A method of calculating the spatial difference of human settlements in urban blocks based on floor area ratio

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Abstract. Based on the method of the Jenks natural break point, this paper constructs the floor area ratio level of urban habitat environmental quality, and proposes a method of analyzing spatial difference characteristics of the human living environment in urban neighborhoods using the Theil-index model and spatial difference measurement index. The proposed method can be used not only to characterize the spatial difference measurement value of urban neighborhoods, but also to calculate the inner spatial difference in city blocks. The effectiveness of the method is verified by the remote sensing image of the case point and the actual data.

1. Introduction
Floor area ratio refers to the ratio of the built area on a particular area of land to the total area of that land parcel. This is the key control index in land planning, as it plays an important role in urban land prices and urban planning. It is also a key index to measure the quality of a community living environment [1]. Usually, researchers apply regulation and optimization of urban floor area ratio to urban land intensity and actual land planning [2-4]. Study of the urban floor area ratio mainly includes examining its determination methods and mechanism [5-6]. Researchers focus on the estimation and regulation of floor area ratio, the relationship between housing prices and floor area ratio, the relationship between traffic and floor area ratio, and floor area ratio and land use intensity [7-8]. Some researchers use real estate data from Dalian, Guangzhou and other cities to calculate and analyze the spatial characteristics and spatial differences in the floor area ratio of residential areas [9-10]. In studies of the spatial structure of urban habitat environmental quality, some studies use the methods of residential area floor ratio and Theil-index to evaluate sustainable development and regional differences in urban environments [11-12]. Other work analyzes the evolution of urban spatial forms and their relationship with spatial efficiency [13-14]. Several studies analyze current conditions, causes and improvement measures with respect to urban floor area ratio from the perspective of urban...
living environments [15-16]. The present paper uses the floor area ratio calculation method to verify spatial differences in urban living environments.

2. Materials and Methods

2.1. Materials
The data needed for this experiment include the residential area data of Anning District of Lanzhou City, construction data of the residential district, 2017 remote sensing image data (GF-2, China Centre For Resources Satellite Data and Application), the administrative planning map, traffic road data and reference data from Google Earth images. For the Anning residential area data acquisition, because the number of residential areas in Anning is too large, and district area vector map fine data are difficult to obtain, the Anning area road network is used to cut the Anning area vector map to get area data for each district. Individual residential areas are located along two or even three streets at the same time. Field visits to such areas were carried out to work out appropriate integration and split, ultimately yielding 183 residential areas. Finally, according to remote sensing image data, the residential area of Anning District was cut for artificial correction, and some remote sensing images cannot be clearly distinguished from field-examined locations.

2.2. Methods
Firstly, we use residential construction data, remote sensing image data, road traffic data and Internet real estate data to process the raw data. Secondly, Nature Breaks (G.F. Jenks, 1967) method was used to classify the floor area ratio of communities. The Theil-Index model is used to quantitatively test the spatial differences of urban living environment. Thirdly, through field investigation and data calculation, the reasons of spatial structure difference of urban living environment quality are analyzed.

2.2.1. Calculation of floor area ratio of residential areas
Using high-resolution remote sensing imagery to obtain the built area and the area occupied by each district, the residential built area is equal to the residential portion of the total built area multiplied by the number of building floors. This study calculates only the above-ground residential area, not the area of underground parking lots. Using data obtained by our experiments, the floor area ratio calculation is carried out on the overall residential area of Anning District, i.e. the total residential area in Anning District divided by the total land area occupied by residential construction; the floor area ratio of each district is then obtained. The distribution of buildings in residential areas of Anning District is shown in Fig. 1.
2.2.2. Classification of floor area ratio of residential areas
After calculating the floor area ratio of all Anning District residential areas, the floor area ratio is graded. The Natural Breaks method is used and is graded according to the 2017 surface composition of the Anning residential area; this yields seven levels. The number of residential areas in each floor area ratio level is counted. The number of residential areas corresponding to the floor area ratio range of each level and the same level of floor area ratio in the Anning area are shown in Tab. 1.

| Plot area ratio level      | Plot ratio range          | Corresponding type of residence                     | Number |
|---------------------------|---------------------------|-----------------------------------------------------|--------|
| Very low (V-L)            | Plot ratio≤0.21           | Single family villa, village cottage                | 86     |
| Low (L)                   | 0.22≤Plot ratio≤0.54      | Double row, townhouse, village bungalow             | 16     |
| Medium-low (M-L)          | 0.55≤Plot ratio≤0.81      | Garden house, low-rise building                     | 20     |
| Medium (M)                | 0.82≤Plot ratio≤1.11      | Multi-storey building                               | 21     |
| Medium-High (M-H)         | 1.12≤Plot ratio≤1.46      | Multi-storey building, small high-rise mixed        | 21     |
| High (H)                  | 1.47≤Plot ratio≤2.07      | Small high-rise building                            | 13     |
| Very High (V-H)           | 2.08≤Plot ratio≤3.10      | High-rise building                                 | 6      |

2.2.3. Theil-index model
The Theil-index model is applied to study the spatial differentiation difference in the Anning residential area. The model can also describe the spatial differentiation between the eight streets in the Anning area and the spatial differentiation within those streets. The formula is as follows:

\[ T = \frac{1}{n} \sum_{i=1}^{n} x_i \log \frac{x_i}{\bar{x}} \]  

Where, \( T \) is the Theil-index; \( n \) is the total number of residential areas in the study area; \( x_i \) is the plot ratio corresponding to the \( i \)th residential area, and \( \bar{x} \) is the average plot ratio of residential quarters in the study area. The maximum value of the Theil-index is 1 and the minimum value is 0; the higher the value, the greater degree of spatial differentiation. \( T=0 \) represents undifferentiated space and \( T=1 \) represents complete spatial differentiation.

2.2.4. Spatial difference measurement index
According to the Theil-index, our model can be converted to calculate regional spatial differences:

\[ T = T_W + T_B \]  

Formula 2 decomposes the spatial differentiation measure into the degree of spatial differentiation between blocks and the degree of spatial differentiation within blocks and streets. The corresponding expression is

\[ T = \sum_{k=1}^{K} \frac{x_k}{y_k} \left( \sum_{i \in G_k} \frac{x_i}{x_k} \log \frac{x_i}{x_k} \right) + \sum_{k=1}^{K} \frac{x_k}{n_k} \log \frac{x_k}{n_k} \]  

Where, \( T_W \) is the degree of spatial differentiation among the eight streets; \( T_B \) is the degree of spatial differentiation within each of the eight streets; \( K \) is the eight research areas, i.e. the eight streets; \( G_k \) \((k = 1,2,...K)\) is the number of residential areas in each study area; \( n_k \) is the number of residential areas in the \( k \)th street; \( x_k \) is the sum of plot ratios corresponding to residential areas in the \( k \)th street; and \( y_k \) is the sum of plot ratios of all residential areas in the study area.
3. Analysis of experimental processes and results

3.1. Floor area ratio and spatial distribution characteristics of residential areas

Following the administrative plan of Anning District, Anning District is divided into eight study areas. The number of residential blocks in the eight study areas is calculated, shown in Tab. 2. The floor area ratio of residential areas in Anning District is graded (Tab. 1).

Table 2. Number of residential quarters in eight streets of Anning District

| Blocks  | Anningpu | AnningXilu | Kongjiaai | Liujiapu | Peili | Shajingyi | Shildian | Yintanlu |
|---------|----------|-------------|-----------|----------|-------|-----------|----------|----------|
| Number  | 39       | 27          | 16        | 36       | 27    | 26        | 34       | 36       |

After grading, ArcGIS 10.3 is used to generate an equivalence chart of the floor area ratio of residential areas in the Anning area (Fig. 2). The three core areas of the Anning area are Shilidian Street, Kongjiaai Street and Yingtanlu Street; their floor area ratio contour lines are dense, large span, with a distribution of high floor area ratios. The core residential area shows high land development intensity, small area, and a high number of floors; meanwhile, its surroundings include village bungalow areas. Due to the large differences in the floor area ratios of residential areas, the equivalence chart of the floor area ratio of the three regions are concentrated and the spatial difference is large. Areas with sparse contour lines are mainly Shajingyi Street and Anningpu Street, with smaller differences in floor area ratios.

![Figure 2. Plot ratio contour map of residential quarter in Anning District](image)

3.2. Spatial difference measurement index and spatial differentiation

Using the Theil-index model, the spatial difference measurement index of the floor area ratio of the Anning District and the spatial difference measurement index of the eight blocks are calculated. The result is shown in Tab. 3.

Table 3. Spatial difference index value of plot ratio between Anning District

| Streets      | Anningpu | AnningXilu | Kongjiaai | Liujiapu | Peili | Shajingyi | Shildian | Yintanlu |
|--------------|----------|-------------|-----------|----------|-------|-----------|----------|----------|
| index value  | 1.046    | 0.105       | 0.034     | 0.192    | 0.344 | 0.134     | 0.130    | 0.239    | 0.241    |

Table 3 shows that the overall difference measurement index of the floor area ratio of residential areas in Anning District is 0.241. The Theil-index model is used to calculate the spatial difference measurement index value of the floor area ratio of each level in the residential area of Anning District. The results are shown in Tab. 4.

Table 4. Measurement index value of spatial difference of plot ratio levels in Anning District

| Plot ratio level | (V-L) | (L) | (M-L) | (M) | (M-H) | (H) | (V-H) |
|-----------------|-------|-----|-------|-----|-------|-----|-------|
| index value     | 0.55799 | 0.00739 | 0.00413 | 0.00428 | 0.00332 | 0.00545 | 0.00693 |
The spatial difference measurement index among the eight streets is calculated and derived by applying Formula (3). \( T_b / T + T_w / T = 1 \), and \( T_b / T \) represents the contribution rate of spatial difference measurement among the eight streets to the overall spatial difference measurement of the Anning area. \( T_w / T \) represents the contribution rate of spatial difference measurement within each of the eight streets to the overall spatial difference measurement of the Anning area District (Tab. 5).

**Table 5.** Measurement index and contribution rate of spatial difference between and within eight streets in Anning District

|                | Between streets | Inside streets | Total  |
|----------------|-----------------|----------------|--------|
| Difference measure index value | 0.06071         | 0.1808         | 0.24151|
| Contribution rate               | 25.14%          | 74.86%         | 100.00%|

Tab. 5 indicates that the spatial difference measurement index within the eight streets is 0.1808 and the spatial difference measurement index among the eight streets is 0.06071.

3.3. Quality of human settlements

The average of the floor area ratio of the eight-street residential area is calculated using the data for the residential area of Anning District, and the results are shown in Tab. 6.

**Table 6.** Average plot ratio of the whole residential area and the eight streets

| Streets     | Anning pu | Anning Xilu | Kongjia ai | Liujiapu | Peili | Shajing yi | Shili dian | Yintan lu | Total  |
|-------------|-----------|-------------|------------|----------|-------|------------|------------|-----------|--------|
| Floor area ratio | 0.020     | 0.530       | 1.247      | 0.345    | 0.569 | 0.081      | 0.718      | 0.570     |

3.4. Spatial structure of human settlement quality in Anning District

The spatial structure of the quality of the living environment in the Anning area was brought forth using ArcGIS10.3, yielding Fig.3 below.

**Figure 3.** Spatial structure of human settlement quality in Anning District

4. Conclusions

The floor area ratio and Theil-index models can calculate the degree of difference between city blocks as a whole, the degree of difference between blocks, the degree of difference within neighborhoods, and the degree of spatial differences among the various volume rate levels of neighborhoods. In this study only the individual factors of data and floor area ratio in 2017 are employed, but some other factors affecting the quality and spatial structure of urban living environments have not been used. For example, it does not address the spatial evolution of multi-phase and multi-scale regional quality of space, which is worthy of our future investigating.
Acknowledgments

Author Contributions: All the authors have contributed to this manuscript. J L.J. and H W.Y. proposed the methodology. J L.J. performed the experiments and wrote the draft of the manuscript. Q.B & G Z J.S and G G.W visualized the diagram. J L.J. analyzed and evaluated the results. H W.Y., Q.B and J L.J. guided the research and revised the manuscript. This work was funded by the National Nature Science Foundation of China (No. 41930101) and the National Key R&D Program of China (No. 2017YFB0504203).

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