhe district around the main city is in a rapid development recently, which has become a new hot spot for the development of Nanjing. This paper chooses Nanjing city as the study area, hoping that through the study of this typical area, on the one hand can reflect the practical significance of research on urban compactness index, on the other hand can be used to verify the grid scale effect index.

The remote sensing data of Nanjing uses seven bands and panchromatic band TM remote sensing images of Nanjing city in 2012 (from the GLCF website: http://glcf.umd.edu/). The map of administrative division of Nanjing city is from the Bureau of Surveying and Mapping Geographic Information in Jiangsu Province (http://www.jschj.gov.cn/). Remote sensing image processing software ERDAS 8.4 is used to complete the band synthesis, geometric correction and data tailoring of TM image data. Geographic information system software ARCGIS 9.3 is used to do the grid analysis and mapping by extracting the data of the distribution of city construction.

3.2. Grid analysis

For further research, this paper chooses 6 different grid scales according to the actual situation, which are 1000m, 2000m, 3000m, 4000m, 5000m, 6000m (Figure 1).
4. Result and Discussion

4.1. Result of Urban Compactness Measurement in Nanjing

The degree of continuity of construction land in Nanjing is still relatively high. However, the distribution of construction land is not balanced, and the construction land is still distributed in the central city. Nanjing has a long history of development. In early times, the relative developed city zone is in the intersection or collection of resources around the main city. Then a variety of economic information radiation has been generated through the traffic corridor, which brings a development of both sides of construction land along it. The lateral connection of the land on both sides of the line is strengthened, when the development of construction land is up to a certain extent, and he broken space is gradually filled [7]. Therefore, the Nanjing construction land around the city is in gathered distribution, which, however, is restrained by the hilly terrain and administrative boundary so that the city is in a north-south narrow form development [8].

Grid analysis at different scale can be done to the construction land of Nanjing, which has different properties. And the indicators will be changed by the change of scale, which directly confirms that there is obvious spatial effect in indexes of continuity and Gini coefficient (Table 1).

| Grid Scale (m) | Continuity | Gini Coefficient |
|---------------|------------|------------------|
| 1000          | 0.256      | 0.613            |
| 2000          | 0.134      | 0.598            |
| 3000          | 0.095      | 0.586            |
| 4000          | 0.074      | 0.572            |
| 5000          | 0.032      | 0.561            |
| 6000          | 0.013      | 0.554            |

The degree of continuity of urban construction land in Nanjing is between 0.013 and 0.256 under different grid scales. The value is close to 0, the degree of continuity of urban construction land in Nanjing is relatively small and the degree of fragmentation is high. Although there is slight deviation compared with the visual perception of the remote sensing image of the construction land in Nanjing, it just shows it has scientific nature and accuracy. As for the case of value of degree of continuity of urban construction land in Nanjing approaches to 0, it might has something to do with the grid scale which is in spatial scale of Nanjing or not. And it needs further research about if its grid scale is relatively large. At the same time, continuity in different grid scale varies greatly. And the maximum value reached 18.7 times the minimum value, which means effect of spatial scale exists. The Gini coefficient of urban construction land in Nanjing is from 0.554 to 0.613, which shows that the spatial distribution of construction land in Nanjing is not balanced. It is consistent with the actual situation of...
Nanjing urban land. The slightly variation in the Gini coefficient shows that there is no big influence on the grid scale calculation results for Gini coefficient, which means the Gini coefficient is not sensitive to the change of research scale. Based on the above two comparisons, it is found that the dependence of different indexes on the scale is different, the degree of continuity is affected by the scale, and the Gini coefficient is under slightly influence of the scale.

4.2. Scale Effect Analysis of Compactness Measurement
According to the analysis of different scale grid (Figure 1), it can be done from two different angles, which makes the result more meaningful.

4.2.1. Selection of the grid scale of same size, analysis of two different index corresponding to the results
Under the grid scale of 6000m, the result of continuity is 0.013, reaching 0. It is presumed that is caused by the choice of small scale. The continuity is significantly affected by grid scale from the calculation results. The greater the grid is, the more map spot in unit grid of land is. And The amount of continuous construction in grid sharply reduces, which results a proportion decrease of continuous construction land. Therefore, the situation of value of continuity reaching 0 happened under 6000m grid system.

The value of Gini coefficient is 0.554 under 6000m grid scale. The larger the value is, the unbalanced the distribution of construction land in Nanjing is. And it is more reasonable. The value of Gini coefficient drops when the scale expands. The increase of grid size results a sharp reduction in the number of land units. The land use type is more diverse, which performance is the decrease of the value of Gini coefficient. The bigger the analysis scale is, the more balanced the distribution of land use is. Meanwhile, the Gini coefficient is slightly affected by grid scale. Its value only has become less than 10% from top to bottom.

In the process of measuring the urban compactness, scale effect of different indexes is different, or the sensitivity of scale effect of different indexes is different through the comparative analysis at the same scale.

4.2.2. Research on structure under different grid scale respectively corresponding to two different indices
With the increase of the grid scale, there is a downward trend of the size of continuity. But the magnitude of decline is relatively large. The value of the Gini coefficient goes down as the scale goes large. But the magnitude of decline is relatively gently (Table 2).

| Table 2. The degree of index reduction at different grid scale. |
|---------------------------------------------------------------|
| **Magnitude of Decline** | 2000m | 3000m | 4000m | 5000m | 6000m |
| **Continuity** | 47.65% | 29.01% | 22.10% | 56.70% | 59.37% |
| **Gini Coefficient** | 2.45% | 2.00% | 2.39% | 1.92% | 1.24% |

There is a same trend between these two indexes, which is there is a downward trend, when the value of these two indexes go down as the scale goes large. There is a relationship between the size of the Gini coefficient and continuity and the scale of grid, and the closeness of the relationship between them is different. The continuity is close to grid scale more than the Gini coefficient. There is the same trend in change of index scale, but the stability of scale which shows the difference of land use is slightly different. And its scale effect is also different. The grid scale effect of continuity is much more obvious than of the Gini coefficient.

There is a particularly decrease in the continuity when in grid scale of 1000m and 2000m from Figure 1. With the increase of grid, the decline of continuity shows the trend of slowing down, because it is affected by the continuous threshold of land use. The change of scale leads to proportion decrease of construction land in grid and the total amount of continuous land sharply decrease. However, there is a difference when the scale up to 4000m. Therefore, it is helpful for the analysis of continuity index by choosing the right grid scale, so as to indentify the degree of fragmentation in city construction land accurately. However, there is steady decline with the change of scale in the Gini coefficient. And its
scale of suitability can be selected according to the actual operating conditions. And it is easy for the use conditions. In the study of urban compactness, the effect of index under the influence of grid scale is different. They all have unique scale effect. Therefore, it is necessary to select the appropriate index, considering its corresponding scale effect, which makes results more reliable in actual process.

5. Conclusion
Based on the analysis of the grid, the Gini coefficient and the continuity reflect the characteristics of the spatial structure of the city, which respectively show the degree of continuity and equilibrium of city land use so as to facilitate the study of urban compactness.

The characteristics of the urban compactness space represented by the index have certain scale dependence, and the continuity and the Gini coefficient will decrease with the increase of the scale, showing a downward trend.

The scale effects of continuity and Gini coefficient are different. With the change of scale, the degree of difference is relatively large, so it is more important to choose the appropriate scale. The Gini coefficient is smaller than the scale, so it has better applicability.

In the actual research, it should pay attention to the scale effect of different index and select the appropriate grid scale to do the research to ensure the certain accuracy of work in order to study the urban compactness through grid analysis of the continuity and Gini coefficient.

This paper has some shortcomings, such as, there are only 6 different grid scales to do the calculation, which makes research limited. There is only one city as the sample, which lacks of comparison with other cities. Hope there will be further research in future.

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7. References
[1] Lin L 2008 The compact strategy of the EU countries: examples from the UK and Netherlands Urban Planning International23 106-116
[2] Shimou Y, Cheng W and Luocheng Z 2008 The influencing factors of resources and environments in the process of urbanization of China Progress In Geography27 94-100
[3] Binyao L 1998 Urban space form of measurement method and its evaluation Urban Planning Forum3 42-45
[4] Lin L and Shen Y 2005 Fundamental problem on spatial scale Geomantic and Information Science of Wuhan University30 200-202
[5] Jing Y, Xiaohuan Y and Dong J 2010 The grid scale effect analysis on town leveled population statistical data spatialization Journal of Geo-information Science12 40-47
[6] Ronghua M, Chaolin G, Yingxiang P, Xiaodong M and Chuangeng Z 2007 Urban spatial sprawl pattern and metrics in south of Jiangsu province along the Yangtze River ActaGeographica Sinica62 1011-1022
[7] Suliu C 2012 The research of bidirectional organizational development character and design of urban morphology Journal of TongjiUniversity(Social Science Section)23 33-39
[8] Chuncai W 2007 The study on the interaction mechanism between urban transportation and urban spatial evolution Urban Problems6 15-19