



# Research on Accessibility of Public Cultural Facilities Based on an Improved Model of 2SFCA—A Case Study of Suzhou City

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## ABSTRACT

Building a socialist cultural powerhouse is foundational to achieving the great rejuvenation of the Chinese nation. Accessibility to cultural facilities serves as a critical metric for assessing the equitable distribution of urban cultural resources. Leveraging public cultural facility POI data and ArcGIS software, this study employs an improved Gaussian Two-Step Floating Catchment Area (Ga2SFCA) model to evaluate the accessibility of cultural facilities across Suzhou City. By integrating clustering analysis of accessibility outcomes and supply-demand dynamics, the study identifies distinct accessibility patterns among demand units. Key findings include: (1) The enhanced Ga2SFCA model significantly improves evaluation accuracy. (2) While Suzhou City exhibits high overall accessibility to cultural facilities, spatial distribution remains highly uneven, with accessibility declining sharply from the urban core to peripheral areas. (3) Demand units are categorized into four clusters: High-Supply High-Demand High-Accessibility (HS-HD-HA) Units, High-Supply Low-Demand High-Accessibility (HS-LD-HA) Units, Low-Supply Low-Demand Low-Accessibility (LS-LD-LA) Units.

## KEYWORDS

Two-Step Floating Catchment Area (2SFCA); public cultural facilities; accessibility; Suzhou City.

## 1. INTRODUCTION

Since the concept of public cultural services was first introduced in 2005, China's public cultural service system has undergone significant institutional refinement, marked by the recent implementation of the Public Cultural Service Guarantee Law and Public Library Law<sup>[1]</sup>. In the current era, both public demand and socioeconomic development necessitate a higher standard of public cultural services. Optimizing the spatial network of cultural facilities and advancing the equalization of basic public cultural services are critical to meeting citizens' aspirations for livable communities and enriched spiritual-cultural lives. As integral components of urban cultural infrastructure and ethical development, cultural facilities serve as vital venues for public engagement, directly addressing the growing demand for cultural enrichment among urban and rural populations<sup>[2]</sup>.

Accessibility analysis has been widely applied to evaluate the rationality and equity of public service facility allocation, shedding light on issues of social equity, spatial justice, and spatial deprivation by examining disparities in service access across demographic groups<sup>[3]-[4]</sup>. While existing studies have measured spatial accessibility for parks, educational institutions, healthcare facilities, elderly care centers, and sports venues, research focusing specifically on public cultural facilities remains limited. Methodologically, scholars have employed service area analysis, network analysis, minimum distance approaches, cumulative opportunity models, and the Two-Step Floating Catchment Area (2SFCA) method to quantify accessibility. Among these, the 2SFCA method stands out for its dual

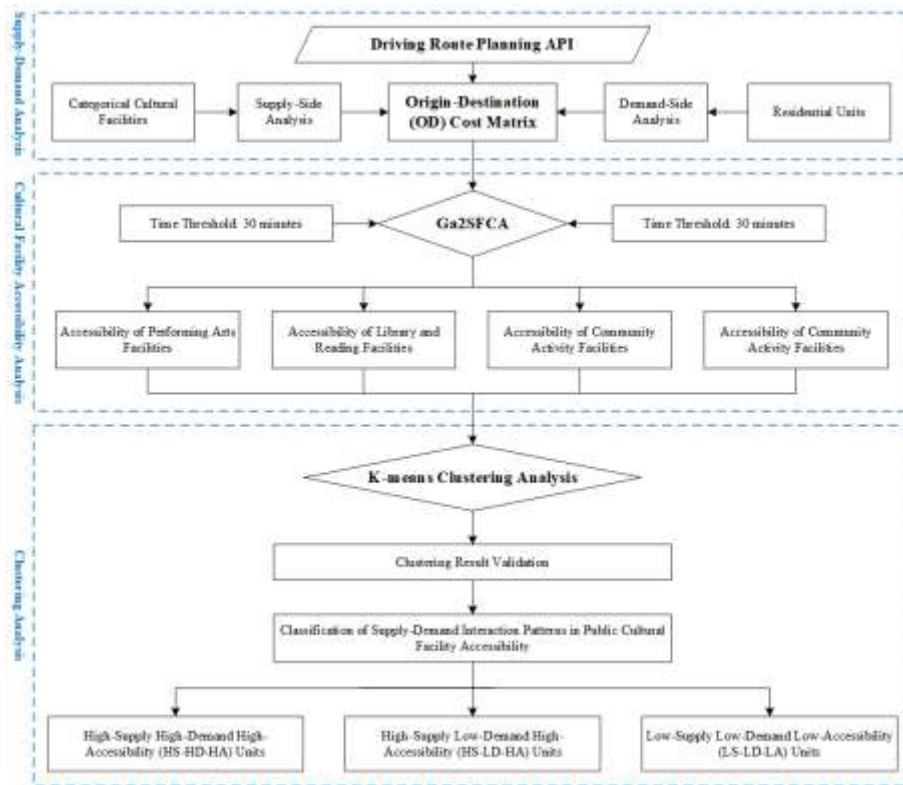
consideration of supply-side service capacity and demand-side population metrics, enhancing the scientific rigor of accessibility evaluations. Despite the methodological advancements of the 2SFCA approach, its application to cultural facility accessibility studies remains constrained by three persistent limitations. First, supply-side oversimplification persists, as prior research predominantly relies on unidimensional metrics such as floor area<sup>[5]</sup>, facility grade, or service capacity<sup>[6]</sup>, overlooking the synergistic effects of multidimensional factors—including operational hours, user satisfaction, and program diversity—that collectively determine a facility’s service efficacy. Second, demand-side analyses often suffer from coarse spatial granularity, with studies defaulting to street-level administrative boundaries<sup>[7]-[8]</sup>, which mask intra-unit demographic heterogeneity and introduce systematic errors in travel cost estimations. Third, conventional distance metrics, such as Euclidean buffers<sup>[9]</sup> or idealized network analyses<sup>[10]</sup>, inadequately capture real-world commuting behaviors shaped by multimodal transportation, traffic congestion, and temporal variability, thereby compromising the ecological validity of accessibility assessments.

As a UNESCO-listed historic city and a national exemplar of public cultural services, Suzhou—renowned as the “Paradise on Earth”—epitomizes the essence of Jiangnan culture (the cultural heritage of China’s Yangtze Delta region). In the new era, Suzhou faces the dual challenge of delivering standardized, equitable cultural facilities while preserving its global cultural identity. Existing research on Suzhou’s cultural infrastructure has focused on case studies<sup>[11]</sup>, planning strategies, institutional mechanisms<sup>[12]</sup>, and spatial layouts<sup>[13]</sup>, leaving gaps in accessibility analysis and supply-demand dynamics. This study addresses these gaps by leveraging Point of Interest (POI) data and an enhanced 2SFCA model to evaluate accessibility for four categories of public cultural facilities: performing arts venues, libraries, community activity centers, and exhibition spaces. Through cluster analysis, we further identify spatial patterns of supply-demand interactions across demand units. Our findings aim to inform the development of a more equitable and comprehensive public cultural facility system in Suzhou.

## **2. RESEARCH FRAMEWORK AND METHODOLOGY**

### **2.1. Research Framework**

This study develops an integrated analytical framework to evaluate the service capacity and accessibility of public cultural facilities, prioritizing both the scientific rigor of commuting cost measurement and the spatial congruence between supply and demand. As depicted in Figure 1, the framework systematically integrates four critical phases: demand-side service capacity assessment, supply unit characterization, accessibility quantification, and supply-demand pattern differentiation. Departing from conventional street-level population data limitations, we employ a 100-meter resolution population grid—generated through Chen Yuehong’s stacked ensemble learning applied to China’s 7th National Population Census and geospatial big data to achieve granular demographic estimation at the neighborhood/village committee scale. On the supply side, public cultural facilities across Suzhou City are evaluated through a multidimensional lens encompassing capacity, physical scale, administrative hierarchy, operational vitality, and user satisfaction metrics. Real-world commuting dynamics are captured via an origin-destination (OD) cost matrix constructed from Amap API driving-mode route planning data, while accessibility is computed using a Gaussian Two-Step Floating Catchment Area (Ga2SFCA) model calibrated with facility-specific search thresholds. The analytical pipeline culminates in cluster analysis to uncover latent spatial patterns in supply-demand interactions, thereby bridging macro-scale resource allocation with micro-scale behavioral realities.



**Figure 1. Research Framework**

## 2.2. Study Area

Suzhou City, a UNESCO-listed historic city and a national exemplar of public cultural services, serves as the study area. The urban core comprises six districts: Gusu, Huqiu, Industrial Park, Wujiang, Wuzhong, and Xiangcheng, encompassing 34 subdistricts, 20 towns, 622 neighborhood committees, and 435 village committees, with a total area of 4,652.84 km<sup>2</sup>. To ensure analytical coherence, this study excludes four county-level cities under Suzhou’s jurisdiction due to significant developmental disparities, focusing exclusively on the urban core to elucidate the spatial heterogeneity of cultural facility distribution and accessibility.

## 2.3. Methodology

### 2.3.1. Kernel Density Estimation (KDE)

Kernel Density Estimation, a non-parametric spatial analysis method, is utilized to visualize the spatial clustering of public cultural facilities<sup>[14]</sup>.

### 2.3.2. Enhanced Gaussian Two-Step Floating Catchment Area (Ga2SFCA) Model

The Gaussian Two-Step Floating Catchment Area (Ga2SFCA) method evaluates facility accessibility through a dual consideration of supply capacity and population demand while accounting for spatial impedance between supply and demand locations<sup>[15]</sup>. However, existing applications of Ga2SFCA to cultural facilities suffer from critical limitations, including oversimplified characterization of service capacity using single metrics and reliance on coarse administrative units for demand estimation, which introduces systematic errors in travel cost calculations. To address these gaps, this study introduces three methodological innovations: a hierarchical evaluation system for multidimensional facility service capacity, refined demand units derived from high-resolution population grids, and realistic travel time metrics based on real-world traffic data.

First, a hierarchical evaluation system is developed to quantify the service capacity of municipal- and district-level cultural facilities across five dimensions: capacity, physical scale, administrative

hierarchy, operational vitality, and user satisfaction. Street-level facilities are assigned standardized scores due to their limited service scope. Second, demand units are refined to 785 neighborhood/village committee-scale zones through spatial disaggregation and merging of non-contiguous or undersized units. Population data for these units are derived from a 100-meter resolution grid generated via stacked ensemble learning applied to China’s 7th National Population Census, outperforming existing datasets in accuracy. Third, realistic travel times are computed using Amap Open Platform’s driving-mode API data (collected during stable traffic periods: 15:00–16:30 on weekdays), overcoming the idealized assumptions of ArcGIS Network Analyst, which fails to capture complex urban traffic dynamics<sup>[16]</sup>. The enhanced Ga2SFCA model operationalizes these advancements through the following steps:

Step 1: Supply-Demand Ratio Calculation. For each public cultural facility  $j$ , represented as a point of interest (POI), a search zone  $j$  is established with a radius equal to the travel time threshold  $t_0$ . The supply-demand ratio  $R_j$  is calculated by aggregating the weighted population within this zone using a Gaussian time-decay function:

$$R_j = \frac{10^6 \times S_j}{\sum_{i \in \{t_{ij} \leq t_0\}} G(t_{ij}) D_i} \quad (1)$$

Where  $D_i$  is the population of demand unit  $i$ ,  $t_{ij}$  denotes the travel time between locations  $i$  and  $j$ , and  $S_j$  represents the composite service capacity of facility  $j$ . Demand units  $i$  are included only if their travel time to  $j$  falls within the threshold ( $t_{ij} \leq t_0$ ).

This study develops a hierarchical evaluation system for public cultural facility service capacity, employing tailored methodologies for facilities at different administrative levels. For municipal- and district-level facilities—which exhibit significantly higher and more variable service capacities compared to subdistrict-level facilities—service capacity is assessed through five dimensions: capacity, physical scale, administrative hierarchy, operational vitality, and user satisfaction (Table 1). A hybrid approach combining expert scoring and the Analytic Hierarchy Process (AHP) is adopted to determine criterion weights. Pairwise comparisons follow a 1–9 preference scale. Subdistrict-level facilities, constrained by limited service scope and minimal capacity variations, are assigned a standardized score of 1. The composite service capacity  $S_j$  for municipal and district facilities is computed as:

$$S_j = \begin{cases} W_a \times S_j^a + W_b \times S_j^b + W_c \times S_j^c + W_d \times S_j^d + W_e \times S_j^e \\ 1 \end{cases} \quad (2)$$

$S_j$ : Composite service capacity of facility  $j$ .  $S_{ja}, S_{jb}, S_{jc}, S_{jd}, S_{je}$ : Scores for capacity, scale, hierarchy, vitality, and satisfaction of municipal/district-level facilities.  $W_a, W_b, W_c, W_d, W_e$ : AHP-derived weights for the five criteria. When  $j$  is a municipal or district facility,  $S_j$  is calculated according to the formula. When  $j$  is a street-level facility, the value of  $S_j$  is 1.

**Table 1.** Municipal and District-Level Public Cultural Facilities Service Capacity Evaluation Index System

Indicator Code	Indicator Name	Grading Criteria	Graded Value Assignment	Remarks
$S_j^a$	Capacity Evaluation	Natural Breaks (Jenks) Method	100 points 80 points 60 points 40 points 20 points	Cultural Facility Floor Area
$S_j^b$	Scale Classification	Extra-Large Cultural Complexes; Large Venues; Medium Facilities; Small Sites	100 points 20 points 10 points 5 points	/
$S_j^c$	Administrative Hierarchy	Municipal-Level Facilities; District-Level Facilities	100 points 30 points	Administrative Hierarchy Correspondence of Cultural Facilities
$S_j^d$	Vitality Assessment	Baidu Heatmap Intensity Scoring	100 points 85.7 points 71.4 points 57.1 points 42.9 points 28.6 points 14.3 points	Baidu Heatmap Intensity values at facility locations were calculated as the mean of 10:00 and 15:00 observations
$S_j^e$	User Satisfaction Evaluation	Five-star, Four-star, Three-star, Two-star, One-star	100 points 80 points 60 points 40 points 20 points	Dianping.com Star Rating

Recognizing the heterogeneous service capacities across hierarchical public cultural facilities, this study establishes differentiated time thresholds based on facility scale and administrative level. While no universal standard exists for service radii, thresholds are calibrated through a synthesis of planning guidelines and empirical studies<sup>[17]-[19]</sup>: municipal-level facilities (60 minutes), district-level (30 minutes), and subdistrict-level (15 minutes). Mega-facilities—characterized by exceptional capacity, extensive collections, citywide cultural influence, and multifunctional spaces—are assigned a 120-minute threshold, corresponding to the maximum observed travel time between supply-demand pairs.

Traditional 2SFCA assumes uniform accessibility within thresholds, neglecting distance/time decay effects. To address this limitation, we introduce a Gaussian decay function  $G(t_{ij})$  that models accessibility attenuation with increasing travel costs:

$$G(t_{ij}) = \frac{e^{-\frac{1}{2} \times \left(\frac{t_{ij}}{t_0}\right)^2} - e^{-\frac{1}{2}}}{1 - e^{-\frac{1}{2}}} \quad (t_{ij} \leq t_0) \quad (3)$$

Step 2: For each demand unit centroid  $i$ , a search zone I is defined with radius  $t_0$ . Accessibility  $A_i^T$  is computed by aggregating supply-demand ratios  $R_j$  of all facilities  $j$  within  $t_0$ , weighted by  $G(t_{ij})$ :

$$A_i^T = \sum_{j \in \{t \leq t_0\}} G(t_{ij}) R_j \quad (4)$$

Higher  $A_i^T$  values indicate superior accessibility.

### 2.3.3. K-means Clustering Analysis

K-means clustering is applied to classify demand units based on three normalized indicators: composite accessibility, population density (demand proxy), and Gaussian-weighted supply capacity. This reveals latent spatial patterns and informs targeted policy interventions.

## 2.4. Data Collection and Processing

(1) Administrative Boundaries: Neighborhood/village committee boundaries (2022) sourced from the National Geomatics Center of China. (2) Facility POIs: 693 public cultural facilities classified into four categories (performing arts venues, libraries, community centers, exhibition spaces) using Suzhou's 2015–2030 Cultural Facility Layout Plan and Amap API data. (3) Population Grids: 100-meter resolution grids derived from the 7th National Population Census via stacked ensemble learning. (4) Travel Time Data: Amap API driving-mode routes (WGS 1984 coordinate system) collected during stable traffic periods. Data processing ensures compatibility across sources, with rigorous cleaning and validation protocols applied.

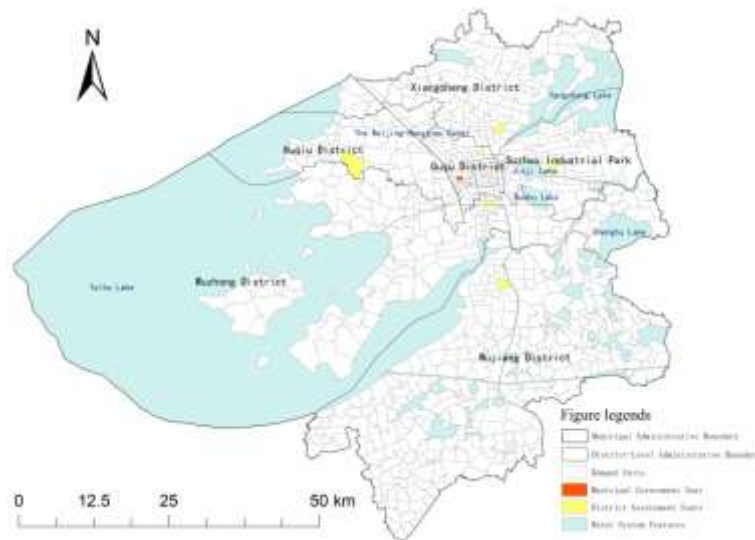


Figure 2. Study Area

## 3. ACCESSIBILITY AND CLUSTER ANALYSIS OF PUBLIC CULTURAL FACILITIES

### 3.1. Spatial Distribution of Public Cultural Facilities

This study collected Point of Interest (POI) data for cultural facilities through the Amap API and conducted data cleaning, resulting in 693 valid entries. These included 50 art performance venues, 143 libraries and reading spaces, 181 public activity centers, and 319 exhibition facilities (Table 2).

**Table 2.** Descriptive Statistics of Public Cultural Facilities

Facility Typology	Facility Count			
	Municipal-Level Facilities	District-Level Facilities	Subdistrict-Level Facilities	Total
Performing Arts Venues	4	8	38	50
Library and Reading Spaces	2	8	133	143
Community Activity Centers	11	38	132	181
Exhibition Facilities	9	38	272	319
Total	26	92	575	693

Kernel density analysis was applied to examine the spatial distribution of cultural facilities in Suzhou. The analysis scope was limited to Suzhou’s core urban zones, with a search radius parameter of 0.02. The results revealed distinct spatial heterogeneity across facility categories (Figure 3), as detailed below:

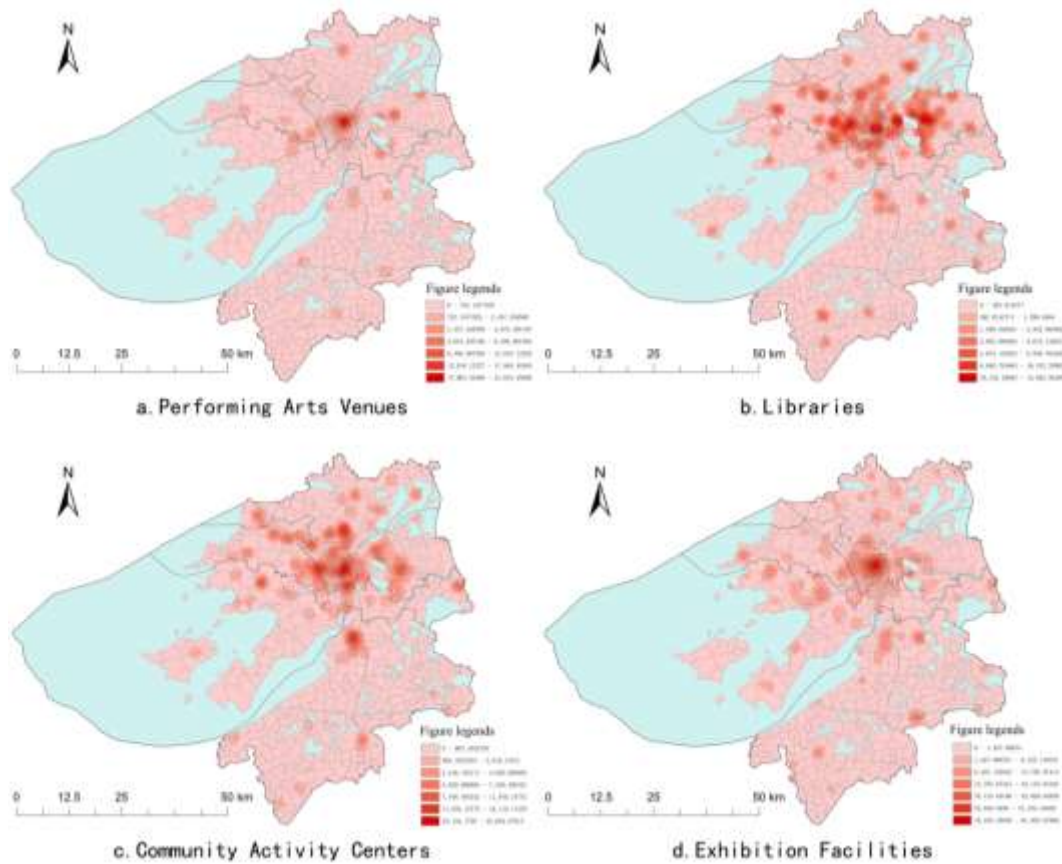
(1) Art performance venues are predominantly clustered in the central urban area, with minimal dispersion in peripheral regions. Within Gusu District, these facilities are densely concentrated inside the historic city moat (Outer City River), showing no expansion northward. In the Industrial Park district, high-density clusters align with Jinji Lake and Dushu Lake. Huqiu District exhibits aggregation around the Shishan Scenic Area, while sporadic clusters appear in other districts. Suzhou’s ancient urban core, recognized as a national historical and cultural preservation zone, sustains these venues through its rich intangible heritage, including Wu folk songs, Suzhou Opera, Suzhou Pingtan, Kunqu Opera, and Guqin—all designated as UNESCO Intangible Cultural Heritage. These traditions have been revitalized through contemporary performance formats.

(2) Libraries and reading facilities demonstrate relatively equitable spatial distribution. High-density zones extend beyond the historic urban center to form continuous clusters around Jinji Lake, Dushu Lake, the Grand Canal, Shishan Scenic Area, and administrative-cultural hubs across districts. Since 2005, Suzhou Library has established 100 branches in collaboration with district governments and subdistrict offices, primarily in Gusu, Huqiu, Xiangcheng, and Industrial Park districts, ensuring service accessibility. In contrast, Wuzhong and Wujiang districts exhibit limited coverage, with only a few district-level libraries and branches.

(3) Public activity facilities display extensive spatial coverage, combining clustered and dispersed distribution patterns. In Gusu District, high-density zones form a contiguous area. The Industrial Park district shows clustering along the western, eastern, and northern shores of Jinji and Dushu Lakes. Huqiu District features high-density zones adjacent to Gusu District and along the Grand Canal, while Xiangcheng, Wuzhong, and Wujiang districts concentrate facilities near administrative-cultural centers. As publicly funded amenities prioritizing equitable access, these facilities are strategically planned to fulfill residents’ basic cultural needs, resulting in broader spatial coverage compared to other categories.

(4) Exhibition facilities exhibit intense clustering in Gusu District and its periphery, transitioning to uniform point-based distribution in outer regions. Within Gusu’s ancient urban core, facilities are densely aggregated and gradually expanding outward. The Industrial Park district hosts numerous venues along Jinji Lake. Wuzhong and Wujiang districts feature clusters along the Taihu Lake Ecological-Cultural Belt and East Taihu Cultural Core Zone, while Xiangcheng and Huqiu districts display evenly distributed nodes. Gusu District, as China’s sole nationally protected historical and cultural city, boasts diverse exhibition resources. The Taihu Lake Ecological-Cultural Belt and Grand

Canal Cultural Belt—the latter leveraging UNESCO World Heritage status—host specialized museums highlighting regional ecology, canal history, and Suzhou’s cultural legacy.

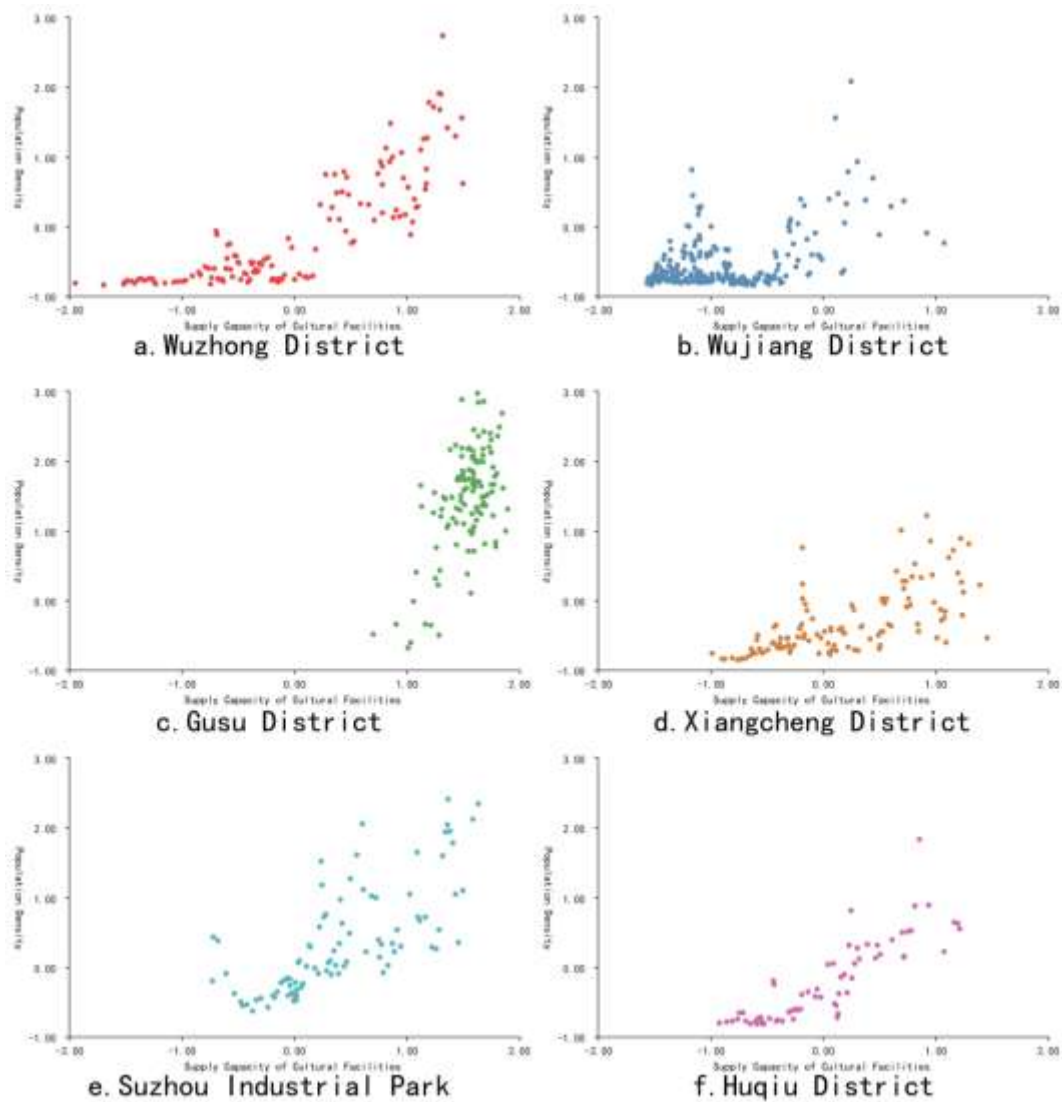


**Figure 3.** Kernel Density Analysis of Public Cultural Facilities

### 3.2. Supply-Demand Relationship of Public Cultural Facilities

The enhanced Gaussian Two-Step Floating Catchment Area (Ga2SFCA) model measures accessibility based on the interaction between supply and demand. Prior to accessibility analysis, supply-demand relationships are visualized using scatterplots, where supply is quantified as the time-decay-weighted sum of cultural facility capacities within each demand unit, and demand is represented by population density. Both variables are normalized via Z-score standardization.

As shown in Figure 4, the majority of demand units exhibit either low-supply-low-demand or high-supply-high-demand patterns, with significant inter-district variations.



**Figure 4.** Scatter Plots of Public Cultural Facility Supply-Demand Relationships Across District-Level Demand Units

### 3.3. Accessibility Analysis of Public Cultural Facilities

Accessibility values for four facility categories are calculated using the enhanced Ga2SFCA model, visualized in ArcGIS with natural breaks classification (Figure 5).

#### 3.3.1. Performing Arts Venues

Accessibility averages 74.47 (SD = 51.43), exhibiting a monocentric spatial structure radiating from Gusu District. Gusu demonstrates the highest accessibility with minimal intra-district variability, while the Industrial Park ranks second but shows pronounced internal disparities, with elevated accessibility near Gusu and the Jinji/Dushu Lake areas. Huqiu, Xiangcheng, Wuzhong, and Wujiang Districts exhibit low overall accessibility, limited to moderate levels in proximal urban cores.

#### 3.3.2. Libraries

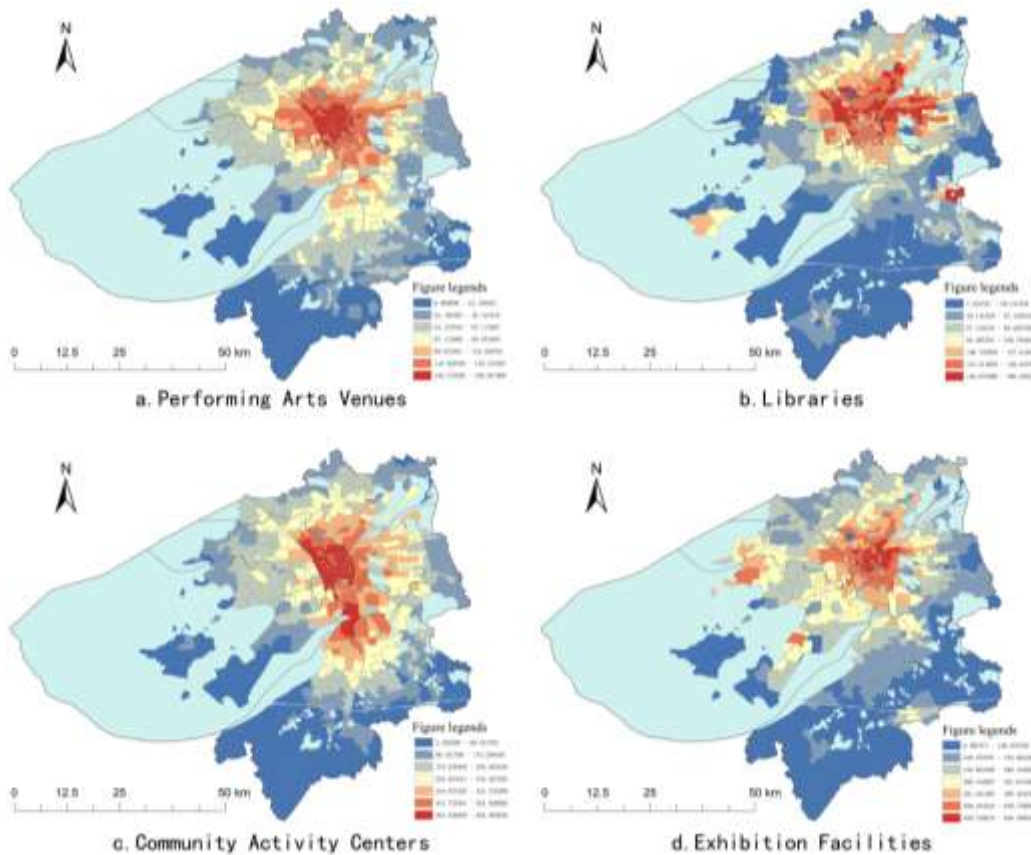
Accessibility averages 86.75 (SD = 41.44), with high-value zones concentrated in northern Gusu. Absence of Suzhou Library branches in Wuzhong and Wujiang results in low accessibility, though Wuzhong's urban fringe outperforms its rural periphery. Gusu, the Industrial Park, Xiangcheng, and Huqiu exhibit balanced library distributions and higher accessibility, with Gusu showing the most equitable spatial pattern.

### 3.3.3. Community Activity Centers

Accessibility averages 293.92 (SD = 196.98), peaking in Gusu and extending to administrative cores in Wuzhong and Wujiang. Gusu maintains high, evenly distributed accessibility. The Industrial Park, Xiangcheng, and Huqiu display moderate accessibility concentrated near Gusu, while Wuzhong and Wujiang's peripheral rural zones—dominated by ecological/agricultural land—exhibit minimal accessibility due to low population density.

### 3.3.4. Exhibition Facilities

Accessibility averages 291.26 (SD = 206.03), with high-value clusters in Gusu and adjacent units. Despite Gusu's dominance, exhibition facilities exhibit the highest variability. Wuzhong achieves moderate accessibility owing to its Taihu Lake eco-cultural corridor, outperforming other facility types.



**Figure 5.** Accessibility Analysis of Public Cultural Facilities by Facility Type

## 3.4. Cluster Analysis of Accessibility and Supply-Demand Patterns

Post Z-score normalization of three variables—composite accessibility, aggregated supply capacity, and population density—K-means clustering (k=3) optimizes the error sum of squares (SSE) and silhouette coefficients. ANOVA confirms significant inter-cluster differences. Cluster centroids (Table 3) define three patterns: high-supply-high-demand-high-accessibility, high-supply-low-demand-high-accessibility, and low-supply-low-demand-low-accessibility.

Spatial Distribution (Figures 6–7):

High-supply-high-demand-high-accessibility units (21.02%, 165 units): Concentrated in Gusu's urban core, benefiting from dense cultural resources and transportation networks despite high population density.

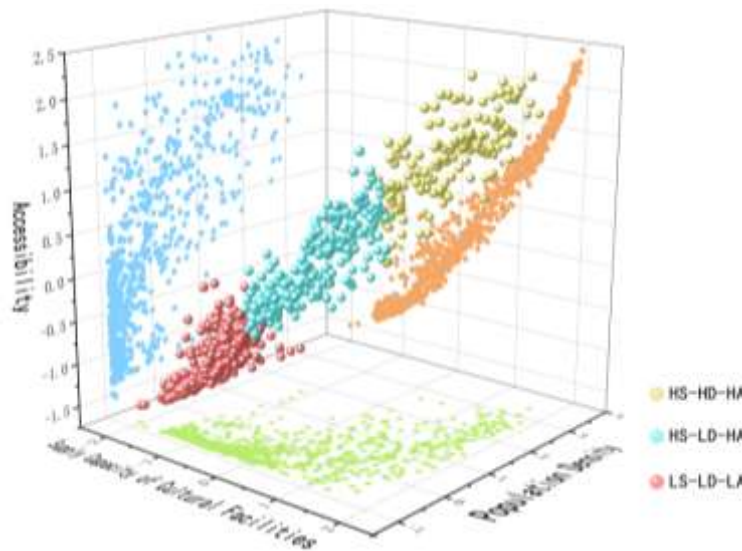
High-supply-low-demand-high-accessibility units (29.81%, 234 units): Form a ring around the core, leveraging proximal cultural infrastructure and Gusu’s spillover effects.

Low-supply-low-demand-low-accessibility units (49.17%, 386 units): Predominant in distant suburbs dominated by agricultural/ecological land, with sparse facilities and high inter-urban travel costs.

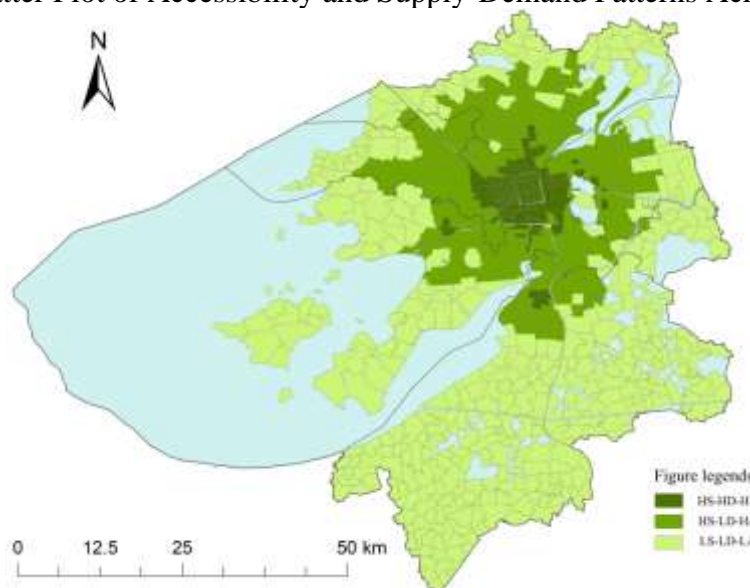
**Table 3.** Final Cluster Centers of Public Cultural Facility Accessibility, Service Capacity, and Population Density

Category	Frequency Count	Percentage	Composite Accessibility Index	Facility Service Capacity	Population Density
HS-HD-HA	165	21.02%	1.437	1.38	1.62
HS-LD-HA	234	29.81%	0.375	0.448	-0.085
LS-LD-LA	386	49.17%	-0.842	-0.861	-0.641

Note: Composite accessibility, comprehensive facility service capacity, and population density variables were Z-score standardized. The K-means clustering analysis yielded a Sum of Squared Errors (SSE) of 463.624 with an average silhouette coefficient of 0.636.



**Figure 6.** 3D Scatter Plot of Accessibility and Supply-Demand Patterns Across Demand Units



**Figure 7.** Clustering Results of Accessibility and Supply-Demand Patterns Across Demand Units

## 4. SUMMARY

This study evaluates the accessibility of public cultural facilities in Suzhou City, focusing on performing arts venues, libraries, community activity centers, and exhibition spaces. By integrating high-resolution population grids, Amap API-derived travel costs, and an enhanced Gaussian Two-Step Floating Catchment Area (Ga2SFCA) model, we systematically assess accessibility and employ K-means clustering to uncover spatial disparities. Key findings are as follows:

(1) Enhanced Ga2SFCA Model: The refined model addresses critical limitations of traditional approaches, including oversimplified supply capacity metrics, coarse demand unit resolution, and idealized travel cost assumptions. By incorporating a multidimensional service capacity evaluation system, machine learning-generated population grids, and real-world commuting data from the Amap API, the model improves accuracy across supply, demand, and transportation dimensions.

(2) Spatial Heterogeneity in Accessibility: While Suzhou exhibits high overall accessibility, spatial equity remains suboptimal, with accessibility declining sharply from the urban core (Gusu District) to peripheries. Gusu's dense cultural infrastructure ensures superior accessibility despite high population density, while the Taihu Lake eco-cultural corridor in Wuzhong District achieves moderate accessibility due to concentrated exhibition facilities. Peripheral areas, characterized by sparse urban development and weaker transportation networks, show significantly lower accessibility.

(3) Cluster-Based Supply-Demand Patterns: Demand units are classified into three clusters (HS-HD-HA units, HS-LD-HA units, and LS-LD-LA units). Tailored strategies—such as decentralizing facilities in low-accessibility zones or optimizing transit networks in high-demand areas—can enhance equity based on local conditions.

## CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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