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Integrated multi-scale and multi-factor regional similarity measurement method

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Abstract: Regional similarity measurement is an important and complex issue. Current research on regional similarity mostly focuses on extracting a single element for comparative analysis at a single scale, and there is relatively little research on the differences in spatial distribution characteristics of regional elements. Based on this, we propose a comprehensive and integrated multi-scale and multi element regional similarity measurement method. Firstly, 12 geographical elements within the region were selected for similarity analysis between regions, and based on their characteristics, the elements were divided into 6 large-scale elements and 6 small-scale elements; Secondly, based on spatial autocorrelation coefficient, Pearson correlation coefficient, Analytic Hierarchy Process (AHP), and mean method, the similarity of 12 elements between regions is measured; Finally, a comprehensive evaluation model for multi factor similarity was designed based on AHP, mean method, and Pareto Principle to calculate the overall similarity of regions. At the same time, one benchmark region and eight compare regions were selected for regional similarity calculation. The results showed that the proposed method combines multi-scale and multi element description information of geographical features, which can provide new ideas and methodological guidance for improving the accuracy and reliability of regional similarity analysis.

1. Introduction

Similarity is a universal law in nature and an important way for humans to understand things and engage in activities. In recent years, with the emergence of research topics such as climate similarity, hydrological similarity, spatial scene similarity, and geographic similarity, the role of regional similarity analysis has become increasingly prominent, and it has been widely applied in site selection analysis [1], land suitability evaluation [2], watershed hydrological analysis [3,4,5], ecological environment analysis [6,7], case reasoning [8,9], and so on. It has played an important role in industrial and agricultural production, natural disaster forecasting and prevention, and battlefield environment analysis, and has had a profound impact on human activities.

Regional similarity measurement is an important and complex problem [10], and many scholars have conducted research on the similarity between regions. Guo et al. [11] proposed a mixed similarity measurement model for regional contour groups based on topological and geometric features. Wang et al. [12] proposed a hierarchical semantic similarity measurement model for road networks that takes into account the hierarchical structure, spatial topology information, and neighborhood feature information of the road network. Yang et al. [13] divided geometric similarity into three levels of indicators for measuring water system similarity: shape feature similarity, local structural feature similarity, and global distribution feature similarity. Robert et al. [14] used 19 climate factors from World climate, including temperature, rainfall, relative humidity, air pressure, wind direction, and wind speed, to measure environmental similarity in different regions and analyze the risk of biological invasion between regions. Based on the law of geographical similarity, Yang et al. [1] selected the location with similar geographical environment characteristics in Qinghai Province as the preselected excellent astronomical observation site according to the four geographical environment characteristics of precipitation, elevation, land use type and human activities of the world's first class astronomical observation site. The above scholars have measured the similarity of some elements in the region, which can reflect the similarity between regions to a certain extent, but the region as a complex overall environment, it is difficult to reasonably evaluate the similarity between regions by a single scale of a single element. At the same time, the spatial distribution characteristics can describe the distribution of geographical things, phenomena and elements in a specific region, which is an important feature to describe the region. However, the above scholars do not consider the spatial distribution differences of elements in the region.

Based on this, we propose a comprehensive and integrated multi-scale and multi factor regional similarity measurement method. Firstly, 12 geographical elements within the region were selected for similarity analysis between regions, and based on the characteristics of the elements, they were divided into 6 large-scale elements and 6 small-scale elements. The large-scale elements include terrain and landforms, six major geographical zones, climate zones, regional area, minimum bounding rectangle length to width ratio, and spatial distance, while the small-scale elements include elevation, slope, surface cover type, spatial distribution of land types, soil types, and meteorology; Secondly, based on spatial autocorrelation coefficient, Pearson correlation coefficient, AHP, and mean method, the similarity of 12 elements between regions is measured; Finally, a multi factor similarity comprehensive evaluation model was designed based on AHP, mean method, and Pareto Principle to calculate the overall similarity of regions. The similarity of large-scale and small-scale factors was comprehensively integrated to obtain the overall similarity degree results between the comparison area and the benchmark area. To verify the effectiveness of the method proposed in this paper, Fanggou Village in Zhengzhou City was selected as the benchmark area for regional similarity analysis, while Taipingqiao Community in Chengdu, Jifeng Village in Guangzhou, Shengli Village in Harbin, Reshui Village in Kunming, Bailang Village in Lhasa, Dazhuang Village in Qingdao, Xierqu Village in Urumqi, and Changfeng Village in Changsha were selected as 8 compare areas. The contributions of this article are as follows:

(1) This article divides different elements within the region into scale based on their characteristics. Among them, terrain and landforms, six major geographical zones, climate zones, regional area, the length to width ratio of the smallest bounding rectangle, and spatial distance are six large-scale elements of the region. Elevation, slope, land type attributes, land type spatial distribution, soil type, and meteorology are six small-scale elements of the region.

(2) Based on the AHP, mean method, and Pareto Principle, this paper designs a multi-factor similarity comprehensive evaluation model, calculates the overall similarity of multi-scale and multi-factor in the region, and solves the problem that the current regional similarity measurement factors are not comprehensive, the scale is single and the spatial distribution difference characteristics of the

factors are not considered;

(3) In order to verify the effectiveness of the method, we select Fanggou Village in Zhengzhou City as the benchmark region, and selects 8 compare regions in different latitudes and longitudes to analyze the similarity between regions.

2. Study area and data

2.1. Study area

To verify the usability of the proposed method, we select a benchmark region and 8 compare regions to analyze the similarity between regions, and the selected regions are shown in Figure 1. Fanggou Village in Zhengzhou City, Henan Province is selected as the benchmark region, and 8 areas with different latitude and longitude locations are selected as the compare regions, which are Taipingqiao Community in Chengdu, Jifeng Village in Guangzhou, Shengli Village in Harbin, Reshui Village in Kunming, Bai Lang Village in Lhasa, Dazhuang Village in Qingdao, Xierqu Village in Urumqi and Changfeng village in Changsha.

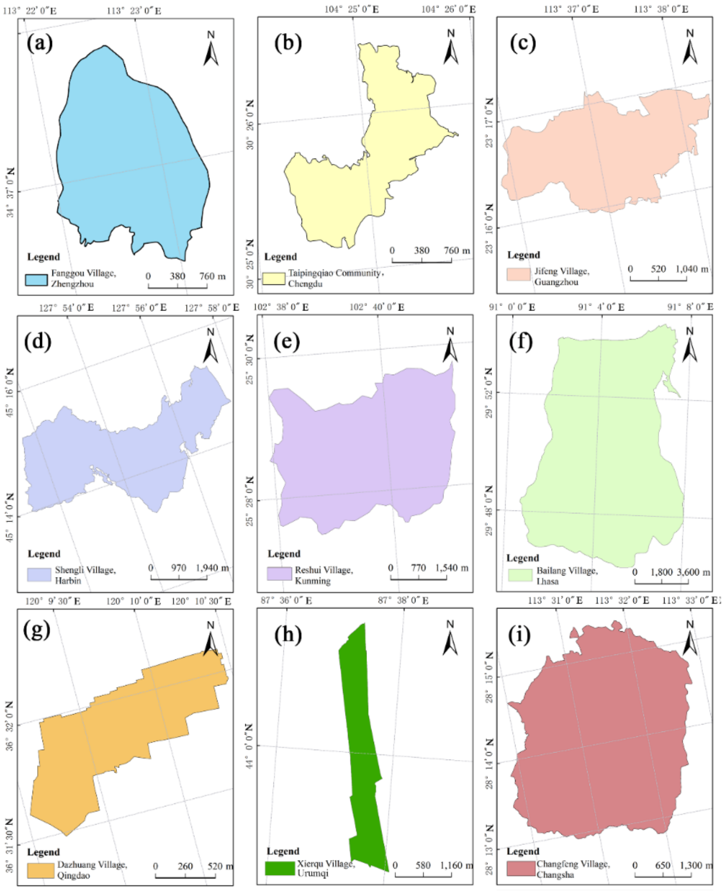

Figure 1: Study area. (a) Fanggou Village, Zhengzhou City. (b) Taipingqiao Community, Chengdu. (c) Jifeng Village, Guangzhou. (d) Shengli Village, Harbin. (e) Reshui Village, Kunming. (f) Bailang Village, Lhasa. (g) Dazhuang Village, Qingdao. (h) Xierqu Village, Urumqi. (i) Changfeng Village, Changsha.

2.2. Data

The study covers a total of 8 kinds of data, including DEM data, slope data, spatial distribution data of China's topography and geomorphology, data of China's six geographical divisions, data of China's climate divisions, data of land cover types, data of soil types and meteorological data. DEM, the spatial distribution of landform, slope, China six major geographical partition and climatic regionalization data are from national earth system science data center (https://www.geodata.cn/data); Soil data were obtained from the National Glacial and Permafrost Desert Science Data Center (http://www.ncdc.ac.cn). Land cover data were obtained from Esri provided by 2020 10m global land cover data (https://www.arcgis.com/apps/instant/media/index); The meteorological data is sourced from the National Meteorological Science Data Center (https://data.cma.cn/). The meteorological data of 9 regions for 5 years from January 1, 2019 to January 1, 2020 are obtained. The time scale of meteorological data is 3 hours, and a total of 131,211 meteorological data are generated.

3. Methods

3.1. Technical route

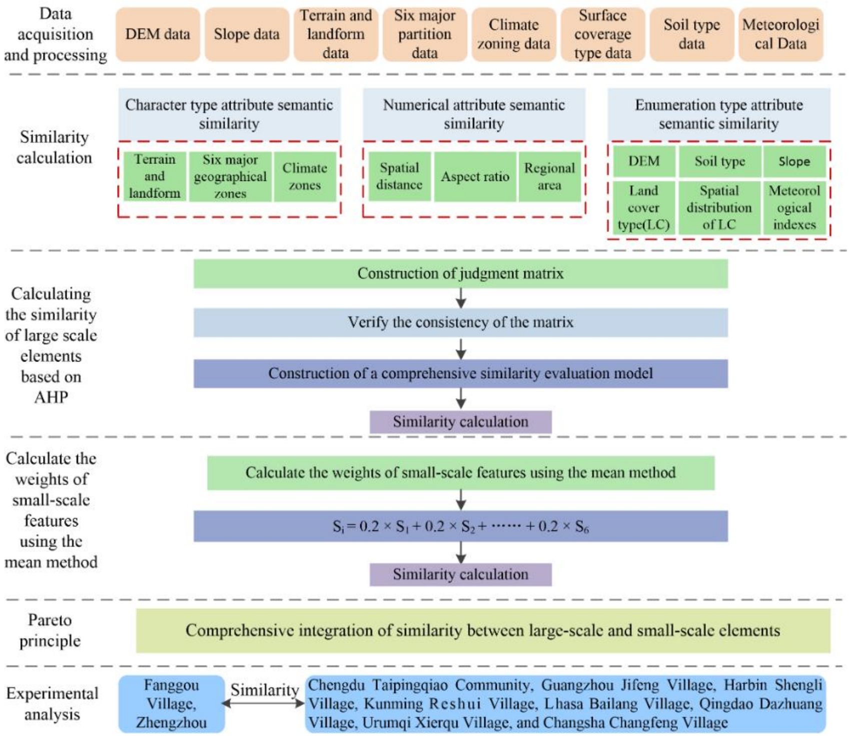

Figure 2: Technical route.

In this paper, a comprehensive and integrated regional similarity measurement method of multi-scale and multi-element is proposed. The method is mainly divided into six parts: data acquisition and processing of benchmark area and comparison area, similarity calculation, large-scale element similarity quantification, small-scale element similarity quantification, large-scale and small-scale element similarity comprehensive integration and experimental analysis. The technical flow is shown in Figure 2.

3.2. Similarity calculation

Analyzing the attribute information of 12 elements, they can be divided into 3 types: character type, numerical type, and enumeration type. Therefore, the similarity calculation methods for the 12 elements are divided into three types: character based attribute semantic similarity calculation, numerical based attribute semantic similarity calculation, and enumeration based attribute semantic similarity calculation. The similarity between the three elements of terrain and landforms, six major geographical zones, and climate zones is calculated using character based attribute semantic similarity calculation method; The numerical attribute semantic similarity calculation method is used to calculate the similarity between the three elements of regional area, minimum bounding rectangle aspect ratio, and spatial distance; The similarity of six elements, including elevation, slope, surface cover type, land type spatial distribution, soil type, and meteorology, between regions is calculated using an enumeration based attribute semantic similarity calculation method. The process of similarity calculation method is as follows:

(1) Semantic similarity calculation of character type attributes

Character based semantics uses strings to represent certain attributes of certain elements in a region. For example, the terrain and topography of Fanggou Village in Zhengzhou are low altitude hills, and their similarity is quantified using a comparative method. The principle of similarity quantification is as follows: if the character attribute semantics of a certain element in the compare region are completely consistent with those in the benchmark region, it is considered that the element in both regions is completely similar, and the similarity is 1; If the character attribute semantics of a certain element in the compare region are completely different from those in the benchmark region, it is considered that the element in the two regions is completely dissimilar, and the similarity is 0; If the semantic part of the character attribute of a certain element in the compare region is consistent with that in the benchmark region, it is considered that the attribute part of the element in the two regions is similar. The similarity calculation formula is shown in equation 1:

$$S_T = \frac{A_1}{A} \times 1 \tag{1}$$

Where S_T represents the similarity of the elements; A_1 is the area of the region where the character attribute semantics of the element in the compare region are the same as those in the benchmark region; A is the area of the compare region.

(2) Semantic similarity calculation of numerical attributes

Numerical semantics uses numbers to represent a certain attribute of a certain element in a region, for example, the area of Fanggou Village in Zhengzhou City is 3.7296 km^2, and its similarity is quantified using a difference ranking method. Firstly, calculate the difference between the attributes of the comparison region and the benchmark region; Secondly, sort the differences in ascending order; Finally, based on the difference ranking, the similarity of the element in the comparison region is quantified. The similarity of the comparison region with the first difference ranking is set to 1, the similarity of the comparison region with the second difference ranking is set to 0.9, and the similarity of the comparison region with the third difference ranking is set to 0.8. The similarity between each comparison region and the benchmark region for this element is sequentially set.

(3) Semantic similarity of enumerative attributes

The enumeration semantics in this article mainly describe the attributes of elements through classification, generally divided into two or more categories, and described by numerical values. For example, in Fanggou Village, Zhengzhou City, the proportion of pixels with an elevation range of 200-500m is 98.99%, and their similarity is also quantified using the difference sorting method. Firstly, classify the elements based on their attribute values; Secondly, calculate the proportion of pixels classified by all elements in the benchmark area and the comparison area separately; Finally, calculate the difference in the proportion of pixels in each category of the feature between the comparison region and the benchmark region, and sort the difference in ascending order. Then, we quantify the similarity between the comparison region and the benchmark region in each category of the attribute based on the sorted difference.

At the same time, due to the fact that different attribute classifications have the same impact on regional similarity, for example, the proportion of pixels with an elevation range of<200m and the proportion of pixels with an elevation range of 200-500m in Fanggou Village, Zhengzhou City have the same overall impact on regional similarity. Therefore, this article sets the average weight of each feature classification on regional similarity, and calculates the total feature similarity value between the comparison and benchmark regions based on the calculated similarity values in each feature classification. The calculation formula is shown in equation 2.

$$S = \frac{1}{i} \times S_1 + \frac{1}{i} \times S_2 + ... + \frac{1}{i} \times S_i \tag{2}$$

Where, S is the comprehensive similarity value of the element between the reference region and the comparison region; $S_1 - S_i$ is the similarity value between each element category in the comparison region and the corresponding element category in the reference region; and i is the number of element classifications in the benchmark area.

3.3. Analytic hierarchy process integrating similarity of large scale elements

Starting from the entire region, this article quantitatively expresses the similarity of six elements between the benchmark area and the comparison area, including terrain and landforms, six major geographical zones, climate zones, regional area, spatial distance, and aspect ratio in the region. But the six elements are independent, and in reality, there may be interactions between them, so it is necessary to integrate the similarities of the six elements comprehensively. AHP is a subjective weighting method that can decompose a problem into different constituent elements based on its nature and the overall goal to be achieved. The elements are then clustered and combined at different levels according to their interrelationships and influences, forming a multi-level analytical structure model. This allows for the determination of the relative importance weights of the lowest level relative to the highest level, and is easy to calculate and understand for decision-makers. Therefore, this article uses the Analytic Hierarchy Process to determine the weights of the six factors that affect regional similarity. Based on expert experience, the AHP judgment matrix constructed in this article and the weights of each element calculated for their impact on regional similarity are shown in Table 1.

Table 1: AHP judgment matrix and weights of the impact of six large-scale factors on regional similarity.

	Terrain and landform	Six major geographical zones	Climate zones	Regional area	Spatial distance	Aspect ratio	Weight
Terrain and landform	1	1	1	2	3	3	0.2387
Six major geographical zones	1	1	1	2	3	3	0.2387
Climate zones	1	1	1	2	3	3	0.2387
Regional area	1/2	1/2	1/2	1	2	2	0.13199
Spatial distance	1/3	1/3	1/3	1/2	1	1	0.07592
Aspect ratio	1/3	1/3	1/3	1/2	1	1	0.07592

By using the consistency index CI and the random consistency ratio CR of the matrix to test the consistency of the AHP judgment matrix, it can be calculated that the CR of the constructed AHP judgment matrix is 0.00229, CR<0.1. The judgment matrix passes the consistency test, and the weights of the calculated factors on the impact of regional similarity can be used.

After calculating the weights of the six factors that affect regional similarity, in order to obtain the overall similarity between the six factors of the comparison region and the benchmark region, and to analyze the similarity between the eight comparison regions and the benchmark region at a large scale, this paper constructs a comprehensive similarity evaluation model, and the model formula is shown in equation 3.

$$S_i^l = W_1 S_1^l + W_2 S_2^l + W_3 S_3^l + W_4 S_4^l + W_5 S_5^l + W_6 S_6^l \tag{3}$$

Where, S_i^l represents the comprehensive similarity of the six large-scale elements in the i-th comparative region, $W_1 - W_6$ represents the weight of the impact of the six elements on regional similarity, and $S_1^l - S_6^l$ represents the similarity value of the six elements.

3.4. The mean method integrates the similarity of small-scale elements

This article quantitatively expresses the similarity of six elements, including elevation, slope, land type attribute, land type spatial distribution, soil type, and meteorology, between the benchmark area and the comparison area based on the elevation, slope, land type attribute, land type spatial distribution, soil type, and 131211 meteorological data of a single pixel. This article believes that the impact of these six elements on regional similarity is the same. Therefore, the weights of the six elements on regional similarity are averaged. Based on the calculated similarity values of each element within the comparison area, the total small-scale element similarity value between the comparison area and the benchmark area is calculated using the formula shown in equation 4.

$$S_i^s = 0.2 \times S_1^s + 0.2 \times S_2^s + 0.2 \times S_3^s + 0.2 \times S_4^s + 0.2 \times S_5^s + 0.2 \times S_6^s \tag{4}$$

where, S_i^s represents the comprehensive similarity value of six small-scale elements in the i-th comparison region, and $S_1^s - S_6^s$ represents the similarity value of each element between the benchmark region and the i-th comparison region.

3.5. Multi scale and Multi element Similarity Integration

In order to comprehensively determine the similarity between the eight comparison areas and the benchmark areas, this paper synthetically integrates the similarity values of large-scale factors and small-scale factors, and constructs a multi-factor similarity comprehensive evaluation model. Referring to the weights of global distribution feature similarity and local structure feature similarity set by Yang et al [13], we set the weights of the influence of large and small scale elements on regional similarity as 0.8 and 0.2, respectively, and the multi-factor similarity comprehensive evaluation model constructed is shown in equation 5.

$$S = (S_1^l + S_2^l + ... + S_i^l) \times 0.8 + (S_1^s + S_2^s + ... + S_i^s) \times 0.2 \tag{5}$$

Where, S is the similarity of multi-scale and multi-factor integrated in benchmark area; S_i^l is the similarity value of each element in large scale; S_i^s is the similarity value of each element at small scale.

4. Results and analysis

4.1. Analysis of regional similarity of large-scale elements

The similarity of large-scale elements describes the rough similarity between regions at a macro level, although not precise, it characterizes the overall characteristics of the region. Table 2 shows the overall similarity between the benchmark area and the comparison area based on the comprehensive analysis of the six large-scale elements of terrain and landforms, six major geographical zones, climate zones, regional area, the length to width ratio of the smallest bounding rectangle, and spatial distance based on the AHP and the mean method. From Table 2, it can be seen that among the 8 compare areas, the areas with high similarity to the benchmark area are Chengdu Taipingqiao Community and Qingdao Dazhuang Village, reaching 0.479 and 0.460, respectively. The topography, area, spatial distance, and minimum external rectangle aspect ratio of Taipingqiao Community in Chengdu are similar to those of Fanggou Village in Zhengzhou, while the area, spatial distance, minimum external rectangle aspect ratio, and climate of Dazhuang Village in Qingdao are similar to those of Fanggou Village in Zhengzhou. The similarity between Guangzhou Jifeng Village and Changsha Changfeng Village and the benchmark area is also high, while the similarity between Lhasa Bailang Village and Kunming Reshui Village and the benchmark area is low.

Table 2: Comparison of regional similarity of large-scale elements.

Area	Terrain and landform	Six major geographical zones	Climate zones	Regional area	Spatial distance	Aspect ratio	Total similarity
Taipingqiao Community	1	0	0	0.9	0.8	0.8	0.479
Jifeng Village	0.094	1	0	0.8	0.7	0.4	0.450
Shengli Village	0	0	0.5	0.4	0.5	0.5	0.248
Reshui Village	0	0	0	0.5	0.6	0.6	0.157
Bailang Village	0	0	0	0.3	0.4	1	0.146
Dazhuang Village	0	0	1	0.7	1	0.7	0.460
Xierqu Village	0	0	0.5	1	0.3	0.3	0.305
Changfeng Village	0	1	0	0.6	0.9	0.9	0.459

4.2. Analysis of regional similarity of large-scale elements

The similarity of small-scale elements describes the similarity between regions from the perspective of a single pixel or a single meteorological data. Although it can't fully characterize the environmental characteristics of the region, it is relatively accurate. Table 3 presents the quantitative results of small-scale element similarity through comprehensive integration, mainly considering the similarity of six elements including elevation, slope, land type attributes, land type spatial distribution, soil type, and meteorology, providing a more refined measure of similarity. Among the 8 compare areas, the similarity between Kunming Reshui Village and Lhasa Bailang Village and the benchmark area was higher, and the total similarity values reached 0.728 and 0.632, respectively. The similarity between Xierqu Village in Urumqi and the benchmark area is the lowest.

In the similarity analysis of individual elements, it can be found that the elevation similarity between Taipingqiao Community and the benchmark area reaches 1, the slope similarity between Changfeng Village and the benchmark area reaches 0.8, the similarity of land type attributes between

Jifeng Village and the benchmark area reaches 0.75. The similarity of spatial distribution characteristics between Jifeng Village and the benchmark area reaches 0.73, the soil type similarity between Hot Water Village and the benchmark area is 1, and the climate zone similarity between Dazhuang Village and the benchmark area is 0.654.

Table 3: Comparison of regional similarity of small-scale elements.

Area	Elevation	Slope	Land cover type attribute features	Land cover types spatial distribution characteristics	Soil type	Meteor-ological	Total similarity
Taipingqiao Community	1	0.5	0.48	0.38	0	0.474	0.472
Jifeng Village	0.88	0.72	0.75	0.73	0	0.388	0.578
Shengli Village	0.96	0.7	0.55	0.55	0	0.454	0.536
Reshui Village	0.92	0.78	0.68	0.72	1	0.266	0.728
Bailang Village	0.92	0.68	0.4	0.68	0.9	0.21	0.632
Dazhuang Village	0.88	0.36	0.6	0.52	0	0.654	0.502
Xierqu Village	0.92	0.5	0.28	0.28	0	0.412	0.399
Changfeng Village	0.92	0.8	0.7	0.6	0	0.546	0.594

4.3. Comprehensive integration of multi-scale and multi factor regional similarity analysis

The similarity of large-scale elements can characterize the overall characteristics of a region but is not precise, while the similarity of small-scale elements is more accurate but cannot fully characterize the environmental features of the region. Therefore, it is important to consider the similarity of both large and small scale elements comprehensively. Table 4 shows the results of regional similarity analysis calculated based on the constructed multi factor similarity comprehensive evaluation model. From the table, it can be seen that compared with the benchmark area, Chengdu Taipingqiao Community and Kunming Reshui Village have the highest similarity in large-scale and small-scale elements, respectively. However, after integrating the similarity of large-scale and small-scale elements using a comprehensive evaluation model, Changsha Changfeng Village has the highest similarity with the benchmark area, reaching 0.486. The similarity between Chengdu Taipingqiao Community and Guangzhou Jifeng Village and the benchmark area also reached 0.477 and 0.476, respectively; The similarity between Lhasa Bailang Village and the benchmark area is the lowest, at 0.243.

Table 4: Quantitative results of multi-scale and multi factor similarity integrated comprehensively.

Area	The similarity of large-scale elements	The similarity of small-scale elements	Total similarity
Taipingqiao Community	0.479	0.472	0.477
Jifeng Village	0.450	0.578	0.476
Shengli Village	0.248	0.536	0.306
Reshui Village	0.157	0.728	0.271
Bailang Village	0.146	0.632	0.243
Dazhuang Village	0.460	0.502	0.469
Xierqu Village	0.305	0.399	0.324
Changfeng Village	0.459	0.594	0.486

5. Discussion and conclusions

We propose a comprehensive and integrated multi-scale and multi element regional similarity measurement method. 6 large-scale regional elements and 6 small-scale regional elements are selected for similarity analysis between regions, and a benchmark region and 8 compare regions are selected for experimental analysis. The conclusions are as follows:

(1) By analyzing the comprehensive similarity of 6 large-scale regional elements between the comparison area and the benchmark area, it was found that the areas with high similarity to the benchmark area were Taipingqiao Community in Chengdu and Dazhuang Village in Qingdao, reaching 0.479 and 0.460, respectively. And the similarity between Bailang Village in Lhasa and Reshui Village in Kunming and the benchmark area was relatively low;

(2) By analyzing the comprehensive similarity of six small-scale regional elements between the comparison area and the benchmark area, it was found that Kunming Reshui Village and Lhasa Bailang Village were similar to the benchmark area, with similarities of 0.728 and 0.632, respectively. And the similarity between Urumqi Xierqu Village and the benchmark area was the lowest;

(3) After integrating the similarity of large-scale and small-scale elements, it was found that Changfeng Village in Changsha had the highest similarity with the benchmark area, reaching 0.486, while Bailang Village in Lhasa had the lowest similarity with the benchmark area, reaching 0.243.

The results indicate that the multi-scale and multi element regional similarity measurement method proposed in this paper can comprehensively consider the advantages of large and small-scale feature similarity measurement, and can comprehensively and quickly measure the similarity between regions, providing new ideas and methodological guidance for regional similarity measurement. However, as the number of elements continues to increase, it affects the efficiency of the method and intensifies the difficulty of evaluation. Therefore, in the next step of our work, we plan to quantitatively analyze the impact of different elements on the measurement of regional similarity, in order to select necessary regional elements and participate in the measurement of regional similarity.

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