

Mapping Community Facility Diversity in Chengdu: A POI and Clustering-Based Approach

Fei CAI*, Zhen WANG, Telin CHEN, Xiaohui MOU

Abstract: Urban community service facilities play a critical role in shaping residents' quality of life and influencing urban livability and development patterns. This study examines the diversity and spatial differentiation of community service facilities in five districts of Chengdu, China, using Points of Interest (POI) data. The Shannon-Wiener diversity index is employed to quantify facility distribution, while spatially constrained multivariate clustering identifies distinct spatial patterns and facility concentration areas. Findings reveal that community facility diversity is highest in the central urban areas, forming a "fan-shaped" pattern of service clusters extending toward the periphery. The clustering results indicate unequal service distribution, with some peripheral areas lacking key community facilities. These insights offer valuable implications for urban planners and policymakers, emphasizing the need for balanced facility allocation, improved accessibility, and community-driven infrastructure planning. Future research should explore dynamic changes in facility distribution over time and the integration of multi-source urban data to refine spatial planning strategies.

Keywords: community service facilities; diversity index; POI data analysis; spatial differentiation; urban planning

1 INTRODUCTION

With the continuous acceleration of China's urbanization process, the scale of cities continues to expand, more and more people have moved into cities [1, 2]. A large number of gated communities in a city constitute a living unit of the city. With the implementation of the new urbanization strategy, the development of urban gated communities in China has gradually changed from pursuing quantity to improving quality, and the construction of livable cities has become an important goal of the current new urbanization in China [3]. Meanwhile, the continuous improvement of China's socioeconomic level has also led to residents' pursuit of higher quality of life [4].

The term "quality of life" was first proposed by American economist K. F. Schuessler in the 1950s [5]. Pacione elaborated on the quality of life of urban residents from the perspective of urban geography [6], and Rogerson also highlighted that quality of life is a crucial aspect of urban competitiveness [7]. Communities serve as the primary living spaces for residents, and the surrounding facilities are of general concern. The living standards and quality of life for residents largely depend on the service levels provided by community service facilities [8]. The diversity of community service facilities plays a vital role in enhancing the overall livability and well-being of community residents [9].

POI data covers information such as the names and geographical locations of various urban service facilities, including restaurants, hospitals, bus stops, etc. With its massive amount of basic data, it can describe the distribution and status of urban service facilities in a static manner, allowing researchers to intuitively see the layout of service facilities in urban space. The large-scale POI data set, with its multi-dimensional and large-capacity data characteristics, opens up a new research path for the research on the diversity of community service facilities and the theoretical construction and empirical analysis of related fields.

The researches on the diversity of community life service facilities have achieved rich achievements, but there is still insufficient research on the spatial differences in considering the diversity of different types of facilities.

For better exploration the diversity of community service facilities and the spatial differentiation characteristics, we take the five urban districts of Chengdu as the research object and construct a POI and clustering-based approach by the calculation of diversity index and spatial clustering analysis. Overall, our research direction is centered around comprehensively understanding the diversity and spatial arrangements of community service facilities, with the ultimate goal of providing a more accurate and data-driven basis for urban planning and enhancing the quality of urban living environments.

2 LITERATURE REVIEW

The spatial distribution of community life service facilities has been extensively studied as an important research hotspot. Researchers have found that the distribution of urban community service facilities in space often exhibits heterogeneity and imbalance. The spatial distribution of service facilities in different regions is quite different. The advanced hospitals are spatially clustered in the center districts of Nanjing, while the number and quality of hospitals in peripheral areas are lower than that in the central area [10]. Chen et al. [11] explore the spatial variances in the allocation of public service facilities within Wenzhou's central urban area, deploying a lens of "living circles" and utilizing a 15-min walkable distance as a pivotal metric. Xu et al. [12] identify inequalities in various types of public facilities and their driving mechanisms by taking 10 typical cities in China as cases. The results clearly show that the spatial distribution of community service facilities is complex and unequal. Therefore, understanding facility diversity is crucial for effective urban planning and resource allocation.

The rich POI data in network maps can depict the distribution of various types of urban service facilities. Through relevant analysis, the urban characteristics and functions of the study area can be detailed [13, 14]. The current extensive POI data also introduces new perspectives on the diversity of community service facilities and related research. Significant progress has

been made in the research on the diversity of community life service facilities based on POI data [15-17]. He et al. [18] assess urban life satisfaction by fusing urban facilities from objective built environment using AmapPOIs and Weibo social media data. Luo et al. [19] analyze the collocation patterns by POIs for facilities in Harbin, China. Song et al. [20] use POI data, population data and building data for supply-demand matching assessment of the public service facilities in 15-minute community life circle. Liu et al. [21] reveal the features of such spatial agglomeration patterns by developing a spatial agglomeration mining model based on POIs of urban recreational facilities. Ma et al. [22] present a hybrid model based on extracting the facility-based service capacity index by integrating POI and mobile phone positioning to map fine-scale population distributions. Evidently, POI data has emerged as a powerful tool in uncovering the diversity and spatial relationships of community facilities, providing valuable insights for research like our study on mapping community facility diversity.

In addition, the distribution of community service facilities is also influenced by political, economic, demographic and other factors [23]. Some studies show that population density, age structure, income level and other factors affect the diversity of community living service facilities. With the development of social economy, the spatial pattern of service facilities in China has gradually changed from spatial equality to social equality [24]. Scholars have studied the spatial differentiation of public cultural facilities in cities in China and found that there are significant regional gradient differences, uneven spatial distribution, and differences in differentiation, aggregation, and change trends among different types of public cultural facilities. Economic and infrastructure factors have the strongest impact, while urbanization factors have the weakest impact [25]. Given these complex influencing factors, clustering-based approaches can be effective in discerning patterns and groupings within the diverse distribution of community service facilities, which will be crucial in the exploration of mapping community facility diversity.

3 RESEARCH METHODOLOGY

3.1 Method Framework

The research framework of the paper is shown in Fig. 1. Firstly, the POI data of the service facilities obtained from the Gaode map are extracted and classified by the selected types of community service facilities. Then, according to the residents' 15-minute living circle [26], the 500-meter area of the community outline is taken as the main living area of the community, and the service facilities within this area are identified as the service facilities of the community [27]. Meanwhile, the 500-meter buffer can sufficiently capture service accessibility. If the walking accessibility range is too large, for example 800-meter buffer zone, the walking accessibility range will be affected by the accuracy of the road network data. Finally, Shannon-Wiener index was used to calculate the diversity index of the whole service facilities and various categories of service facilities in each community, and finally the whole research area was identified and divided by cluster analysis [28].

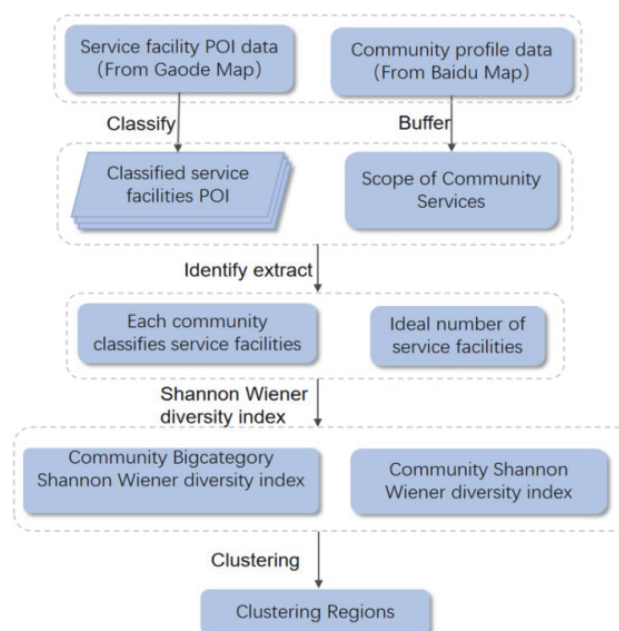


Figure 1 Research framework

3.2 Shannon Wiener Diversity Index

The Shannon Wiener Index, also known as information entropy, was jointly proposed by the founders of information theory, Claude Shannon and Warren Weaver, in 1948. The Shannon Wiener index is a mathematical concept used to measure the average amount of information in a message, commonly used in the fields of information theory and communication. The higher the Shannon Wiener index, the more information is contained in a message.

The Shannon Wiener index has a wide range of applications in information theory [29], such as in data compression and cryptography. In the field of data compression, information compression can be achieved by utilizing statistical patterns in messages. In cryptography, the Shannon Wiener index can be used to measure the security of a cryptosystem, as a secure cryptosystem should have high entropy, meaning that the amount of information in a message is very high and difficult to crack.

In addition, the Shannon Wiener index is widely used in other fields from the perspective of information transmission [30]. In ecology, the index is mainly used to measure the diversity of biological communities, and the principle of the index is to use the information theory of uncertainty measurement, that is, to predict the type of sample individuals belong to. The more diverse the community, the greater the uncertainty. In the field of urban research, the Shannon Wiener index is commonly used to measure the distribution of resources within a city. This index can measure the balance of population, facilities within the city, which is of great significance for urban planning. Through Shannon Wiener index, we can understand the balance of resource utilization in the city, and optimize the development and resource allocation of the city.

Shannon-Wiener index can be calculated by combining the richness of urban facilities and the evenness of distribution of various types of facilities based on the principle of information entropy. For example, an area with a balanced distribution of multiple facility types will have

a significantly higher index value than an area with a single facility or a few dominant facilities. Shannon-Wiener index was originally used to measure the stability of the ecosystem, and the diversity of urban facilities also needs to reflect the resilience of the system function. For example, areas with rich and evenly distributed types of facilities are more resilient to emergencies. However, other diversity indicators, such as Simpson index and Berger-Parker index [31, 32], pay more attention to the dominance of advantageous facilities and are not suitable for evaluating the overall diversity of urban service facilities.

Overall, the Shannon Wiener Index has a wide range of applications in various fields. Therefore, the Shannon Wiener Index was chosen as the indicator for measuring the diversity of urban residential service facilities in the paper. The formula is presented in Eq. (1):

$$H = -\sum_1^s (P_i \cdot \ln P_i) \tag{1}$$

where P_i represents the proportion of facilities of the i -th category within the scope of community service, and S is the total number of categories of community service facilities.

3.3 Spatially Constrained Multivariate Clustering

Spatial constrained multivariate clustering is a clustering model that can reveal the maximum difference among regions and the highest similarity within regions [33]. The working principle is that, given the number of clusters to be created, it will search for a solution that can make all the elements in each cluster as similar as possible, but as different from one cluster to another as possible.

Spatial constrained multivariate clustering mainly uses connected graph (minimum span tree) and a method called SKATER to find natural clusters in the data, and evaluates cluster dependency likelihood method through evidence accumulation [34]. This clustering method is unsupervised, which means it does not require a set of pre classified elements to guide or train, and can determine the clustering of data. This model utilizes the minimum span tree to ensure the continuity and integrity of the region, thereby greatly reducing the discreteness and fragmentation of clustering results [35]. The Calinski-Harabasz index was used to evaluate the effectiveness of clustering [36]. It is calculated based on the ratio between the covariance within the cluster and the covariance between the clusters. The larger the value of the Calinski-Harabasz index, the better the clustering effect. The formula of Calinski-Harabasz index is presented in Eq. (2) and Eq. (3):

$$CH_{index} = \frac{\left(\frac{R^2}{n_c - 1} \right)}{\left(\frac{1 - R^2}{n - n_c} \right)} \tag{2}$$

$$R^2 = \frac{SST - SSE}{SST} \tag{3}$$

where, SST reflects the difference between clusters, SSE reflects the similarity within clusters. The formula is presented in Eq. (4) and Eq. (5):

$$SST = \sum_{i=1}^{n_c} \sum_{j=1}^{n_i} \sum_{k=1}^{n_v} \left(V_{ij}^k - \overline{V^k} \right) \tag{4}$$

$$SSE = \sum_{i=1}^{n_c} \sum_{j=1}^{n_i} \sum_{k=1}^{n_v} \left(V_{ij}^k - \overline{V_t^k} \right) \tag{5}$$

where, n represents element number; n_i represents number of elements in cluster i ; n_c represents number of classes (clusters); n_v represents number of variables used to cluster elements; V_{ij}^k represents k -th variable values of j -th elements in i -th clustering.

In the paper, the spatial constrained multivariate clustering in ArcGIS Pro software is used, and the diversity index of different types of service facilities in each community is used as the research variable. The number of clusters and the minimum value of spatial unit clustering are the two main parameters.

4 CASE STUDY

4.1 Study Area

According to the results of the seventh census of China, the total population of China is 141.78 million, and the urban population is 90.99 million, with an urbanization rate of 63.89% [37]. Chengdu, the capital of Sichuan province, is located in the western part of the Sichuan basin, with flat terrain, a network of rivers, rich products, and developed agriculture. By the end of 2022, the urban area of Chengdu was 3639.81 km², of which the built-up area of the city was 885.6 km², with a resident population of 10.970 million [38]. The study area covers the central urban area of Chengdu, including Qingyang district, Jinniu district, Chenghua district, Wuhou district, and Jinjiang district, with a resident population of more than 4.4 million (Fig. 2).



Figure 2 Study area

The central urban area of Chengdu are the economically developed, technologically advanced, and commercially prosperous urban areas in Chengdu, Sichuan Province, and even the whole west region, with a high degree of community density and a high standard of living for residents, so it is of representative significance to study this area.

4.2 Data Description

The data used in the paper mainly include POI data and community profile data. The POI data of community service facilities are crawled from Gaode map POI data, which contains stores, restaurants, schools, hospitals, gymnasiums and other facilities points needed by residents in their daily lives.



Figure 3 Community description map in the study area

Gaode map is one of the major online maps in China, and the POI data are updated four times a year, which has good timeliness. The community profile data are the community profile data of Baidu map crawled by crawlers. Baidu map, as the largest intelligent location service

platform in China, has the largest collection team and the most leading collection equipment in China, so the reliability of community profile data is good. A total of 2883 community profile data were obtained from the collected profile data through screening and cleaning (Fig. 3). A total of 178000 POI data were collected. The collected data were screened and extracted according to our definition of community service facilities, and classified according to the actual situation of the study area. Finally, a total of 138000 POI data were extracted.

Since the data used in the research is sourced from two major Chinese internet map providers, the community profile data and POI data obtained may have problems such as data missing, data duplication, data and actual inconsistency, etc. Moreover, due to the large volume of data, the classification of POIs is mainly reclassified based on the original classification of the crawled data, and there may be problems such as inaccurate POI classification.

5 RESULTS AND DISCUSSION

5.1 Classification of Service Facilities

According to the existing classification of the obtained data, considering the actual living needs of Chengdu residents, the community life service facilities are divided into eight first-level categories: food beverage, public service, shopping service, finance service, scientific and cultural education service, daily life service, sports recreation and medical service, as shown in Tab. 1.

Table 1 Classification of service facilities

First-level categories	Secondary-level categories
Food beverage	Local cuisine restaurant, Bakery dessert, Fast food restaurant, Specialty restaurant, Foreign restaurant, Drink shop, Chinese Food Restaurant
Public service	Subway Station, Tourist Attraction Related, Public Toilet, Bus Station, Park Square, Parking Lot
Shopping service	Convenience Store, Supermarket, Shopping Plaza, Franchise Store, Comprehensive Market
Finance service	ATM, Bank
Scientific and cultural education service	School, University, College, Cultural exhibition hall
Daily life service	Lottery Store, Telecom Office, Photo Finishing, Repair Store, Laundry, Bath massage center, Baby service place
Sports recreation	Recreation place, Theatre cinema, Recreation center, Sports stadium
Medical service	Veterinary hospital, Pharmacy, Clinic, Special hospital, Hospital

Table 2 Statistical table of the number of service facilities

First-level categories	Count	Proportion / %	Identity count	Identity proportion / %	Identity count/count
Food beverage	52378	37.82	398341	38.76	7.61
Public service	12997	9.39	87564	8.52	6.74
Shopping service	16350	11.81	122852	11.95	7.51
Finance service	7140	5.15	54756	5.33	7.67
Scientific and cultural education service	4487	3.24	30756	2.99	6.85
Daily life service	16047	11.59	120360	11.71	7.50
Sports recreation	11571	8.36	85462	8.31	7.39
Medical service	17500	12.64	127744	12.43	7.30

By taking the 500-meter buffer zone of the community's outline boundary as the main living region of a gated community, classified service facilities within the region are counted, as shown in Tab. 2. It can be clearly seen that food beverage accounts for the largest proportion of 37.82%, while scientific and cultural education service accounts for the lowest proportion. All service facilities are identified according to the buffer zone of each community. At this time, service facilities serving many communities will be counted repeatedly, and the proportion of various facilities after statistics is basically consistent with the proportion of the original data. Through further analysis

and calculation, the number of service facilities serving only one community is 19972, accounting for 14.42% of the total number of service facilities.

5.2 Calculation Results of Diversity Index

Firstly, the overall diversity index values of community service facilities in the five districts of Chengdu city are calculated, and then the diversity index values of various first-level categories of service facilities in the five districts of Chengdu city are calculated respectively. The spatial distribution of overall diversity

index values of community service facilities in different communities is shown in Fig. 4, and the spatial distributions of diversity index values of different first-level categories of community service facilities are shown in Fig. 5.

As can be seen from Fig. 4, the overall diversity of the central area is higher than that of the surrounding areas indicating that the service facilities of the central area are relatively rich and complete. In the outer part of the study area, the community diversity index values are high, showing a phenomenon of small agglomeration. The diversity index values of some large communities are also higher than that of small communities, and the diversity index values of service facilities around most communities are not high, indicating that service facilities are not complete.

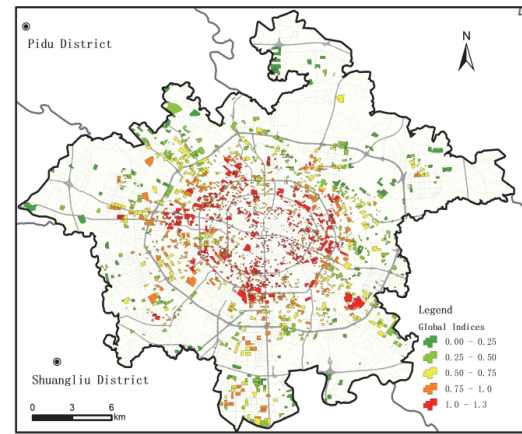
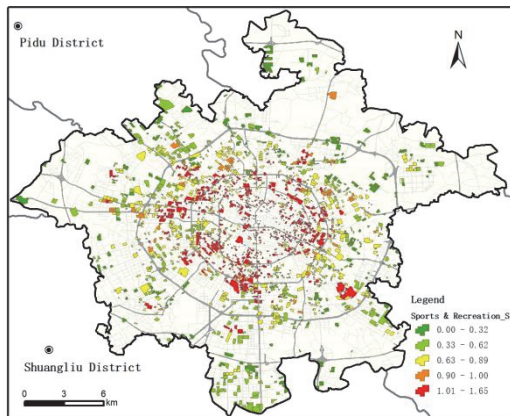
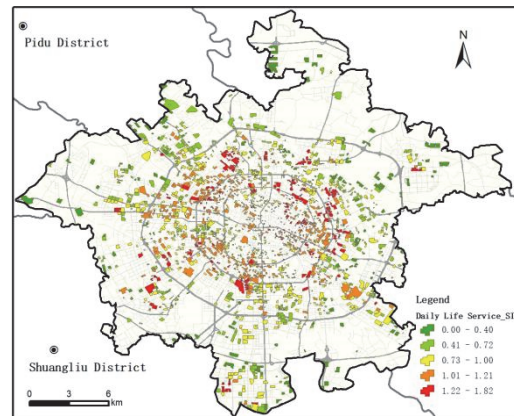


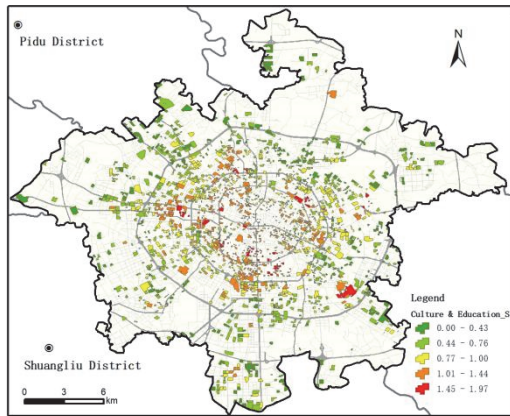
Figure 4 Community diversity in the central urban area of Chengdu



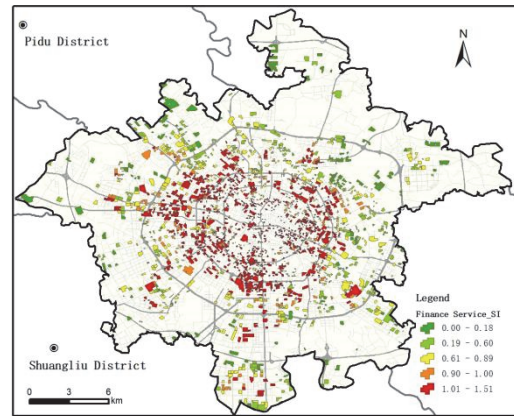
(a) Sports & Recreation



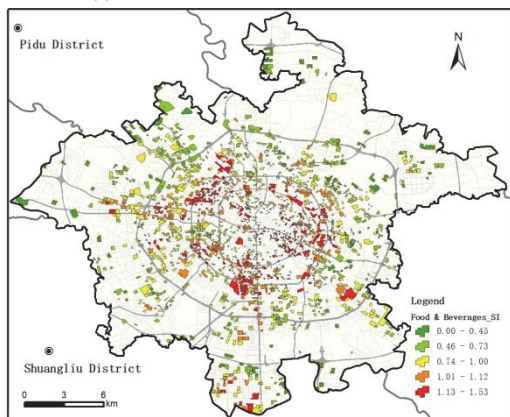
(b) Daily Life Service



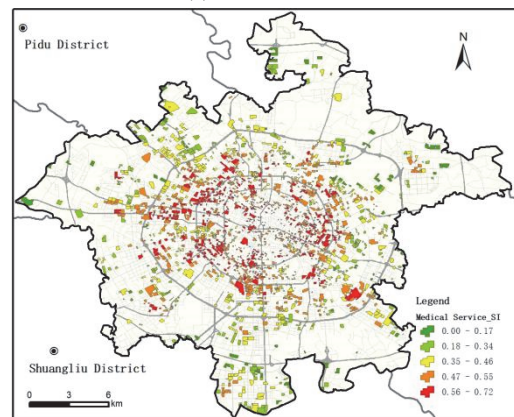
(c) Science/Culture & Education Service



(d) Finance Service



(e) Shopping Service



(f) Public Service

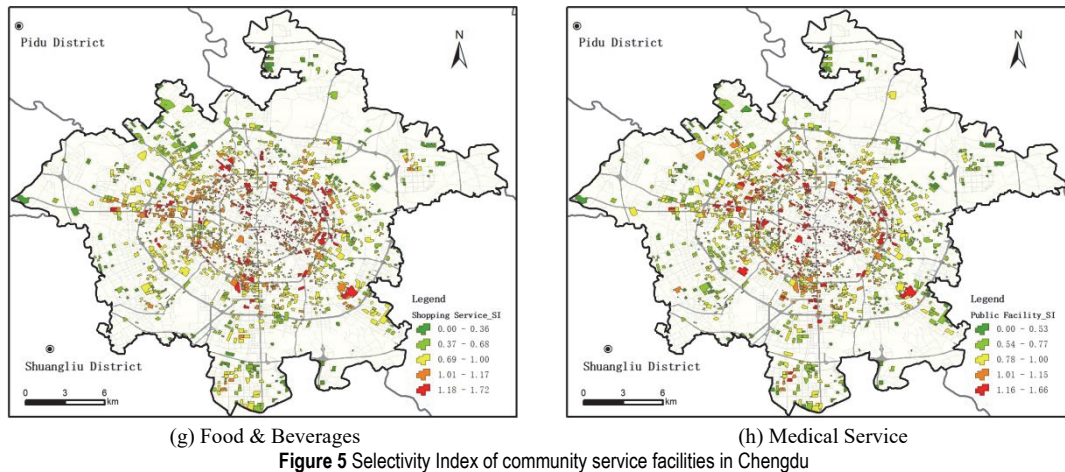


Figure 5 Selectivity Index of community service facilities in Chengdu

As can be seen from Fig. 4, the spatial distribution of selectivity index values of the eight types of service facilities are generally characterized by "low in the periphery and high in the center". The high values are concentrated in the central area due to the long development time of urban central area and relatively complete various service facilities. Newly developed communities are mostly located in the peripheral areas of the central urban area and service facilities here still need to be further developed and improved. The spatial characteristics of the "small agglomeration" of various service facilities are different, which may be caused by the differences in the types and living habits of the residents.

From Fig. 5a, 5c, 5e, 5f and 5g, it can be seen that the spatial distribution of diversity index values of sports recreation facilities, shopping service facilities, public service facilities, science, education and culture service facilities and catering service facilities presents the characteristics of "high-value agglomeration". From Fig. 5b, it can be seen that the spatial distribution of diversity index values of living service facilities shows the characteristics of "low-high-low" annular distribution. This is mainly because there are many commercial buildings and fewer communities in the central area. Moreover, the rent in the central area is high, which is not suitable for the development of living facilities. As can be seen from Fig. 5d, the distribution of diversity index values of finance service facilities presents a feature of "high in the center and low around the periphery", and the high-value area covers a wide range and is evenly distributed in the central urban area, indicating that most community finance service facilities in the research center area have good diversity. As can be seen from Fig. 5h, the overall diversity index values of medical service facilities are low, indicating that all communities have not reached the ideal quantity state, but the overall distribution still presents a distribution pattern of "high in the center and low in the periphery".

Fig. 6 shows the results of multiple cluster analysis on the diversity of service facilities in various categories of the community in Chengdu. The results are divided into 7 categories, with category 4 being the main category in the central area and the remaining categories distributed around the center. Category 4 is the community with better diversity of various service facilities, category 2 is the community with poor diversity of various service facilities,

which are concentrated in the northern part of the research area, and the number is small. The remaining five categories have small differences in diversity of various service facilities, of which category 1 is slightly higher and category 7 is slightly lower. The central areas of the five districts in Chengdu have the best diversity of community service facilities, and other areas have high and balanced diversity of community service facilities, indicating that the allocation of community service facilities in the research area has been relatively complete. With the continuous development and expansion of the city, the diversity of edge areas is also constantly improving.

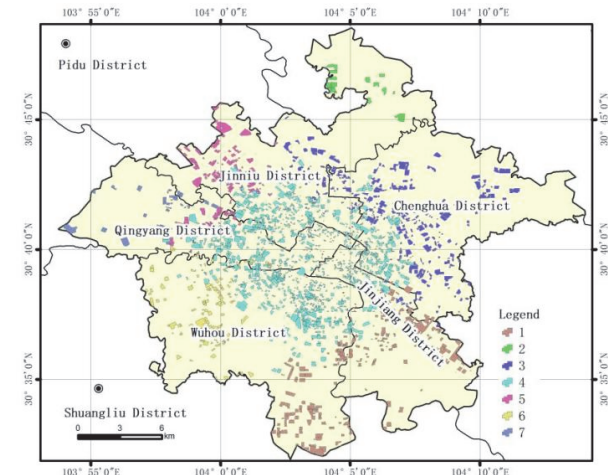


Figure 6 Clustering results in Chengdu

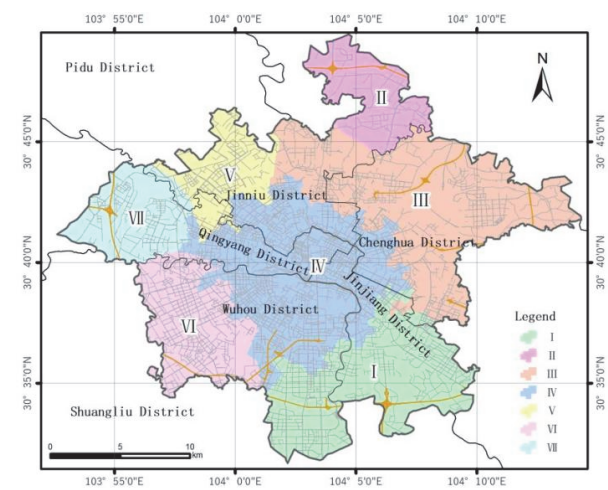


Figure 7 Identified region in Chengdu

For the calculated diversity of various service facilities, the feature regions are identified through spatially constrained multivariate clustering, and the recognition results are shown in Fig. 7. As can be seen from Fig. 7, the distribution pattern of the identified areas is that area V is the core, and other areas are evenly distributed around area V. Area V belongs to the area with high diversity of community service facilities, high house prices and perfect equipment. Other areas also have relatively complete service facilities and are still in the stage of continuous development and improvement, with high potential.

In order to further determine whether these patterns are unique to Chengdu or common to urban development, we selected Jinan, a provincial capital city in northern China, as the comparison city for our comparative experiment. The study area is the main urban area of Jinan City. The main urban area of Jinan City is affected by the Yellow River in the north and the Mount Taishan Mountain in the south. The urban development is strip shaped from east to west, and the main direction of urban development is the east. The old urban area is located at the junction of Shizhong District, Tianqiao District and Lixia District. The spatial distribution of overall diversity index values of community service facilities in different communities of Jinan is shown in Fig. 8, and the spatial distributions of diversity index values of different first-level categories of community service facilities of Jinan are shown in Fig. 9.

As can be seen from Fig. 8, the overall diversity of the main urban area of Jinan also shows that the old urban area is higher than the old urban area and lower around it. Different from Chengdu, the old urban area of Jinan is located in the west of the main urban area. As can be seen from Fig. 9, the spatial distribution of the selectivity index values of the eight types of service facilities is basically the same as that in Fig. 8.

Through multivariate cluster analysis, various community diversity indexes were clustered into 7 categories, and the results are shown in Fig. 10. As can be seen from Fig. 10, category 1, 3 and 5 are located in the south of the main urban area, close to the southern Taishan Mountains, in the central District.

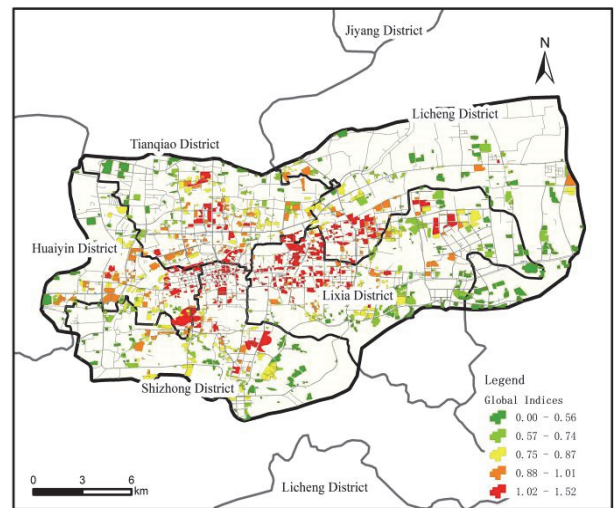
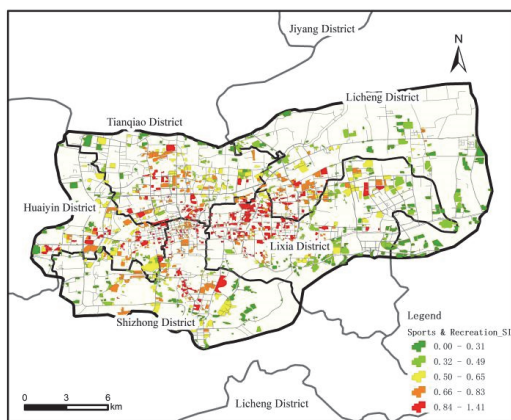
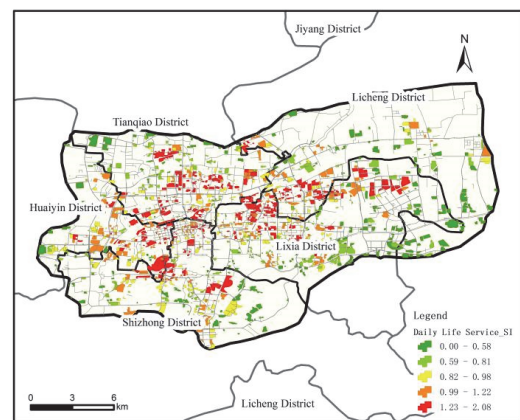


Figure 8 Community diversity in main urban area of Jinan

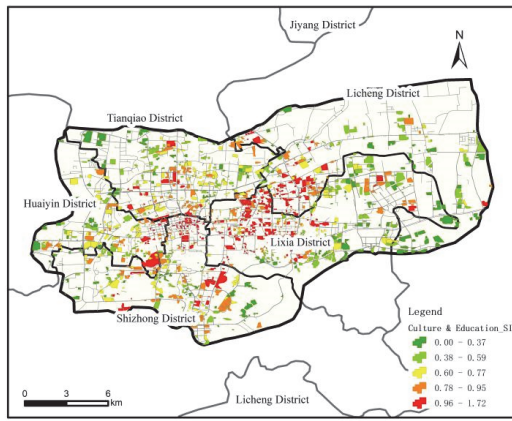
Category 4 is located in Huaiyin District, Tianqiao District and the west of the central District. Category 6 is the old city. Category 7 is located at the junction of Lixia District and Licheng District and category 2 is located in Licheng District. For easier observation, we regionalized the clustering results and re-numbered them with Greek numerals, as shown in Fig. 11. As can be seen from Fig. 11, the main urban area of Jinan city is divided into 7 cluster regions. Region I, as the old urban area, has a higher overall diversity index and presents a pattern of sudden eastward development, which is basically consistent with the trend of early urban development of Jinan City. The outward expansion of regions II, III, IV and VI around region I belongs to the process of urban development. Due to geographical and policy reasons, the main urban area of Jinan city further developed in the east of Region II, forming the eastern new area V. From the results of clustering and zoning, the development of the city is highly consistent with the research results. Due to the superposition of multiple factors such as foreign population and local development, the diversity of service facilities in the main urban area of Jinan city shows regionalization.



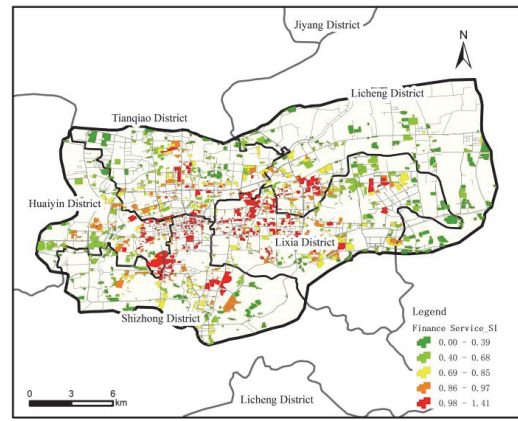
(a) Sports & Recreation



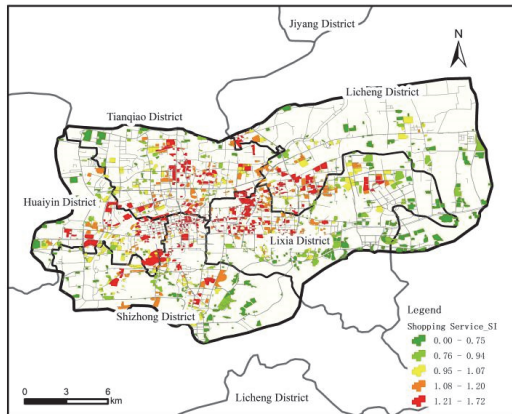
(b) Daily Life Service



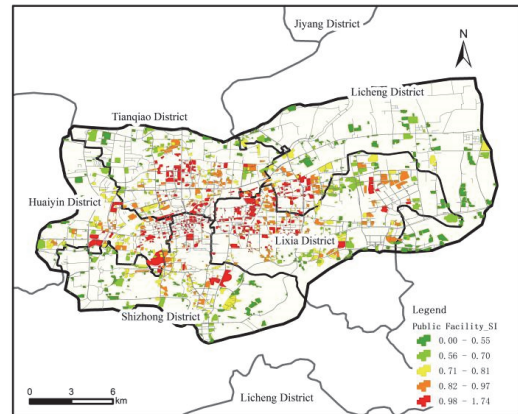
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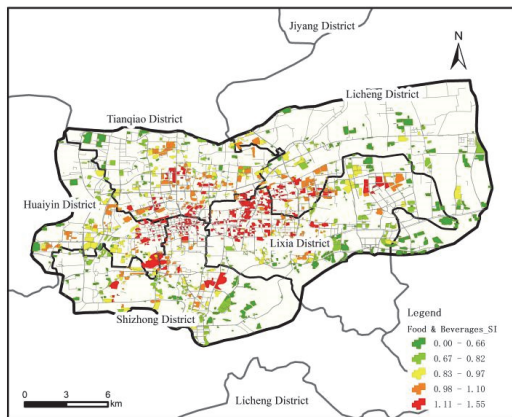
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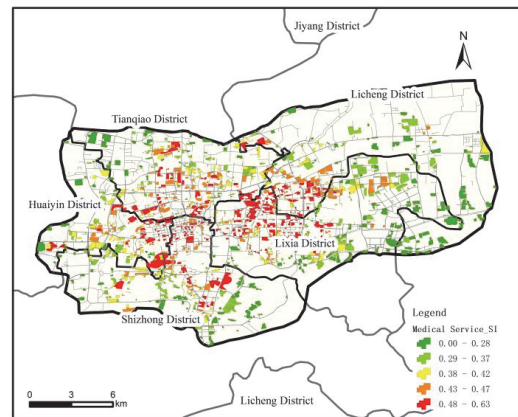
(e) Shopping Service



(f) Public Service



(g) Food & Beverages



(h) Medical Service

Figure 9 Selectivity Index of community service facilities in Jinan

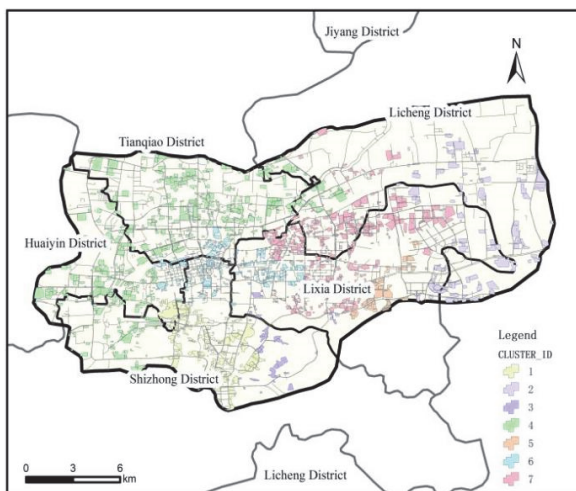


Figure 10 Clustering results in Jinan

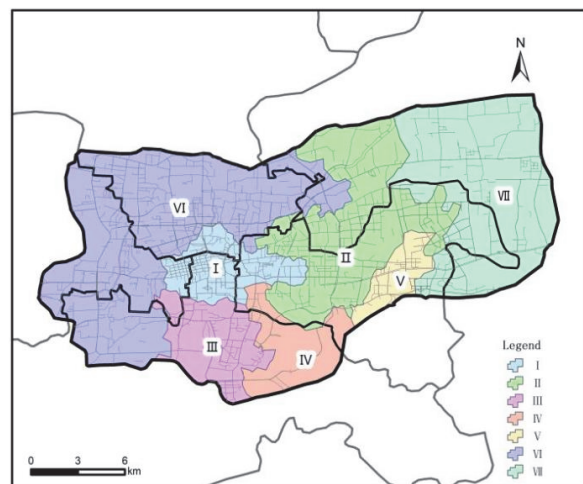


Figure 11 Identified region in Jinan

6 CONCLUSIONS

The diversity of community peripheral service facilities has a significant impact on the quality of life of residents. Based on network map service facilities POI data and community area data, the diversity of service facilities around communities is analyzed by using Shannon Weiner index, and the spatial differentiation of regional service facilities diversity is analyzed by using multivariate clustering method. The approach is also carried out in the main urban area of Jinan City to determine whether "fan-shaped" patterns are unique to Chengdu or common to urban development. The results show that the diversities of service facilities of cities in China generally present "fan-shaped" patterns, with slight differences among different cities. The research results indicate that the central area has developed earlier and has relatively complete service facilities in five districts of Chengdu. The diversity of various facilities and overall service facilities are relatively good. From the perspective of the central urban area of Chengdu, the distribution of diversity is consistent with urban development. The diversity of various living service facilities shows a circular distribution pattern, and the communities with high selectivity are mainly concentrated in the central area, mainly because the various service facilities in the central area are relatively perfect. The "small agglomeration" in the spatial distribution of various service facilities is different in the periphery of the study area, which may be caused by the types and living habits of new urban residents. The different development directions around the central urban area may correspond to different needs of different types of residents for facilities. The results show that in the process of outward expansion with the old urban area as the core, the development of the city is restricted by many factors, and the expansion may focus on a certain direction. In our next step, the main research goal is to focus on the composition and characteristics of the corresponding population in the feature areas identified by multivariate clustering, as well as the influencing factors in the formation process of the feature areas, so as to identify the urban development and evolution process. There are still some deficiencies in the study, and subsequent studies may need to further improve these deficiencies. The study used a fixed bandwidth approach to determine the spatial relationship between communities and service facilities. The actual relationship between service facilities and communities may be more complex, and the accessibility distance thresholds for different types of service facilities may also vary. In addition, the study only used the Shannon Wiener index as an indicator of diversity. In addition to the Shannon Weiner Index, there are Simpson Index, Berger-Parker Index, McIntosh Index and so on. We have not fully compared the differences between different types of indexes, and we can conduct multiple experiments in the future to study the differences between different types of indexes on the diversity of service facilities around communities.

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7 REFERENCES

- [1] Sun, L., Chen, J., Li, Q., & Huang, D. (2020). Dramatic uneven urbanization of large cities throughout the world in recent decades. *Nature Communications*, 11(1), 5366. <https://doi.org/10.1038/s41467-020-19158-1>
- [2] Jiang, L. & O'Neill, B. C. (2017). Global urbanization projections for the Shared Socioeconomic Pathways. *Global Environmental Change*, 42, 193-199. <https://doi.org/10.1016/j.gloenvcha.2015.03.008>
- [3] Lin, X. (2023). Strategic Allocation of Building Carbon Emission Rights Within Urban Frameworks: A Case Study of Henan Province Under China's Dual Carbon Objectives. *Journal of Urban Development and Management*, 2(4), 222-236. <https://doi.org/10.56578/judm020405>
- [4] Ma, L., Liu, S., Fang, F., Che, X., & Chen, M. (2020). Evaluation of urban-rural difference and integration based on quality of life. *Sustainable Cities and Society*, 54, 101877. <https://doi.org/10.1016/j.scs.2019.101877>
- [5] Schuessler, K. F. & Fisher, G. A. (1985). Quality of life research and sociology. *Annual Review of Sociology*, 11, 129-149. <https://doi.org/10.1146/annurev.so.11.080185.001021>
- [6] Hosseini, A., Finn, B. M., Sajjadi, S. A., & Mosavei, T. (2023). Urban disparities and quality of life among afghan refugees living in informal settlements in mashhad, Iran. *Applied Research in Quality of Life*, 18(2), 1073-1097. <https://doi.org/10.1007/s11482-022-10133-0>
- [7] Rogerson, R. J. (1999). Quality of life and city competitiveness. *Urban Studies*, 36(5-6), 969-985. <https://doi.org/10.1080/0042098993303>
- [8] Modai-Snir, T. & van Ham, M. (2018). Neighbourhood change and spatial polarization: The roles of increasing inequality and divergent urban development. *Cities*, 82, 108-118. <https://doi.org/10.1016/j.cities.2018.05.009>
- [9] Ma, W., Wang, N., Li, Y., & Sun, D. J. (2023). 15-min pedestrian distance life circle and sustainable community governance in Chinese metropolitan cities: A diagnosis. *Humanities and Social Sciences Communications*, 10(1), 364. <https://doi.org/10.1057/s41599-023-01812-w>
- [10] Cai, Z., Cheng, T., Li, Y., Guan, C., & Tang, J. (2024). Spatial analysis of hospital accessibility in Nanjing: The role of community health service centers. *Applied Spatial Analysis and Policy*, 17(3), 1081-1103. <https://doi.org/10.1007/s12061-024-09577-8>
- [11] Chen, X., Zhang, Q., & Zhang, H. (2024). Disparities in the geospatial allocation of public facilities from the perspective of living circles. *Open Geosciences*, 16(1), 20220654. <https://doi.org/10.1515/geo-2022-0654>
- [12] Xu, R., Yue, W., Wei, F., Yang, G., Chen, Y., & Pan, K. (2022). Inequality of public facilities between urban and rural areas and its driving factors in ten cities of China. *Scientific Reports*, 12(1), 13244. <https://doi.org/10.1038/s41598-022-17569-2>
- [13] Wang X. P., Ghani, M. Z. A., Gu, Y., Zaman, N. Q., & Sarkom, Y. (2023). Research on the spatial distribution of public service facilities in Nanchang old city, China based on point of interest (POI) data. *Planning Malaysia*, 21(29), 432-446. <https://doi.org/10.21837/pm.v21i29.1381>
- [14] Ma, C. X. & Peng, F. L. (2023). Evaluation of spatial performance and supply-demand ratios of urban

- underground space based on POI data: A case study of Shanghai. *Tunnelling and Underground Space Technology*, 131, 104775. <https://doi.org/10.1016/j.tust.2022.104775>
- [15] Wang, Z., Ma, D., Sun, D., & Zhang, J. (2021). Identification and analysis of urban functional area in Hangzhou based on OSM and POI data. *PLoS one*, 16(5), e0251988. <https://doi.org/10.1371/journal.pone.0251988>
- [16] Roslan, S. N. M., Gohain, K., Mustafa, A. M. A. A., Ismail, M. M., & Kumaran, V. V. (2025). Designing Affordable Urban Ecosystems: A Quantitative Model to Enhance the Quality of Life for the Urban Poor in Malaysia Through Employment, Housing, and Digital Access. *Challenges in Sustainability*, 13(1), 18-34. <https://doi.org/10.56578/cis130102>
- [17] He, X., Zhang, Z., & Yang, Z. (2021). Extraction of urban built-up area based on the fusion of night-time light data and point of interest data. *Royal Society Open Science*, 8(8), 210838. <https://doi.org/10.1098/rsos.210838>
- [18] He, X., Zhou, Y., Yuan, X., & Zhu, M. (2024). The coordination relationship between urban development and urban life satisfaction in Chinese cities - An empirical analysis based on multi-source data. *Cities*, 150, 105016. <https://doi.org/10.1016/j.cities.2024.105016>
- [19] Luo, Y., Zou, G., & Liu, Q. (2025). Relationships between community public service facilities and social capital: An exploratory study of Harbin, China. *PloS One*, 20(2), e0318144. <https://doi.org/10.1371/journal.pone.0318144>
- [20] Song, L., Kong, X., & Cheng, P. (2024). Supply-demand matching assessment of the public service facilities in 15-minute community life circle based on residents' behaviors. *Cities*, 144, 104637. <https://doi.org/10.1016/j.cities.2023.104637>
- [21] Liu, Y., Xiao, W., Xu, T., He, B., Wang, Y., & Mu, J. (2024). Spatial agglomeration mining of urban recreational amenities: The case of the greater bay area in China. *Leisure Sciences*. <https://doi.org/10.1080/01490400.2024.2396499>
- [22] Ma, Y., Zhou, C., & Li, M. (2024). A novel approach to improve population mapping considering facility-based service capacity and land livability. *International Journal of Geographical Information Science*, 39(2), 346-375. <https://doi.org/10.1080/13658816.2024.2411434>
- [23] Febryano, I. G., Wahyuni, P., Kaskoyo, H., Damai, A. A., & Mayaguezz, H. (2022). The Potential of Tourism in Pahawang Island, Lampung Province, Indonesia. *Journal of Green Economy and Low-Carbon Development*, 1(1), 34-44. <https://doi.org/10.56578/jgelcd010104>
- [24] Lu, Y., Cai, M., Lai, Z., & Jiang, H. (2024). Characteristics of coupling between multi-scale community living circles public service facilities supply and spatial centers. *Transactions on Social Science, Education and Humanities Research*, 7, 316-327. <https://doi.org/10.62051/yhmjx08>
- [25] Xie, J. L., Yang, Y. J., & Chen, J. L. (2023). Mechanisms of Digital Economy Empowering High-Quality Development in Manufacturing: A Case Study of Hebei Province, a Traditional Manufacturing Powerhouse in China. *Journal of Organizations, Technology and Entrepreneurship*, 1(1), 47-57. <https://doi.org/10.56578/jote010104>
- [26] Wu, W. & Divigalpitiya, P. (2023). The distribution characteristics of facilities in 15-minute Community Life Circle: the case study of Jinan City. *Journal of Architecture and Urban Design, Kyushu University*, 43, 23-27.
- [27] Ding, Y. & Yang, B. (2023). Method of improving the service capacity of public facilities in smart communities. *Sensors and Materials*, 35(2), 563-577. <https://doi.org/10.18494/SAM4172>
- [28] Jaeger, A. & Banks, D. (2023). Cluster analysis: A modern statistical review. *Wiley Interdisciplinary Reviews: Computational Statistics*, 15(3), e1597. <https://doi.org/10.1002/wics.1597>
- [29] Saraiva, P. (2023). On Shannon entropy and its applications. *Kuwait Journal of Science*, 50(3), 194-199. <https://doi.org/10.1016/j.kjs.2023.05.004>
- [30] Sun, W. & Ren, C. (2021). The impact of energy consumption structure on China's carbon emissions: Taking the Shannon-Wiener index as a new indicator. *Energy Reports*, 7, 2605-2614. <https://doi.org/10.1016/j.egyr.2021.04.061>
- [31] Pandey, P. C. (2024). Relationship of bioclimatic and topographic variation on species-biomass distribution in tropical forest reserve. *Tropical Ecology*, 65, 677-691. <https://doi.org/10.1007/s42965-024-00356-7>
- [32] Jiang, Y., Wu, F., Fang, X., Wang, H., Xie, Y., & Yu, C. (2025). Effective palynological diversity indices for reconstructing angiosperm diversity in China. *Plant Diversity*, 47, 244-254. <https://doi.org/10.1016/j.pld.2025.01.004>
- [33] Jin, Y., Wakayama, T., Jiang, R., & Sugawara, S. (2025). Clustered factor analysis for multivariate spatial data. *Spatial Statistics*, 66, 100889. <https://doi.org/10.1016/j.spasta.2025.100889>
- [34] Anselin, L. & Amaral, P. (2024). Endogenous spatial regimes. *Journal of Geographical Systems*, 26(2), 209-234. <https://doi.org/10.1007/s10109-023-00411-2>
- [35] Tang, Y., Xie, L., Chen, Y., Sun, S., Zha, W., & Lin, H. (2023). Automatic recognition of slide mass and inversion analysis of landslide based on discrete element method. *Computers & Geosciences*, 176, 105338. <https://doi.org/10.1016/j.cageo.2023.105338>
- [36] Lima, S. P. & Cruz, M. D. (2020). A genetic algorithm using Calinski-Harabasz index for automatic clustering problem. *Revista Brasileira de Computação Aplicada*, 12(3), 97-106. <https://doi.org/10.5335/rbca.v12i3.11117>
- [37] Akimov, A. V., Gemueva, K. A., & Semenova, N. K. (2021). The seventh population census in the PRC: results and prospects of the country's demographic development. *Herald of the Russian Academy of Sciences*, 91(6), 724-735. <https://doi.org/10.1134/S1019331621060083>
- [38] Liang, W., Ahmad, Y., & Mohidin, H. H. B. (2024). Spatial pattern and influencing factors of tourism based on POI data in Chengdu, China. *Environment, Development and Sustainability*, 26(4), 10127-10143. <https://doi.org/10.1007/s10668-023-03138-8>

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