# Vitality Characteristics and Influencing Mechanisms of Recreational Spaces in High-Density Mountainous Cities: A Case Study of Wanzhou District, Chongqing

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Abstract:High-density mountainous cities, characterized by compact spatial layouts, represent a typical urban type in China. As centers of urban public life, recreational spaces in these cities need to be effectively planned and managed in line with activity patterns and preferences of urban residents. While numerous studies have examined the vitality of recreational spaces in plain cities and their planning and optimization, the unique and complex terrain features and the limited developable land in mountainous cities create vitality patterns distinct from plain cities. Even scattered spaces such as street corners can support significant recreational activities, influenced by factors such as inadequate and unevenly distributed recreational spaces and reduced service coverage. These characteristics underscore the need to further investigate tailored to high-density mountainous environments. Using Wanzhou District, Chongqing as a case study, this paper finds that the typical access distance to recreational spaces in mountainous cities is generally within 1.5 kilometers. By comparing four representative recreational spaces in high-density mountainous cities—park green spaces, plazas, streets, and community green spaces—the paper reveals that streets and community green spaces accommodate a substantial proportion of recreational activities. Finally, by analyzing the built environment factors shaping the vitality of recreational spaces in high-density mountainous cities and by employing a geographically weighted regression model, this paper explains the difference in the influence mechanisms of vitality among the four types of recreational spaces.

Keywords

Recreational space vitality; identification of recreational activities; mountainous cities; geographically weighted regression model

## 1. Research Foundations for Recreational Space Vitality in High-Density Mountainous Cities

### 1.1 Connotations and Characterization of Recreational Space Vitality

Vitality is the comprehensive representation of economic, social, and cultural activities in space[17-18]. In a narrow sense, it can be understood as interpersonal interaction and exchange, urban life activities, and the richness and diversity of urban life and its place carriers are necessary conditions for maintaining local traditional vitality[19]. Jacobs[20] considered that urban vitality is obtained through the interweaving of people and their living activity places; human activities are regarded as the fundamental elements of vitality, and understanding recreational space vitality based on human activities can effectively capture recreational space vitality.

Recreational space vitality refers to the intensity of recreational activities such as social interaction, rest, and appreciation carried out within the recreational space range. Gehl[21] regarded its core as selective, social activities rather than necessary commuting activities.

The measurement methods of vitality are shifting from small-scale questionnaire surveys and on-site research[22-23] to emerging data technologies with large-scale spatiotemporal big data[24-25] and lighting data[26][27]. Emerging data technologies have advantages of low cost, real-time efficiency, and higher granularity, enabling more precise depiction of recreational space vitality[29]. The measurement indicators of vitality include multiple forms such as access frequency, duration, and mixing degree[30], with its core still being the degree of human aggregation[31]. For recreational spaces, this study uses recreational activity density per unit area to measure them.

### 1.2 Characteristics of Recreational Space Vitality in High-Density Mountainous Cities

Recreational space vitality in high-density mountainous cities is the combined result of physical space supply and recreational activity demand.

From the perspective of physical space supply, mountainous cities have complex terrain changes and high-density, concentrated construction[32], with limited developable space; recreational spaces face issues of insufficient scale and uneven distribution[33]; at the same time, due to drastic terrain slopes and undulation, the accessibility of recreational spaces is weakened, and the service range scale is reduced[34].

From the perspective of recreational activity demand, recreation has become a normalized activity in urban residents' daily lives: on one hand, higher development intensity in mountainous cities means higher population density, generating greater recreational activity demand per unit area; on the other hand, significant terrain slopes significantly limit the travel capabilities of mountainous city populations, leading to limited distribution of park green spaces and other spaces unable to meet large amounts of recreational activity demand, and small-scale scattered spaces such as street corners and street sides bearing large amounts of recreational activity demand, having become important tools for expanding outdoor recreational spaces in high-density urban areas[35].

In summary, the service range scale of recreational space vitality in high-density mountainous cities is reduced, requiring attention to mountainous city-unique factors such as terrain slopes and other elements; further discussion is needed on the service range scale of recreational space vitality. The types and scope of material spaces bearing recreational vitality are more extensive, requiring attention to more extensive recreational space types such as scattered spaces—for example, whether there are differences in vitality among different types of recreational spaces, especially the role borne by scattered spaces in recreational space vitality.

## 2. Research Case and Data Methods

### 2.1 Case Selection

The urban area of Wanzhou District in Chongqing Municipality is located in the hilly zone between parallel ridges and valleys in eastern Sichuan, with the Yangtze River flowing through the city, making it one of the central cities in the Three Gorges Reservoir area. Against the background of construction in the Three Gorges Reservoir and rapid urbanization, the scale of available construction land in the urban area has further shrunk, while a large population has rapidly gathered in Wanzhou urban area, and urban construction has developed toward high-density and high-intensity forms, representing a typical high-density mountainous city.

Because construction land in mountainous cities is inherently limited, the problem of insufficient scale and quantity of recreational spaces is more pronounced. According to the 2020 national land change survey data, the per capita green space in Wanzhou urban area is far below the standard of 10m²/person, and a large number of street-side and corner spaces have become the main places for recreational activities. Therefore, research on recreational space vitality in Wanzhou urban area can understand the particularity of characteristics and influence mechanisms of recreational space vitality in mountainous cities, and this study selects it as the research case for recreational space vitality in high-density mountainous cities, with a scope covering the Wanzhou urban area construction land and surrounding mountains and waters, approximately 235km² in area.

## 2.2 Data Collection

This study uses LBS data to calculate and characterize recreational space vitality. LBS data has high spatiotemporal resolution and can characterize the spatiotemporal behavioral characteristics of microscopic individuals. After data cleaning and organization, a total of over 1.13 million LBS data points were obtained within 7 days in Wanzhou District. The sources and collection times of other data such as current land use are shown in Table 1.

Table 1: Introduction to Data Sources

| Data Type | Source | Collection Time |
|---|---|---|
| LBS data | Mobile information push service provider | April 1-7, 2019 |
| Current land use data | Wanzhou Planning and Natural Resources Bureau | 2019 |
| Building outline data | Wanzhou Planning and Natural Resources Bureau | 2019 |
| Terrain DEM data | NASA-SRTM DEM data | 2019 |
| Point of Interest (POI) data | Amap Open Platform | June 2019 |
| Remote sensing satellite data | Wanzhou Planning and Natural Resources Bureau | 2019 |

## 2.3 Methods for Identifying Recreational Spaces and Recreational Activities

### 2.3.1 Recreational Space Identification

The types and scope definition methods for recreational spaces are diverse. Research on recreational spaces mainly includes multiple types such as park green spaces, plazas, streets, pocket parks, community green spaces, and commercial areas. This study limits research to outdoor urban recreational spaces. Field surveys found that daily recreational activities of people in high-density mountainous cities mainly occur in park green spaces, plazas, community green spaces, and street-side and street corners, so park green spaces, plazas, community green spaces, and streets were selected as the four typical recreational space types for study.

The difficulty in identifying recreational spaces lies in the identification of scattered spaces such as street corners and community green spaces. The boundary scopes of park green space and plaza land uses have been clearly specified in the "Urban Land Use Classification and Planning Construction Land Standards" (GB 50137-2011), and can be directly extracted based on current land use data. Due to their diverse forms, blurred boundaries, and large numbers, conducting research on the vitality of each street corner and community green space would make it difficult to draw effective conclusions due to factors such as overly small area scale.

For street corners, this study takes intersections as dividing points to segment them, integrating them into different street segments for research. For community green spaces, deep learning methods were used to identify them from high-precision remote sensing satellite data[36]. First, sample areas were selected in Wanzhou urban area for data annotation, constructing a green space sample database to ensure that training tiles cover multiple green space types such as lawns, shrubs, and woodlands. Then the DeepLabv3 model[37] was used for training, iterating 11 times, during which the sample database was divided into training and validation sets, with validation set verification achieving a result accuracy of 93%, effectively identifying green space boundaries in mountainous cities. The identified green space results were then overlapped with residential land in the current land use data to extract community green space results.

### 2.3.2 Recreational Activity Identification

Recreational activity points can be identified by fusing POI data[38-39] or Area of Interest (AOI) data[40] with LBS data through their spatiotemporal characteristics. First, in ArcGISPro, "find stay locations" was used to identify all stay points within 100m that stay for more than 5 minutes, defining activities staying for more than 5 minutes within 100m as effective recreational activities, so time and space thresholds were set to 5 minutes and 100m respectively.

However, due to the functional composite nature of recreational spaces, identifying stay points alone may contain a large number of non-recreational activity points. For example, due to the proximity of commercial areas on both sides of streets, employment activity points may be identified as recreational activities. Similarly, since community green spaces are close to residential areas, residential activity points may be identified as recreational activities.

Therefore, through the job-housing identification method[41-42], residential and employment activity points were identified, and recreational activity points within 50m of each id's two types of activity points were removed as the final recreational activity results.

## 2.4 Model Construction

### 2.4.1 Selection and Calculation of Built Environment Indicators

Numerous studies indicate significant correlations between urban population activities and elements such as spatial accessibility[43], functional combinations, and building forms. For recreational space vitality, its internal space quality[44], facility elements[45], and plant landscape features[46] are also important influencing elements.

Therefore, considering the background of high-density mountainous cities and combining the characteristics of recreational spaces themselves and their surrounding environment, this study selected recreational space vitality influence indicators.

The influence of recreational space's own characteristics on vitality is mainly reflected in three aspects: first, existing studies indicate that recreational space area scale has an inhibitory effect on space vitality[47]; second, recreational space surface openness can reflect recreational space ventilation and sunlight conditions[48], mountainous cities have high building density, and ventilation and sunlight environments are relatively poor[49], it is inferred that surface openness has an influence relationship with its vitality; finally, terrain slope and vegetation coverage may affect population recreational experience, thereby affecting recreational space vitality.

The influence of recreational space surrounding environment characteristics on space vitality is mainly reflected in four aspects: accessibility, function, population distribution, and building capacity. High accessibility reflects the difficulty for residents to reach recreational spaces[50]; different commercial function facilities have a promoting effect on recreational space vitality. Through preliminary regression analysis, shopping services and catering services, two functions highly correlated with recreational space vitality, were selected for characterization. At the same time, functional diversity reflects the completeness of surrounding environment function facilities, so functional diversity was selected for supplementation.

Surrounding population characteristics include residential and employed populations. These two types of population distributions serve as the most basic anchor point activities in cities[51], and their distribution is closely related to recreational space vitality. Surrounding building capacity indicates the activity carrying capacity of that area, which is also one of the elements affecting recreational space vitality. The calculation methods for indicators are shown in Table 2.

Table 2: Calculation Methods and Formulas of Influencing Indicators

| Indicator | Calculation Method | Value Standard |
| --- | --- | --- |
| Own Characteristics | | |
| Area scale | Calculate the area of each recreational space using the "calculate geometry" function in ArcGISPro, unit: $hm^2$ | Between 0.01 and 46.5 $hm^2$ |
| Surface openness | Sky view factor (SVF) calculated from surface raster (including building height) | Between 0 and 1, higher value indicates more open site |
| Terrain slope | Calculate using the "slope" function in ArcGISPro | Between 0 and 90 degrees, higher value indicates steeper site |
| Vegetation coverage | Ratio of green area to total area | Between 0 and 1 |
| Surrounding Characteristics | | |
| Surrounding terrain slope | Average slope within buffer zone | Between 0 and 90 degrees |
| Road network accessibility | Calculated using Kriging interpolation in ArcGISPro | Between 479 and 3063 |
| Bus density | Count bus stops within buffer divided by buffer area | Between 0 and 6 |
| Shopping service density | Count shopping services within buffer divided by buffer area | Between 0 and 52 |
| Catering service density | Count catering services within buffer divided by buffer area | Between 0 and 24 |
| Functional diversity | Shannon entropy index | Between 0 and 2.2 |
| Residential population density | Count residential population within buffer divided by buffer area | Between 0 and 284 |
| Employed population density | Count employed population within buffer divided by buffer area | Between 0 and 233 |
| Building density | Sum of building footprint | Between 0 and 0.46 |

| | | |
|---|---|---|
| | area within buffer divided by buffer area | |
| Development intensity | Sum of building floor area within buffer divided by buffer area | Between 0 and 5.9 |

### 2.4.2 Geographically Weighted Regression Model

The geographically weighted regression (GWR) model dynamically adjusts model parameters to accurately capture local differences between different regions to adapt to spatial changes. Compared with traditional global regression analysis, the GWR model not only solves spatial data regression problems but also allows coefficients to change with geographic location, thereby more detailedly revealing the influence of built environment elements on recreational space vitality[52].

This study selected recreational space vitality as the dependent variable, and constructed 5 GWR models to reflect spatial differentiation characteristics of different types of recreational space vitality influence. The model formula is:

$$Y_i = \beta_0(u_i, v_i) + \Sigma_{k=1}^{n} \beta_k(u_i, v_i)X_{ik} + \varepsilon_i$$

Where: the dependent variable $Y_i$ represents recreational space vitality; $(u_i, v_i)$ are the longitude and latitude coordinates respectively; $\beta_0(u_i, v_i)$ is the geographic location intercept, representing the expected value of recreational space vitality; $\beta_k(u_i, v_i)$ are the regression analysis coefficients; $X_{ik}$ represents the value of the k-th independent variable for recreational space i; $\varepsilon_i$ is the error term.

## 3. Recreational Space Vitality Characteristics

### 3.1 Recreational Space Vitality Distribution Characteristics

Recreational space vitality and spatial distribution generally form a mismatched pattern, with hotspot areas mainly in regions with smaller single-area scale and more scattered recreational spaces, while park green spaces and other recreational spaces with larger single-area scale have lower vitality.

Three major recreational activity hotspot areas emerged: Gaosuntang-Taibai, Beishan, and Bai'anba. A total of 71,525 recreational activities were generated during the sampling period, with a vitality density of 105.8 visits/hm² (Table 3), which may be because streets have the most uniform and widespread spatial distribution, and their street-side and corner spaces bear important roles in recreational activities in mountainous cities.

Plaza vitality density ranked second, but their quantity and distribution were the smallest, indicating that mountainous city populations tend to conduct recreational activities in plazas. Field surveys confirmed that plazas host many large-scale collective recreational activities such as square dancing and fitness activities. Park green space vitality density was lowest, with smaller quantity, larger single-area scale, and being located in mountainous areas around the urban area, therefore accessibility is relatively lower than other recreational space types.

Table 3: Overview of Activities in Different Types of Recreational Spaces

| Recreational Space Type | Recreational Activity Frequency (visits) | Recreational Space Total Area (hm²) | Recreational Vitality Density (visits/hm²) |
|---|---|---|---|
| Park green space | 3,108 | 323.8 | 9.6 |
| Plaza | 3,098 | 46.5 | 66.6 |
| Street | 71,525 | 683.8 | 105.8 |

| | | | |
|---|---|---|---|
| Community green space | 17,271 | 308.6 | 56.0 |

Community green space recreational activity frequency was relatively high, indicating that community green spaces are also the main places for recreational activities of mountainous city populations. Differences in vitality among different recreational space types were significant, with streets having the highest recreational activity frequency and vitality density, followed by community green spaces, then plazas, with park green spaces lowest.

3.2 Recreational Space Travel Distance Characteristics

Based on LBS data, travel OD lines with recreational spaces as destinations in Wanzhou District urban area were identified, with shortest distance within 10m and longest distance approximately 12km, average distance 1.2km. Figure 1 shows the proportion distribution of travel distances for different recreational space types.

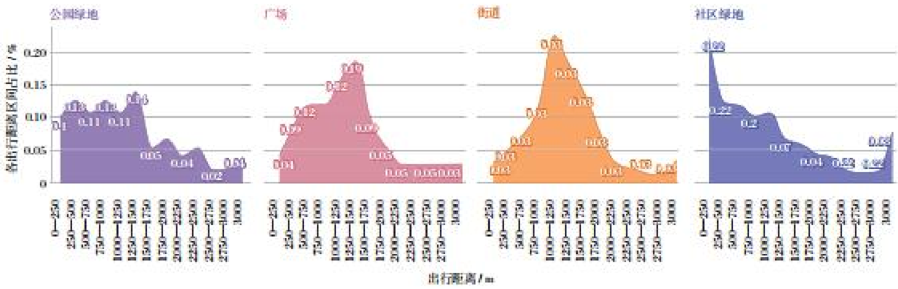



Fig.1 Proportion of travel distances for different types of recreational spaces

For Wanzhou, 70% of recreational space travel distances do not exceed 1.5km. When recreational space travel distance exceeds 2km, travel volume sharply decreases. Therefore, it can be considered that Wanzhou's recreational spaces mainly serve within a range scale of 1.5km.

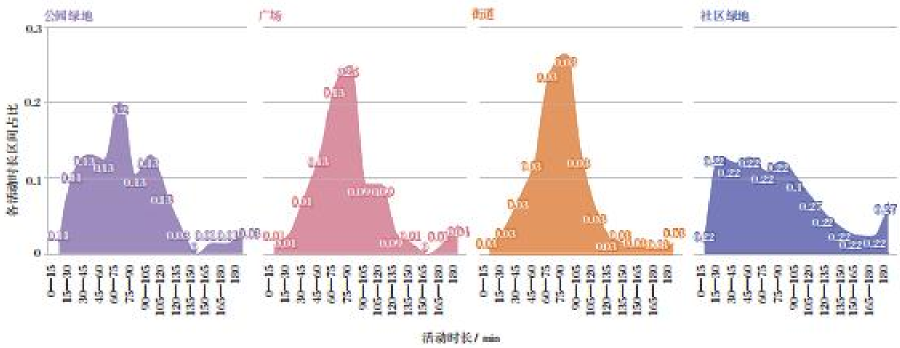
The distribution difference in travel distances for different recreational space types indicates their different service range scales. Within the 1.5km main service range scale, park green space recreational activity distance distribution is relatively average, indicating it can simultaneously attract populations from different surrounding ranges. Plaza and street recreational activity attraction ranges are mainly 1.0-1.25km and 1.0-1.25km respectively, with relatively fewer short-distance and long-distance recreational activities. Community green space recreational activities are mainly nearby behaviors, showing a significant trend of decreasing recreational activity volume with increasing distance.

3.3 Recreational Space Activity Duration Characteristics

Recreational space activity duration can reflect urban population's recreational activity needs and satisfaction with recreational spaces[53]. Wanzhou District urban population's average stay duration in recreational spaces is 82 minutes, with recreational activity duration median of 75 minutes, indicating that Wanzhou District urban population's recreational activity needs are strong, and most recreational activity durations are between 15-105 minutes

(Figure 2).

Fig.2 Proportion of activity durations for different types of recreational spaces




Among different recreational space types, community green space and park green space recreational activity duration distributions are more uniform. These two types of spaces can simultaneously attract short-duration and long-duration recreational activities. Field surveys found that park green spaces and community green spaces include more short-duration recreational activity types such as rest and strolling, as well as many long-duration stay activities such as fitness. Plaza and street recreational activity durations have obvious peak duration characteristics, mainly between 60-90 minutes, with the above spaces mainly conducting card games, square dancing, and other strong-purpose recreational activities.

## 4. Recreational Space Vitality Influence Mechanisms

### 4.1 Comparison of Results for Different Recreational Space Type Models

Based on the characteristic that Wanzhou recreational spaces mainly serve within a 1,500m range scale, this study further divided into recreational space buffer ranges of 100m, 250m, 500m, 1,000m, and 1,500m, extracted built environment influence elements to construct GWR models.

Results showed that as buffer distance increased, GWR model adjusted $R^2$ successively was 0.59, 0.52, 0.49, and when buffer distance was greater than or equal to 1,000m, model results showed multicollinearity issues—that is, the differentiation of different influence elements in that buffer zone results decreased. This indicates that as distance increases, the influence result of surrounding environment on recreational space vitality in mountainous cities decreases. Therefore, this study selected the 100m buffer distance for further analysis.

This study constructed 5 GWR models for analysis, including 1 comprehensive recreational space model and 4 specialized models for park green space, plaza, street, and community green space. Results are shown in Table 4. Due to multicollinearity characteristics between surrounding employed population density and surrounding development intensity indicators and other indicators, they were removed in the final model. All remaining variables passed significance testing.

Comparing the 5 GWR models, the comprehensive model had relatively lower explanatory power, indicating that built environment elements have different influence mechanisms on different recreational space types. In the comprehensive model, elements such as surrounding catering service density, surrounding residential population density, and surrounding bus density had higher influence degrees, and unique indicators such as surface openness and terrain slope also had relatively significant influence effects, with different effects for different models.

Table 4: Results of Geographically Weighted Regression Model

| Indicator | Comprehensive Model | Park Green Space Model | Plaza Model | Street Model | Community Green Space Model |
|---|---|---|---|---|---|
| Own Characteristics | | | | | |
| Area scale | -0.04 | -0.01 | 0.12 | 0.03 | -0.01 |
| Surface openness | -0.05 | -0.20 | -0.22 | -0.01 | -0.35 |
| Terrain slope | -0.03 | 0.01 | 0.08 | -0.03 | -0.07 |
| Vegetation coverage | -0.01 | -0.22 | -0.04 | 0.03 | -0.13 |
| Surrounding Characteristics | | | | | |
| Surrounding terrain slope | -0.02 | -0.04 | 0.01 | -0.04 | -0.01 |
| Road network accessibility | 0.02 | -0.12 | 0.02 | -0.01 | 0.02 |
| Bus density | 0.14 | -0.07 | 0.21 | 0.18 | 0.03 |
| Shopping service density | 0.17 | -0.14 | 0.30 | 0.17 | 0.02 |
| Catering service density | 0.35 | 0.11 | 0.31 | 0.35 | 0.12 |
| Functional diversity | 0.02 | 0.01 | 0.00 | 0.03 | -0.06 |
| Residential population density | 0.20 | 0.53 | -0.06 | 0.26 | 0.55 |
| Employed population density | Removed | Removed | Removed | Removed | Removed |
| Building density | 0.02 | 0.12 | 0.10 | 0.04 | -0.16 |
| Development intensity | Removed | Removed | Removed | Removed | Removed |
| Model Statistics | | | | | |
| $R^2$ | 0.61 | 0.71 | 0.69 | 0.70 | 0.64 |
| Adjusted $R^2$ | 0.59 | 0.64 | 0.59 | 0.68 | 0.60 |
| AICc | 3693.85 | 307.82 | 183.67 | 2344.68 | 572.79 |
| Sigma-Squared MLE | 0.39 | 0.29 | 0.31 | 0.30 | 0.36 |

## 4.2 Differences in Recreational Space Vitality Influence Mechanisms by Type

The coefficients of different variables in Table 4 indicate their influence degree on recreational space vitality changes. Own characteristics generally produce inhibitory effects on space vitality—that is, the higher the area scale, surface openness, terrain slope, and vegetation coverage, the lower the corresponding space vitality. Area scale has a promoting effect on plaza space vitality, indicating that increasing plaza area is conducive to enhancing recreational space vitality. Field surveys found that in the morning and evening, populations tend to conduct group activities on large-area plaza land, so it is necessary to lay out plazas of certain scale in mountainous cities.

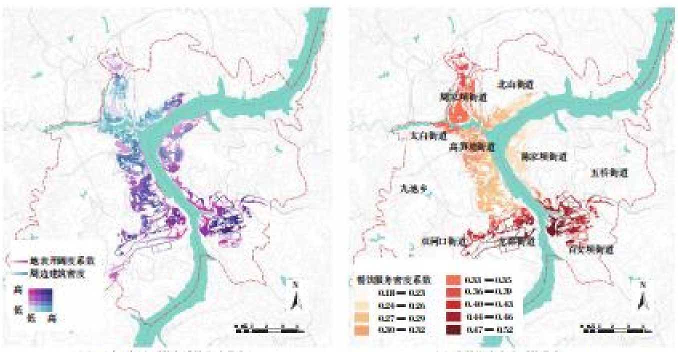
For surface openness, due to lack of large-scale land space for recreational activities in regions with high building density such as Gaosuntang and Beishan, the above results appear. In regions with lower building density, surface openness is positively correlated with recreational space vitality, while due to compact land use in most areas of mountainous cities, recreational spaces are laid out in high-density mountain environments with lower openness, so surface openness is mainly negatively correlated with recreational space vitality.

Vegetation coverage has a large inhibitory effect on park green space and community green space vitality, reasons similar to surface openness—not that vegetation coverage reduces recreational space vitality, but that in high-density mountain cities, it is difficult to lay out spaces with high vegetation coverage for recreation use, while surrounding areas contain large numbers of mountain parks with high vegetation coverage, but due to insufficient surrounding residential population density, the above results emerge. Vegetation coverage has weaker influence on plaza and street space vitality.

Terrain slope has weaker influence on all four recreational space types, generally showing an inhibitory relationship.

The higher the surrounding accessibility conditions, the higher the corresponding increase in recreational space vitality. Surrounding terrain slope is mainly inhibitory on recreational space vitality—that is, increased surrounding terrain slope reduces certain recreational space vitality. Surrounding road network accessibility has a high promoting effect on park green space vitality, with weaker bus density influence, indicating that populations around park green spaces tend to reach recreational activities by walking, requiring improvement of park green space surrounding road network accessibility. Surrounding bus density has higher influence on plaza and street model space vitality, indicating larger populations reaching these types of recreational spaces by public transportation, which can be combined with layout of plazas around bus stops and excavating street recreational space utilization potential.

Surrounding accessibility characteristics have lower influence on community green space vitality, indicating community green space vitality is mainly from community populations, and surrounding residential population density influence degree also proves corresponding viewpoint.



(a) 地表开阔度系数与建筑密度分布　(b) 餐饮服务密度系数分布

Fig.3 Distribution of coefficients for key influencing factors in the comprehensive model

Surrounding functional characteristics mainly produce promoting effects on recreational spaces. Surrounding catering service density is positively correlated with recreational space vitality, especially in plaza and street models where the above two types have smaller area scale and more open surrounding environment, so surrounding function facilities can effectively increase plaza and street space vitality. This positive effect has center-edge differences in space—that is, in regions with high catering service industry agglomeration such as Gaosuntang and Jiangnan New District, the promoting effect of catering service industry forms is reduced, while in regions such as Shuanghekou and Bai'anba, catering service industry agglomeration has a greater promoting effect on recreational space vitality [Figure 3(b)]. Surrounding shopping service density's inhibitory effect on park green space mainly appears in high-density regions such as Gaosuntang and Beishan, indicating that surrounding shopping service density is overly dense in these regions, and its density increase no longer has a promoting effect on park green space vitality. Additionally, surrounding functional diversity has weaker effects on all four recreational space types.

Surrounding residential population density has highly significant promoting effects on park green space, street, and community green space vitality, and in regions with dense residential populations, surrounding residential population density coefficients are larger, with strong recreational activity demand, so corresponding recreational spaces can be increased in these regions. Surrounding residential population density has less influence on plaza space vitality; field surveys found its inhibitory effect mainly appears in regions such as Bai'anba and Longdu with smaller residential population density, suggesting moderate guidance of residential population agglomeration.

Surrounding building capacity has promoting effects on park green spaces, plazas, and streets—that is, as surrounding building density increases, the above recreational space vitality correspondingly increases. For community green spaces, perhaps due to increased surrounding building density, populations are more inclined to leave high-density community environments for recreational activities.

## 5. Discussion and Conclusions

### 5.1 Particularity of Recreational Space Vitality in High-Density Mountainous Cities

This study took Wanzhou District, Chongqing as a case to research recreational space vitality characteristics and influence mechanisms in high-density mountainous cities, obtaining specific conclusions as follows:

① Due to complex terrain influence, Wanzhou's main recreational travel distance is within 1.5km, and high-density mountainous city recreational space vitality's main service range scale is relatively significantly reduced compared to plain cities.

② In high-density mountainous city recreational spaces, streets and community green spaces have widespread spatial distribution, can effectively supplement insufficiency of park green spaces and plazas, and therefore bear large amounts of recreational activities. By comparing recreational activity duration, it was found that park green spaces and community green spaces compared to streets and plazas can satisfy more different durations of recreational activities, it is inferred that the recreational activity types they bear are richer.

### 5.2 Differences in Recreational Space Vitality Influence Mechanisms by Type

This study explains the differences in recreational space vitality influence mechanisms for different recreational space types through geographically weighted regression analysis. Through these differences, different types of recreational spaces can be coordinatively laid out—for example, in regions with better surrounding road network accessibility conditions, park green spaces rather than plaza hard spaces can be preferentially considered, while in regions with higher surrounding shopping service density, the opposite applies.

This difference reflects the different synergistic effects of recreational activities in different recreational space types with other types of behavioral activities (such as shopping), which can be analyzed in next-step research. Additionally, vitality enhancement strategies can be proposed for different recreational spaces based on these influence mechanisms.

### 5.3 Recreational Space Vitality Enhancement Strategies in High-Density Mountainous Cities

In the built environment of high-density mountainous cities, large recreational spaces may mean lower recreational vitality, requiring more consideration of increasing scattered spaces laid out in a "stitching" manner. Large amounts of research have already discovered the significant advantages of these scattered spaces in high-density cities[54-55], such as lower construction costs, ability to be widely distributed, and increasing scattered space layout and construction can effectively satisfy high-density mountainous city population's recreational needs.

Regions with high building density and low surface openness have higher recreational needs, requiring large increases in recreational space layout. Additionally, for park green spaces, road accessibility conditions should be considered, enhancing recreational space vitality through measures such as adding entrances, installing ladders and elevators. Plaza and street vitality influence mechanisms are similar—both should consider surrounding functional characteristics, and combined layout with shopping and catering can effectively improve their utilization. The main factors influencing community green space vitality are surrounding residential populations, so community green space area scale should be considered in combination with community population scale.

### 5.4 Limitations and Prospects

This study researched recreational space vitality in high-density mountainous cities. One of the main conclusions is that streets and community green spaces play very important roles in high-density mountainous city recreational activities, yet certain limitations remain in research:

① Theoretical research on scattered recreational space vitality influence mechanisms is insufficient. Current methods mainly focus on overall research on mountainous city recreational spaces and comparative studies, while scattered spaces as important recreational spaces among them may have influence mechanisms related to more microscopic elements such as recreational facilities and paved area, requiring combined scattered space proposals for corresponding vitality influence mechanism research.

② Insufficient methods for defining and identifying scattered recreational spaces. In urban streets, except for motor vehicle lanes, all are physical spaces where populations can conduct recreational activities, making it difficult to identify street-side and corner scattered space boundaries. Community green spaces have the characteristics of numerous quantity and scattered distribution, so this study integrated community green spaces, street-side and corner scattered spaces into each plot and each street for research. In follow-up research, precise identification and definition methods need to be proposed, thereby more refinedly researching their influence mechanisms.

Notes

① This data is event-triggered data generated when users use mobile internet positioning requests, originating from multiple APPs—that is, instantaneous geographic location data formed when users perform events such as login, search, sending and receiving information, and push notifications in various APPs. The data has been anonymized and does not involve personal privacy.

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