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Urban Livability Analysis Based on Multi-Source Remote Sensing Data

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Abstract

Under the background of city physical examination and assessment in territorial spatial planning, urban livability has become a focus of interest. Urban livability reflects residents' overall satisfaction with their living environment. Previous studies have been constrained by issues such as low data precision, coarse spatial scales, and limited practical applicability. To address these limitations, this study developed a refined livability evaluation framework by multi-source remote sensing data, with a primary emphasis on high-resolution domestic satellite imagery, including Gaofen (GF-1) and Ziyuan (ZY-3). Integrated with Suomi NPP night-time light data and socio-economic datasets, the research assessed four key dimensions, which were safety and resilience, residential comfort, recreation convenience, and quality and vitality in the city of Wuhan and Yibin at a detailed kilometer-grid scale. Results revealed distinct spatial patterns of urban livability of the two cities: Wuhan's central urban areas exhibited higher, more clustered livability, driven largely by quality and vitality, whereas Yibin showed a more fragmented pattern with strengths in recreation convenience but relative weaknesses in residential comfort and urban vitality. This study underscores the significant value of high-resolution, multi-source remote sensing data in enabling precise, spatially explicit livability analysis, thereby providing a scientific basis for targeted spatial planning and urban quality enhancement.

1. Introduction

Urban livability reflects residents' overall experience of their living environment and quality of life, which is closely related to their life satisfaction and well-being (Zhang, 2016; Wu, 2018). As early as 1996, the Second United Nations Conference on Human Settlements proposed that cities should be livable human settlements. In 2005, the "Beijing Urban Master Plan" put forward the concept of "livable city" in China. The China Urban Competitiveness Research Institute conducts research and evaluation on cities across the country by constructing an indicator system covering ecological health, urban safety, life convenience, life comfort, economic prosperity, social civilization, and urban reputation, and regularly releases the list of top ten livable cities.

In June 2021, China's Ministry of Natural Resources released the "Regulations for Territorial Spatial Planning City Physical Examination and Assessment," which utilizes the five development concepts as assessment dimensions. Within this framework, the "Sharing" dimension includes indicators for livability, suitability for aging, and employment suitability, aiming to evaluate residents' sense of happiness and fulfillment.

Early studies on urban livability (Tan and Dong, 2017; Cui et al., 2018; Zhang et al., 2019; Dong et al., 2020; Zhang and Meng, 2025) constrained by issues such as low data precision, coarse spatial scales, and limited practical applicability. These studies primarily rely on statistical data aggregated by administrative units. Although some scholars have incorporated remote sensing data as a supplementary source, they predominantly utilize a limited number of open-source, low-resolution remote sensing products. Furthermore, livability research has mainly focused on administrative divisions like districts, counties, and sub-districts, lacking fine-scale spatial analysis and thus providing limited support for detailed territorial spatial planning.

Multi-source remote sensing data offer convenient and extensive access to obtain information of the environment and human activities. Through techniques such as remote sensing intelligent interpretation and band retrieval, they provide crucial data and technical support for urban livability studies. Utilizing multi-source remote sensing data, with a focus on high-resolution satellite imagery, for applied research on urban livability holds significant innovation and application value.

Starting from the goal of enhancing urban spatial quality, this study established an indicator system framework and calculation methods. Based on satellite remote sensing imagery and integrating multi-source remote sensing data, it conducted an analysis and evaluation of urban livability at a kilometer grid scale for the city of Wuhan and Yibin. The research aims to explore different dimensions of urban livability, thereby providing support for efficient territorial spatial governance and high-quality development.

2. Study area and data sources

2.1 Study Area

This study focuses on two representative cities in China: Wuhan and Yibin. Wuhan, the capital of Hubei Province, is a major city in the middle reaches of the Yangtze River. It is characterized by a dense urban core, numerous rivers and lakes, and significant economic activity. Wuhan is an important central city with distinct urban spatial patterns of central concentration and peripheral radiation, including Jiang'an District, Jianghan District, Wuchang District and other central urban areas, as well as Huangpi District, Xinzhou District, Jiangxia District and other suburban districts and counties.

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Yibin, located in Sichuan Province, is a designated regional central city in the Yangtze River Economic Belt, including Cuiping District, Nanxi District, Xuzhou District and seven counties. Its urban development is heavily influenced by its mountainous terrain and abundant water resources, presenting a different urban morphology from Wuhan.

2.2 Data Sources

The data used in this study mainly include satellite remote sensing data, supplemented by socio-economic big data, ensuring the comprehensiveness and accuracy of the evaluation indicators.

The satellite remote sensing imagery data used in this study include Gaofen-1 (GF-1), Ziyuan-3 (ZY-3), and Suomi National Polar-orbiting Partnership (Suomi NPP) satellite. GF-1 and ZY-3 satellite data are used to interpret and identify surface thematic elements such as urban built-up areas, land cover, building rooftops, road networks, outdoor sports fields, and river and lake water surfaces; Suomi NPP satellite products are used to obtain night-time light intensity information, which is an indicator of economic vitality.

Socio-economic big data include internet-based Point of Interest (POI) data, enterprise industrial and commercial registration information data, and online review data. Among them, POI data include the names and location information of various facilities such as health care, education, commerce, parks and gas stations; enterprise industrial and commercial registration information data include enterprise number, unified social credit code, registration date, enterprise type, registered capital, business scope, registration place, etc.; internet review data include store type, location, user satisfaction score and other information.

The data time involved in the study is mainly concentrated between 2018 and 2020, which is consistent with the data time of remote sensing interpretation and socio-economic data collection, ensuring the consistency and comparability of the research data.

3. Methodology

The technical process is structured into three key stages: defining the indicator system, calculating indicators using remote sensing and multi-source data, and applying analytical methods for evaluation.

3.1 Construction of Livability Evaluation Indicator System

Urban livability was conceptualized across four dimensions, with 15 specific indicators chosen to capture their multifaceted nature. The indicators and their calculation methods are detailed in Table 1.

For some of the indicators have more than one factor, there are a total of 20 single factors to obtain urban livability index of the two cities.

Table 1. Urban Livability Indicators and Calculation Methods

Dimension	Indicator	Calculation Method
Safety & Resilience	Regional Development Intensity (%)	Urban built-up area / Total area
	Building Density (%)	Building footprint area / Urban built-up area
	Hazard Proximity (%)	Area within 1000m of gas stations
Residential Comfort	Road Network Density (km/km²)	Total road length / Total area
	Public Service Facility Coverage (%)	Buffer coverage of metro stations (800m), schools (800m), hospitals (1000m), clinics (500m), sports fields (1000m)
	Commercial Service Coverage (%)	Buffer coverage of large shopping malls (1000m), convenience services (500m)
Recreation Convenience	3D Greenness Index	(Tree area×3 + Shrub area×2 + Grass area×1) / Total area
	Vegetation Index	NDVI
	Water Surface Ratio (%)	Water area / Total area
	Park Accessibility (%)	Area within 500m of parks
Quality & Vitality	Night Lights Index	Night lights intensity
	Industrial Agglomeration (No./km²)	Number of registered enterprises / Area
	Industrial Diversity Index	Shannon-Wiener Index based on enterprise types
	Consumption Heat	Number of online reviews for shopping/dining
	Consumption Satisfaction	Average of environment, service, and taste scores

3.2 Extraction and Calculation of Indicators

First, through high-resolution remote sensing image surface element identification and extraction technology, surface thematic element information such as urban built-up area scope, land cover, building rooftops, roads, outdoor sports fields, and river and lake water surfaces is obtained; at the same time, information such as the Normalized Difference Vegetation Index (NDVI) is calculated through band calculation.

Then, combined with multi-source socio-economic big data, the calculation method of each single indicator is determined. For example, the regional development intensity is calculated as the ratio of urban built-up area to regional area; the road network density is the ratio of road network length to regional area; the public service facility coverage is calculated by buffer zone analysis based on the location data of relevant facilities; the three-dimensional greenness index is calculated by multiplying the area of vegetation type by the vegetation height index and then dividing by the regional area.

All the indicators are calculated and distributed by every 1km rule grid of the two cities, in order to evaluate each dimension and comprehensive urban livability index.

3.3 Evaluation and Analysis Methods

On the basis of the calculation of single indicators, the entropy method is used to determine the weight of each indicator, and the four-dimensional indicator values of safety and resilience, residential comfort, recreation convenience, and quality and vitality of Wuhan and Yibin are obtained by superposition.

The wind rose diagram method is used to characterize the contribution of each dimension to livability, and the differences in livability between the two cities are compared and analyzed.

4. Results and Discussions

4.1 Livability Evaluation Results of Wuhan

4.1.1 Safety & Resilience: The regional development intensity (Fig. 1) and building density show a clear "high in the center, low in the periphery" pattern. The core districts (Jiang'an, Jianghan, Wuchang) are near saturation, while peripheral districts (Huangpi, Xinzhou) have lower intensity. The urban development of Wuhan has a significant agglomeration effect in the main urban area, and has strong attractiveness to the surrounding areas. Among the six suburban districts, except that the urban built-up area of Hannan is not adjacent to the central urban area, the areas with the highest regional development intensity in the other five districts are all adjacent to the main urban area. The distribution of building density is similar to the pattern of regional development intensity. The hazard proximity is concentrated in the center of urban area.

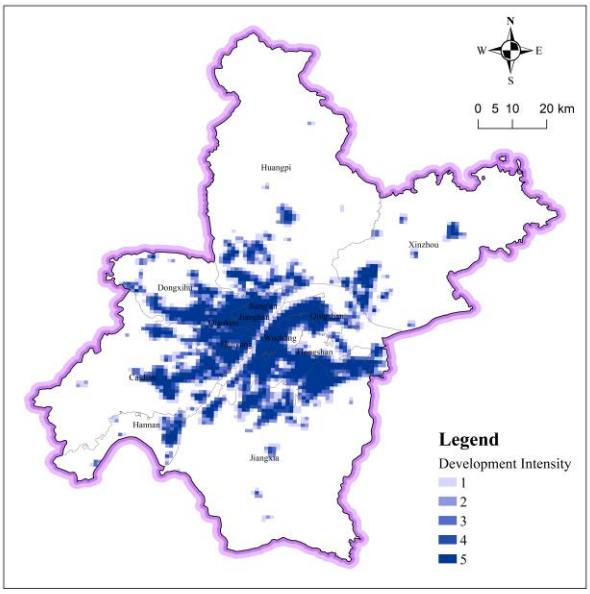

Figure.1. Regional Development Intensity of Wuhan
(Due to space constraints, only one indicator is shown for each dimension of Wuhan and Yibin.)

4.1.2 Residential Comfort: Road network density is significantly higher in the central urban area, so as the coverage of commercial and public services. While community-level services are relatively well-covered, city-level services like large hospitals (Fig. 2) and metro stations could be further expanded.

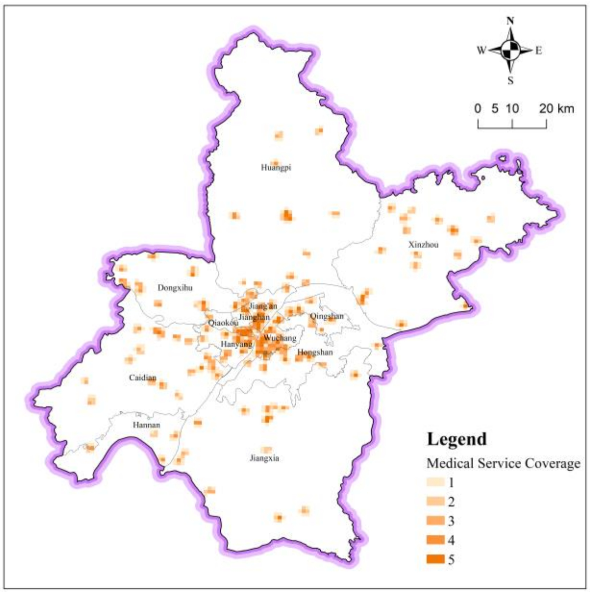

Figure.2. Medical Service Coverage of Wuhan

4.1.3 Recreation Convenience: High 3D Greenness index values (Fig. 3) align with mountain and forest distributions (e.g., northwest Huangpi). The overall vegetation index shows a trend of high in suburban districts and counties, while relatively low in the central urban area. The water surface ratio is high due to the city's numerous rivers and lakes. Park accessibility is concentrated in the central area.

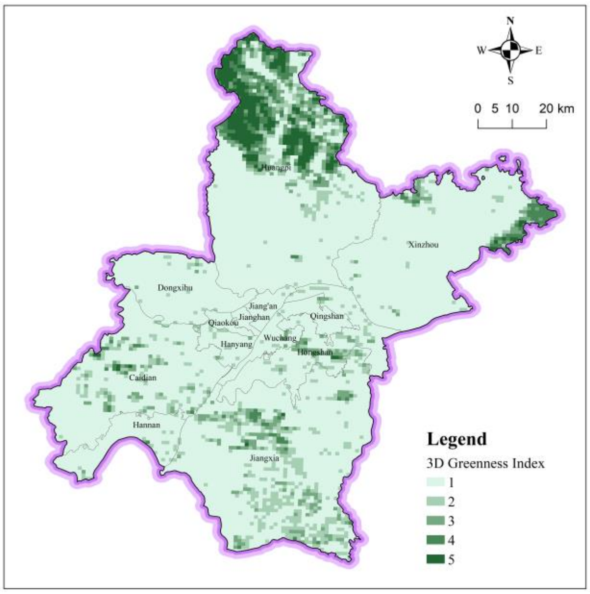

Figure.3. 3D Greenness Index of Wuhan

4.1.4 Quality & Vitality: Night lights index, industrial agglomeration, and consumption heat are heavily concentrated in the central urban districts, such as Jiang'an, Jianghan, Qiaokou, Wuchang and Hongshan, indicating a vibrant core economy. Industrial diversity (Fig. 4) and consumption satisfaction are more evenly distributed.

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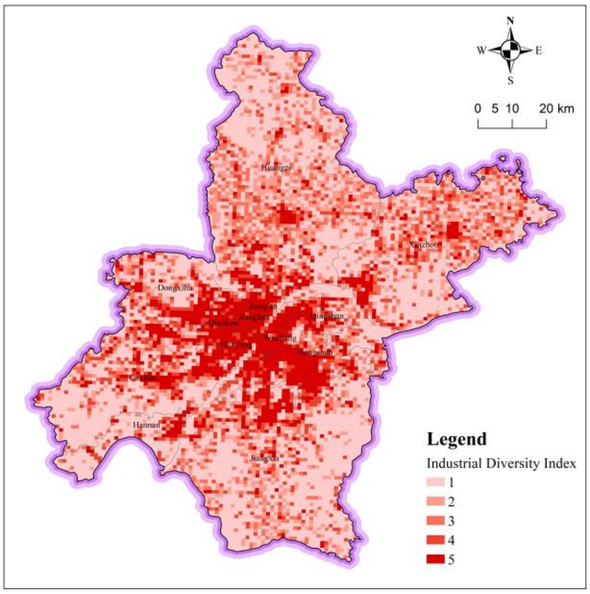

Figure.4. Industrial Diversity Index of Wuhan

4.1.5 Comprehensive Evaluation: As Fig. 5 shows, Wuhan’s comprehensive livability index is higher in the central urban area, with a contiguous high-value zone spanning Jiang'an, Qiaokou and Dongxihu districts. Peripheral high-value areas are scattered as points in county towns.

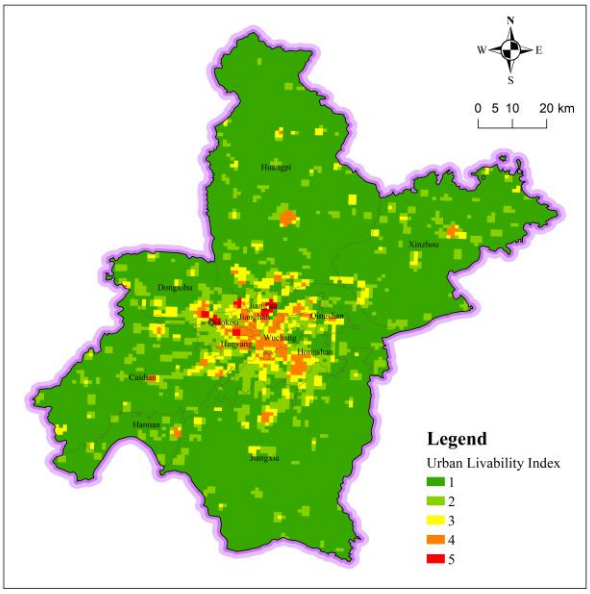

Figure.5. Urban Livability Index of Wuhan

4.2 Livability Evaluation Results of Yibin

4.2.1 Safety & Resilience: Affected by the terrain, the regional development intensity (Fig. 6) and building density are patchy, with a concentration in the southern part of Cuiping District, reflecting a development pattern adapted to the terrain. The hazard proximity is related to regional development and road construction layout.

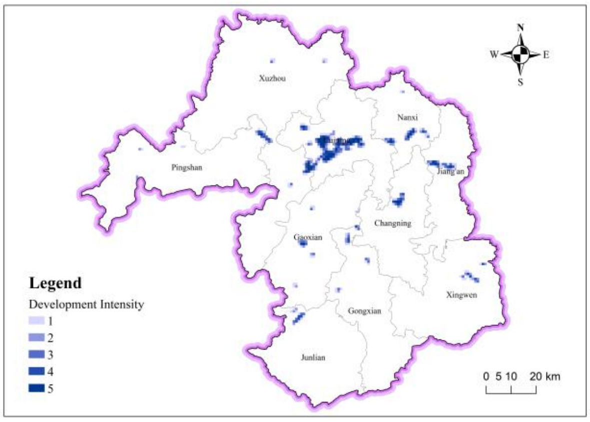

Figure.6. Regional Development Intensity of Yibin

4.2.2 Residential Comfort: Road network density is relatively uniform but lower in mountainous areas. Public and commercial service coverage is patchy. The coverage of municipal-level grade hospitals is relatively low (Fig. 7), while the coverage of community-level primary and secondary schools, sports fields, and health services is excellent. City-level facilities are lacking, though community-level coverage is adequate relatively.

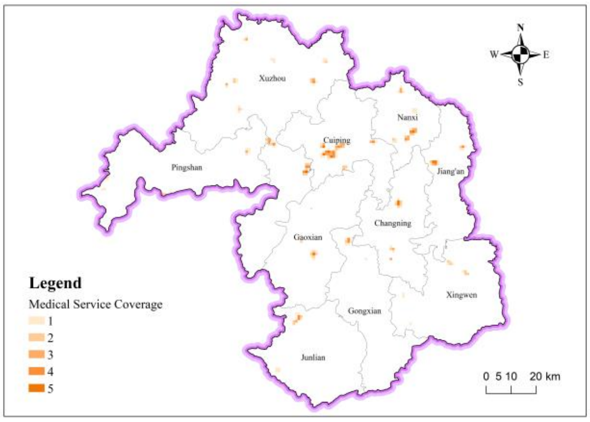

Figure.7. Medical Service Coverage of Yibin

4.2.3 Recreation Convenience: This is a key strength for Yibin. The overall 3D greenness index (Fig. 8) of Yibin is high across the region, aligning with forested areas. Except for the urban built-up areas, the vegetation coverage is high as well. The distribution of water surface ratio is consistent with the distribution of major rivers and lakes. The accessibility of parks and squares is patchy but has a concentrated area near the Cuiping-Xuzhou district border.

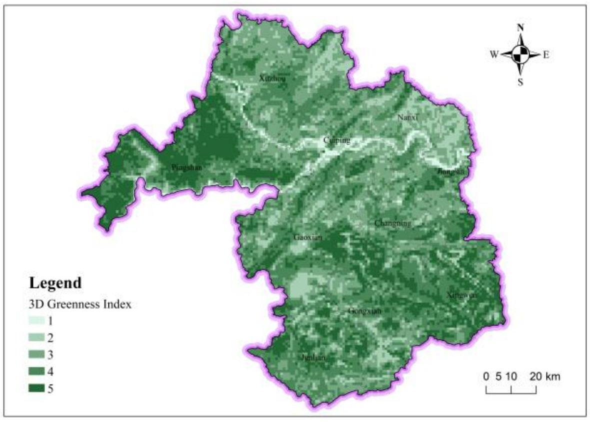

Figure.8. 3D Greenness Index of Yibin

4.2.4 Quality & Vitality: High-value areas for night lights index, industrial agglomeration, and consumption heat are concentrated in the developed zone between Cuiping and Xuzhou districts, with other districts showing point-like distributions. The distribution of industrial diversity (Fig. 9) is relatively scattered compared with the industrial agglomeration degree. Consumption satisfaction is relatively uniform.

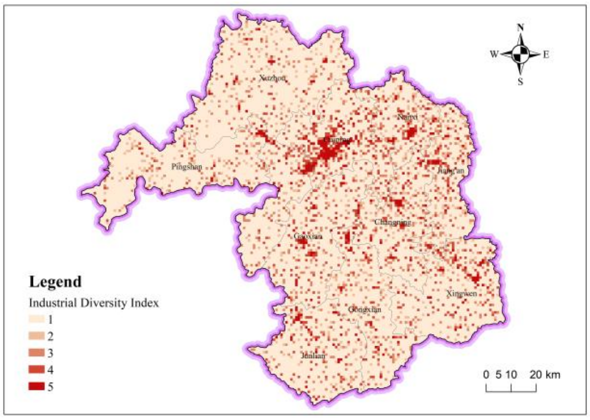

Figure.9. Industrial Diversity Index of Yibin

4.2.5 Comprehensive Evaluation: As Fig. 10 shows, high comprehensive livability values are concentrated in the developed areas of each district, particularly in Cuiping District, Xingwen County, Gong County.

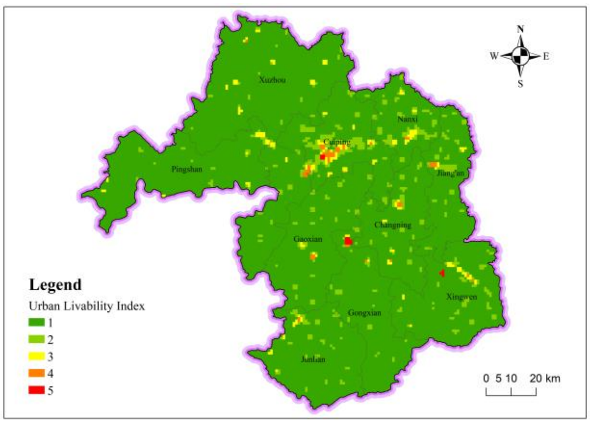

Figure.10. Urban Livability Index of Yibin

4.3 Comparative Analysis of Livability Between Wuhan and Yibin

The wind rose diagram (Fig. 11) clearly illustrates the differences in the contribution of the four livability dimensions between the two cities.

The results indicated that the comprehensive livability index for Wuhan is higher in the central urban area compared to the surrounding suburban districts and counties. Within the central urban area, zones of high livability exhibited a contiguous distribution pattern. Higher livability areas in the surrounding districts and counties are scattered. In Wuhan, the dimensions contributing most significantly to overall livability are quality and vitality, followed by residential comfort, then recreation convenience, with safety and resilience contributing the least. This suggests that Wuhan's appeal as a livable city is driven by its economic opportunities, diverse consumption options, and well-developed public services and infrastructure. However, the high development intensity and building density in the core areas represent a potential vulnerability for safety and resilience.

In Yibin, areas with high comprehensive livability indices are mainly concentrated in the developed zones of its respective districts and counties. The contribution levels of the four livability dimensions in Yibin differed significantly from those in Wuhan. Yibin demonstrated relatively high performance in recreation convenience but showed shortcomings in quality and vitality, as well as residential comfort. This suggested a need for further improvements in areas such as infrastructure development, industrial support, consumption upgrading, and employment guidance.

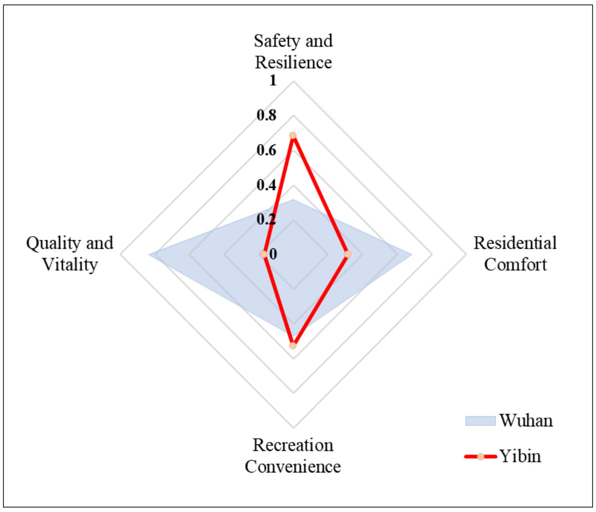

Figure.11. Wind rose diagram of urban livability in the city of Wuhan and Yibin

5. Conclusions

Based on the connotation of urban livability under the background of territorial spatial governance, this study takes satellite remote sensing data as the main data source, supplemented by socio-economic big data and territorial spatial planning data, and constructs an urban livability evaluation indicator system covering four dimensions: safety and resilience, residential comfort, recreation convenience, and quality and vitality. Taking Wuhan and Yibin as examples, the livability evaluation is carried out at the 1km grid scale, and the spatial distribution characteristics and dimensional contribution differences of livability in the two cities are clarified.

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The research results show that there are obvious differences in the livability level and dimensional characteristics between Wuhan and Yibin. Wuhan has advantages in quality and vitality and residential comfort, but needs to improve the level of safety and resilience; Yibin has outstanding advantages in recreation convenience, but needs to strengthen infrastructure construction and industrial development to make up for the shortcomings in quality and vitality and residential comfort.

With the continuous enrichment of satellite observation methods, more and more satellite observation data with loads such as hyperspectral, SAR, and thermal infrared are available. Each type of load observation data can reflect urban livability from different dimensions. Therefore, in future research, SAR data, three-dimensional elevation data, hyperspectral remote sensing products and other data can be fully used to continuously enrich the urban livability evaluation indicator system. At the same time, the correlation between different indicators should be studied to propose more scientific and appropriate urban livability evaluation indicators, conduct regular evaluation and analysis on typical cities, and provide targeted services for urban spatial governance and territorial spatial optimization.

6. Acknowledgements

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