

GIS-based Study on Urban Spatial Distribution and Geographic Coverage of Public Library Main-Branch Systems: Postprint

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Abstract

[Purpose/Significance] The spatial distribution and geographic coverage of the main-branch public library system hold significant importance for achieving universal coverage and equalization of public library services. [Method/Process] Based on an interpretation of “universal coverage” and “equalization” in the context of the spatial distribution and geographic coverage of main-branch public library systems, this study employs GIS tools to calculate and analyze the spatial distribution and geographic coverage status of Suzhou’s public library main-branch system, using Suzhou as a case study, in order to plan the future layout of main-branch libraries. [Results/Conclusion] Measuring the dynamic service load and service radius of main-branch public libraries can effectively reveal blind spots in their layout, identify priority areas for construction and development, further reduce inter-regional service disparities, and establish urban coverage standards. However, it is also necessary to adapt to local conditions by integrating user population numbers and demand characteristics, thereby achieving scientific layout and precise services to enhance the overall effectiveness of the main-branch public library system.

Full Text

Preamble

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Research on Urban Spatial Distribution and Geographic Coverage of Public Library Main-Branch Systems Based on GIS

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Abstract

[Purpose/Significance] The spatial distribution and geographic coverage of public library main-branch systems are of great significance for achieving full coverage and equalization of public library services. **[Method/Process]** Based on an interpretation of “full coverage” and “equalization” in the context of public library spatial distribution and geographic coverage, this study employs GIS tools to calculate and analyze the spatial distribution and geographic coverage of Suzhou’s public library main-branch system, using Suzhou as a case study to inform future layout planning. **[Result/Conclusion]** Measuring the dynamic service load and service radius of public library main-branch systems can effectively reveal blind spots in library layout, determine priority construction and development areas, further narrow service disparities between regions, and establish urban coverage standards. However, it is also necessary to adapt measures to local conditions by integrating the quantitative characteristics and demand patterns of service populations to achieve scientific layout and precise service delivery, thereby improving the overall efficiency of the public library main-branch system.

Under the development goal of establishing a modern public cultural service system that covers urban and rural areas, is inclusive, ensures basic services, promotes equalization, and is sustainable, the trend in China’s public library development is the extension of main-branch library construction to the grassroots and community levels, gradually forming a comprehensive and equalized public library main-branch system that expands from points to areas. Different regions have developed distinct construction models adapted to local conditions. Meanwhile, with increased national investment in public services, higher requirements and richer connotations have been placed on full coverage and equalization in public library development.

However, administrative divisions and tiered fiscal systems continue to constrain the development of public library main-branch networks, and disparities remain in the layout of public cultural service systems. From the perspective of service objects, achieving full coverage of library services and equalization of library access requires starting from universal equality in geographic space and revealing the scientific and rational basis for urban public library network construction. This study aims to address the imbalance and insufficiency in urban public library main-branch layout by providing evidence for determining priority construction and development areas, further narrowing regional service gaps, and setting urban coverage standards. Only then can full coverage and equalization of public library services be realized.

The goal of providing equitable information resources for all citizens requires that public library main-branch systems not only establish at least one library

or reading room in every community and administrative village according to administrative divisions—achieving the “from scratch” establishment of libraries and supporting facilities—but also achieve comprehensive coverage of administrative regions in layout, enabling all service populations to access library services equally and conveniently [1].

Yet measuring full coverage and equalization in a region cannot be limited to simply considering whether libraries exist. More precise evaluation of library quantity, coverage area, and service population is necessary. Public library main-branch systems should implement supply-side structural reform concepts, focusing on resolving issues of unbalanced and insufficient development between regions and populations, and eliminating barriers to universal equality.

2. Interpretation of “Full Coverage” and “Equalization” in Public Library Main-Branch Spatial Distribution and Geographic Coverage

2.1 Accessibility in Full Coverage and Equalization

Accessibility can be defined geographically as “the distance between one location and other designated locations.” In fact, numerous social science disciplines—including psychology, economics, and political science—have interpreted accessibility from their specific disciplinary perspectives. The common concern across these disciplines is identifying factors that facilitate or restrict user access to specific activities or services. Physical accessibility is considered a fundamental measure of freedom to participate in activities, serving as a basic indicator of whether equal opportunities exist. The Public Library Manifesto explicitly articulates the equalization and universalization of public libraries, stating that “public libraries should provide equal services to all people regardless of age, race, gender, religion, nationality, language, or social status.” So-called universal and equal public library services mean that a national or regional public library service system can ensure that all residents, regardless of socioeconomic status, age, gender, physical condition, race, religion, or other distinctions, can access needed knowledge, information, cultural resources, and other library services nearby [3]. However, from a geographic perspective, although public libraries impose no restrictions on service objects, this does not mean that opportunities to use libraries are equal under the influence of geographic spatial factors. Meanwhile, users differ in their distance from libraries and their acceptable spatial distances and time costs. For example, Guangzhou Library’s 2014 *Urban Public Library Services and Reader Reading Behavior Survey Report* indicates that nearly 70% of readers traveled more than 15 minutes to reach the library, representing a significant gap from the ideal distance of within 15 minutes [4]. Library location distribution directly affects whether public libraries effectively cover all areas and whether users can equally access libraries. This is particularly true as main-branch systems continuously extend to communities and streets, forming a more convenient library network. This constitutes fundamental content for an-

alyzing public library network system distribution and improving point-to-area library network planning. Applying Geographic Information Systems (GIS) in public library layout can achieve quantification, visualization, and precision.

2.2 GIS Application in Library Spatial Research

GIS applications in libraries can map user physical addresses and areas, identify and display service regions on maps, and greatly benefit improvements in library service efficiency [5-6]. GIS functionality is powerful; integrating transportation networks, demographic statistics, planning zones, and other data will yield new insights for library planning, distribution, and resource and service allocation [7]. For example, integrating GIS with demographic data can facilitate library planning and allocation of characteristic resources and services [2]. Regarding library layout and provision, geographic distribution studies of public libraries nationwide reveal relationships between library development and regional development, exposing inter-state disparities in the United States from a geographic distribution perspective [8]. Additional research utilizes GIS to measure equity in library utilization and access within specific regions [9-10]. GIS application in library and information science has only just begun, and existing library accessibility studies are mostly found in Western contexts, possibly due to the lack of open and free data [11]. Compared with developed countries, China faces certain difficulties in data collection and processing, with numerous constraints imposed by raw data availability.

3. Spatial Distribution and Coverage of Public Library Main-Branch Systems

3.1 Relationship Between Spatial Distribution and Accessibility of Public Library Main-Branch Systems

Domestic and international research has already paid considerable attention to library geographic distribution. Early studies identified library geographic location as a factor affecting library use [12-14]; research on library site selection [15] has also focused on this issue. Over the past two decades, library geographic space research has deepened further, concentrating on measuring distances between users and their most frequently used local public libraries to analyze public library accessibility. Library spatial accessibility significantly correlates with library use, meaning that higher spatial accessibility typically accompanies increased library utilization [7]. From an overall urban perspective, improving the accessibility and convenience of public library main-branch systems for residents—making it easier for urban residents to use nearby libraries—can influence the overall opportunities, frequency, and perceived value of library use across the entire city [16].

Consequently, scholars have proposed relative accessibility and integral accessibility. The former refers to “the degree of connection between two places on the same surface,” which is frequently applied in public library site selection

to consider facilitating more convenient library access for users within specific service areas. Integral accessibility refers to a point's "interconnection degree" with all other points [17], which is more suitable for weighing the rationality of main-branch layout within a region. Since every node in a main-branch system is open to all residents within a city, its essence is measuring the public service guarantee capacity reflected in a city's library layout. While resource guarantee capacity is typically considered an important foundation for library service capacity, the distribution of public library main-branch systems is the prerequisite for the physical layout of resources. The main-branch system layout directly relates to users' awareness of, access to, and convenience in obtaining collection resources within a region.

3.2 Standards and Basis for Accessibility

Currently, there is no clear and unified standard for defining the coverage scope of public libraries. From domestic and international development situations, coverage is typically determined using administrative divisions, access distance and time, or access distance and service capacity to define public library coverage scope [18].

3.2.1 Administrative Divisions This primarily refers to whether grassroots libraries or the administrative regions where main-branch nodes are located have been recognized by the government as the library's coverage area. This meaning of "full coverage" applies to judgments about public library construction from scratch on a national or large regional scale. Moreover, without considering the area and population of administrative divisions, it can serve as a rough basis for quantity-oriented judgment of overall public library layout. Its equalization implies that every county, district, etc., has public library provision at the administrative division level, achieving uniformity and equality across administrative divisions. During China's Tenth Five-Year Plan period, the goal of having libraries in every county was already achieved. Currently proposed universal equality, full coverage, and equalization require more precise extension to the grassroots level.

3.2.2 Access Distance and Time This approach primarily starts from service object accessibility, determining library coverage scope based on service objects' access distance and acceptable time. It defines "full coverage" from the actual possibility of readers reaching libraries, with equalization meaning that every service object can access libraries nearby within a certain distance range and at acceptable time cost. However, public library area, resources, and other service capacity bearable are not considered in measuring full coverage and equalization. Reference indicators include public cultural service circles, among others.

3.2.3 Access Distance and Service Capacity The service capacity of public library main-branch nodes and accessibility guarantees actual service effec-

tiveness for service objects. China's *Public Library Construction Standards* and *Public Library Construction Land Indicators* officially implemented on November 1, 2008, established reference standards for public library service capacity (area, collection volume, and reading seats), service population, and access distance [19]. This approach faces the following difficulties in precise practical operation: First, the basis for establishing public libraries is difficult to obtain with precise data. Articles 16 of the *Land Indicators* and 11 of the *Construction Standards* determine public library construction scale according to service population, with set brackets of 1.5 million people and 200,000 people. However, in the process of extending main-branch libraries to communities, grassroots and community population statistics involve multiple measurement systems and rapidly changing data, making it difficult to serve as a basis for precise estimation of main-branch node construction scale. Similarly, 200,000 people as the basic service population unit for public library establishment is clearly inapplicable in grassroots community extension. In the public library scale classification, county-level libraries are small libraries, with the *Construction Standards* establishing an interval of 300–800 square meters [20] for service populations under 200,000 [20]. However, this standard cannot serve as a basis in main-branch library establishment. Many public library branches in Suzhou have a basic area of 200 square meters, with some self-service libraries only 50 square meters, making it difficult to evaluate service scope and radius using existing standards. In the process of achieving full coverage and equalization at the grassroots community level, the measurement basis and evaluation methods require new theoretical and practical guidance. The “full coverage” goal of public library service systems must be built upon actual service capacity [18]; the “equalization” of public library service systems requires precisely targeting service areas and service objects.

4. Spatial Distribution and Coverage Indicators in Public Library Standards

4.1 Service Radius

Users' tolerance for distance and time to reach libraries is limited [20]. Regarding library geographic coverage, certain standards can be set to determine service geographic radius, delineate the farthest distance for users to reach libraries, and determine main-branch quantities. From the perspective of population coverage, the ratio of population that must be served by establishing a library or corresponding library scale (area, collections, etc.) can be determined. The service radius proposed in the *Land Indicators* refers to the geographic scope radiated by library services [21], determined by the farthest linear distance for readers to reach public libraries. Readers within this distance range are typically considered to conveniently access and use libraries, enabling effective library coverage of readers [19].

4.2 Foreign Service Radius Requirements

Lenin believed that library services should be available to every citizen within no more than 1.5–2 versts (approximately 1.6–2.1 km) from residential points [19]. *Serving Our Public 3.0: Standards for Illinois Public Libraries* states that “libraries (including branches or other service points) should be located in the most convenient places in the community” [22]. Wisconsin standards stipulate library service radius by calculating driving time, specifying that all residents in the service jurisdiction can access library facilities at any time—within 15 minutes driving in urban areas and within 30 minutes in rural areas [23]. A 2015 GIS survey and evaluation across U.S. states found that after weighted averaging of population with access to the nearest public library, the distance was 2.1 miles (approximately 3.38 km), with substantive regional variations in public library accessibility [24]. The UK public library service standard *Comprehensive, Efficient and Modern Public Libraries—Standards and Assessment* uses the ratio of households within a certain distance of fixed libraries as an indicator: in inner London, 100% of households can reach a library within 1 mile; in outer London, 99% within 1 mile; in metropolitan areas, 95% within 1 mile and 100% within 2 miles; in borough areas, 88% within 1 mile and 100% within 2 miles; in county areas, 85% within 2 miles; and in sparsely populated areas, 72% within 2 miles. Areas and populations not covered by fixed libraries are supplemented by mobile libraries and “other library service forms” [25].

4.3 Domestic Public Cultural Service Circle Radius Requirements

How to make it more convenient for the general public to utilize libraries nearby, and how to enable the rich collections of central libraries and characteristic collections of branch libraries to meet the needs of readers in different areas and groups throughout the city, maximizing collection resource benefits—these are new propositions for the further development of urban central libraries [23]. Particularly in improving public cultural service systems, many cities have proposed the concept of public cultural service circles and established standards for public library layout. Shanghai’s *Shanghai Urban Master Plan (2017–2035)* requires that “district-level public service facilities be allocated by central city administrative districts, main city districts, and urban circles, and community-level public service facilities be allocated by community life circles. By 2035, the 15-minute walking coverage rate of community public service facilities such as health, elderly care, education, culture, and sports will reach approximately 99%” and that “each community life circle should be equipped with at least one community cultural activity center and one community library” [26]. In 2017, Suzhou Industrial Park gradually constructed and improved a three level linkage system of physical, virtual, and social networks in its public library main-branch system layout, creating a “10-minute reading circle” [27]. Shenzhen’s Futian District has formed a “1-kilometer cultural circle,” meaning that from any location in Futian District, within a 10-minute walk (1 km), residents can find libraries, museums, concert halls, central bookstores, and other public cultural service fa-

cilities [28]. These requirements demonstrate that libraries need overall layout to achieve universal equality in geographic space distribution.

5. Investigation of Urban Public Library Main-Branch Spatial Distribution and Coverage—A Suzhou Urban District Sample

5.1 Overview of Public Library Main-Branch Construction in Suzhou Urban Districts

Suzhou is a pioneer city in public library main-branch development in China, emphasizing the construction of a public library service system covering urban areas and forming the nationally influential “Suzhou Model” [29]. Suzhou urban districts comprise six districts: Gusu, Xiangcheng, Wuzhong, Industrial Park, Huqiu (High-tech Zone), and Wujiang. Suzhou Library primarily undertakes branch construction in Gusu, Xiangcheng, and Huqiu (High-tech Zone), while branch construction in Industrial Park, Wuzhong, and Wujiang is mainly undertaken by their respective district libraries—for example, public library branches in Wuzhong District are planned and constructed by Wuzhong District. As of September 2019, Suzhou Library had 1 main library, 99 branch libraries, 2 24-hour self-service libraries, 4 rail transit libraries, and 103 community delivery points for online borrowing. To understand the distribution of Suzhou’s public libraries, geographic coordinates of main-branch libraries in each district were obtained and marked in the ArcGIS system to display the distribution of the main-branch system across urban districts. Since Suzhou urban districts have numerous water systems, water area was further marked to correct visualization bias, as shown in Figure 1 [Figure 1: see original paper].

Note: The map annotations use local Suzhou colloquial expressions, but accurate administrative region names follow the legend.

5.2 Distribution Density of Suzhou Public Library Main-Branch System

Due to varying district areas, library scales, and population densities, public library coverage cannot be judged by quantity alone. Distribution density is calculated separately by geographic area and by population.

(1) **Distribution density of public library main-branch system by regional area (area density)**

δ_s : Library area density (square meters/square kilometer)

Ls: Total library area

Ds: Area where the library is located

(2) **Distribution density of public library main-branch system by regional population (population density)**

δ_{sp} : Library area population density (square meters/thousand people)

Ls: Total library area

Dp: Population of the area where the library is located (thousand people)

Based on publicly available data from library websites of Suzhou districts, public library areas in Gusu District, Industrial Park, Xiangcheng District, and High-tech Zone were compiled (data for the other two districts were not publicly available). After obtaining the total public library area for the four districts, area density and population density were calculated for each district (see Table 1). Overall, library area in each district shows a positive correlation with district area, with service loads being relatively similar across districts except for Gusu District.

Table 1. Distribution Density and Service Load of Suzhou Public Libraries

Districts	Area (km ²)	Population (thousand) Dp*	Library Area Ls (m ²)	Area Density (m ² /km ²) δs	Population Density (m ² /thousand people) δsp	Service Load Ss (km ² /m ²)	Theoretical Service Radius Average (km)
Gusu	105.45	479.77	34.14	0.0032	0.0711	3.0886	0.99
Industrial Park	121.40	106.96	37.15	0.0089	0.3474	0.1124	0.59
Xiangcheng	38.22	71.84	38.22	0.0093	0.5320	0.1075	0.58
High-tech Zone	34.14	37.15	38.22	0.0095	0.8716	0.1054	0.58

Note: Population data are permanent resident statistics for Suzhou districts as of December 31, 2018. Data source: http://www.tjcn.org/tjgb/10js/36013_3.html, accessed September 15, 2019.

5.3 Service Radius of Suzhou Public Library Main-Branch System

By calculating the service load per unit library area—that is, how much geographic area each unit of library area serves—differences in unit library service load across districts become apparent. These differences arise because varying investment in main-branch construction across administrative divisions leads to different numbers and areas of public libraries, resulting in different service loads.

Through service load calculations, the current service area and service radius for each library can be determined (due to the large number of libraries, these are not presented in tabular form). Mapping these reveals blind spots and overlaps in public library service network coverage. The significance of theoretical service radius lies in showing how large an administrative area each public library main-branch should serve based on regional unit library area service load conditions.

Its essence is to express, through service load conditions, the baseline library service capacity that regional libraries should possess. Service load only reveals the bearing condition of regional library service area from a geographic coverage perspective. When the service load value is large, indicating that each unit of library area should serve a large geographic area, consideration should be given to increasing library quantity or improving unit library service capacity (area, resources, space, etc.). Large service areas must consider acceptable distance ranges and time costs for service objects near libraries. When the service load value is small, each unit of library area serves a small geographic coverage range, suitable for layout in densely populated areas.

Service Load Formula:

$$S_s = D_s / L_s$$

Where S_s is service load (library unit area service area, km^2/m^2), L_s is total library area, and D_s is area where the library is located.

Theoretical Service Area Formula:

$$T S_s = S_s \times L_s = \pi r t^2$$

Where $T S_s$ is theoretical service area per library (km^2), S_s is unit library area load, L_s is individual library area, and $r t$ is individual library theoretical service radius.

Calculations for each of the 207 libraries in four Suzhou districts reveal an average theoretical service radius of 1.03 km, a median of 0.78 km (less than 1 km), with 80% of library nodes having a service radius within one kilometer and a standard deviation of 1.51. This indicates a service circle of approximately a 12-minute walk or 6-minute bicycle ride for residents. As shown in Figure 2 [Figure 2: see original paper], shaded areas represent regions covered by the public library service network. From the mean service radius of individual libraries in each district, significant differences exist among districts (see Table 1), and some areas (regions beyond diagonal lines) remain uncovered by the public library service network, representing priorities for new branch layout.

6. Analysis of Urban Public Library Main-Branch Spatial Distribution and Geographic Coverage

6.1 Dynamic Service Load and Service Radius of Public Library Main-Branch Systems

Calculating dynamic service load and dynamically setting service radii for public library main-branch systems can reveal overall coverage conditions. This approach leverages the linkage effects between different nodes in the service system and helps overcome administrative division constraints. This enables standardized and equalized services provided by different nodes to eliminate, to some extent, impacts from administrative division constraints, allowing service objects to equally and freely access public libraries nearby. On one hand, it can measure whether the public library main-branch network covers the entire

region, identifying areas where library layout needs strengthening—for example, the northern and northeastern parts of Industrial Park and northern Gusu District in Figure 2. On the other hand, dynamic service radii can coordinate the relationship between branch quantity and service system quality, shifting focus from branch numbers to more effective branch layout to achieve overall regional improvement in full coverage and equalization quality.

As shown in Table 1, population density is an important reference indicator for actual service load and service radius in public library layout. In areas with high population density, unit library actual service load should be appropriately reduced and service radius shortened. However, population density has not been used as a specific indicator in calculating public library main-branch spatial distribution and geographic coverage. This is because, on one hand, public library main-branch establishment is based on potential user numbers—that is, permanent residents in the service area. As public library main-branch layout sinks to the grassroots community level, precise population data and demand conditions require supplementary community field surveys. When planning public library main-branch node layout, geographic space, library area allocation, and service population should be integrated to improve planning methods and processes, providing more feasible allocation and service solutions. On the other hand, comprehensive consideration of service population, service load, and service radius can determine the priority level of main-branch establishment. In Table 1, Xiangcheng District has nearly double the population density of other areas and relatively high service load, making it a priority area for public library main-branch network layout. The recent preparation and opening of Suzhou's second library will greatly improve public library coverage in Xiangcheng District, demonstrating from one perspective that Suzhou's actual practice aligns with evaluation data on public library spatial distribution and geographic coverage.

6.2 Regional Disparities in Public Library Main-Branch Distribution and Coverage

GIS application not only provides visual revelation of public library main-branch coverage conditions but also reflects, to a certain extent, disparities in distribution and layout among Suzhou's districts. As shown in Figure 3 [Figure 3: see original paper], each district has areas requiring library layout and extension. Overall, High-tech Zone has relatively high public library node coverage and maintains rapid growth. Between September 2018 and September 2019, six new branches were added—the fastest growth among all districts—further improving public library service system accessibility. Meanwhile, differences in branch coverage are influenced by variations in main-branch construction models and investment. Among Suzhou's districts, Gusu District, High-tech Zone, and Xiangcheng District have branches uniformly constructed by Suzhou Library, with administrative coordination by Suzhou Library and fiscal implementation through separate district budgets, where investment levels directly manifest as

differences in branch quantity and coverage. Industrial Park, Wuzhong District, and Wujiang District have main-branch systems planned and constructed by their respective district libraries, with greater autonomy for each district's main library, resulting in different characteristics. For example, Industrial Park promotes deep layout and service extension to the grassroots level of public library nodes through community reading room construction.

Therefore, coordinating Suzhou's overall main-branch construction and distribution requires a "whole chessboard" approach, establishing a user-centered coordination mechanism based on actual conditions. This represents a key focus and difficulty for future public library full coverage and equalization. Calculating overall service load and service radius means for Suzhou's public libraries facilitates the formation of dynamic standards aligned with development realities, providing valuable reference for establishing cross-district collaborative standards for public library main-branch spatial distribution and geographic coverage.

6.3 Precise Identification of Service Areas and Service Objects for Public Libraries

As seen in Figure 2, while reasonable overlaps exist considering population density and library feasibility, each district also has areas of unreasonable overlap. Within each public library main-branch node's coverage area, numerous factors affect library utilization, but distance is a significant factor. Physical accessibility factors are highly positively correlated with library use [7]. Scientific and precise layout of public library main-branch systems requires further accurate data collection and analysis of service object quantitative characteristics, access needs, and behavioral habits. This study only uses linear service radius to preliminarily delineate coverage areas of public library main-branch systems, providing initial basis for overall planning of public libraries in specific regions. Subsequent research must measure actual paths for service objects to access public libraries through GIS before conducting specific planning and allocation for libraries. With clear service areas and service objects, librarians can create user profiles and achieve precision services from a user-centered perspective. This approach continuously promotes high-quality planning of public library main-branch systems [30], systematically advancing full coverage and equalization while improving overall effectiveness.

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Author Contributions

Xu Wei: Conceptualized the paper structure and wrote the initial draft.

Li Zhuozhuo: Conducted data collection and GIS modeling, selected the research topic.

Ding Jiayou: Handled formulas and revised the paper.

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