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Application of Geographic GIS Technology in Population Spatial Distribution Analysis and Public Service Resource Allocation

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ABSTRACT
Against the backdrop of accelerating urbanization intertwined with demands for social equity, the spatial precision of public service resource allocation has emerged as a core indicator for assessing urban governance capacity and public welfare. This paper deconstructs the theoretical framework and practical paradigms of Geographic Information System (GIS) technology in analyzing population spatial distribution and optimizing public service resource allocation. The research systematically elucidates the methodological advantages of GIS spatial analysis in revealing the geographical coupling patterns between population and resources, while critically pointing out the functional deficiencies of existing statistical methods in identifying micro-spatial units, objectively quantifying facility accessibility, and simulating development scenarios. It innovatively proposes a three-pronged technical integration pathway to bridge this cognitive gap: high-precision population distribution modeling, multidimensional assessment of public service coverage effectiveness, and constructing a three-dimensional GIS decision support platform.

KEYWORDS
Geographic Information System (GIS) technology; Population spatial distribution; Public service resource allocation

1 Introduction

As spatial carriers of human civilization, cities are enduring unprecedented scales of population attraction and systemic pressures. The quality of their intrinsic spatial organization directly determines the fairness of social development and the realization of citizen well-being. In this process, the spatial adaptation efficiency of basic education facilities, healthcare services, public transportation networks, and public green space systems has become a core benchmark for evaluating global urban governance capabilities. This allocation represents a redistribution function of finite public resources within a three-dimensional geographic space, addressing fluid and fragmented social demands. The prevailing practice of single-unit zoning-based resource allocation in China perpetuates the path dependency of total volume and administrative orientation from the planned economy era. Constrained by administrative boundaries, this supply model systematically obscures heterogeneous realities within cities—such as population density gradients, separation of work and residence, and social spatial polarization—ultimately transforming spatial misalignment of educational and healthcare resources into structural social conflicts. A noteworthy theoretical shift is occurring: academic focus is transitioning from debates over the scale of resource supply to discussions about the justice of spatial accessibility and utilization efficiency. This cognitive transformation reveals that the spatial dimension has become the ontological foundation for resolving resource allocation dilemmas. Geographic Information Systems (GIS), constructed based on geospatial data, provide the technical meta-language for reconstructing this spatial governance rationality.

2 Theoretical logic of GIS technology application in population analysis and resource allocation

2.1 Core functions of GIS technology in spatial data analysis

Geographic Information Systems (GIS) fundamentally constitute an integrated technical framework for spatial data collection, management, analysis, and visualization. Their core value lies in profoundly revealing geographic phenomena, distribution patterns, and associative mechanisms, far surpassing traditional cartography's scope. Its key technological advantages manifest in three dimensions: First, in heterogeneous data integration, it achieves unified geographic coordinate referencing and spatial overlay for demographic statistics, land use types, transportation network data, and infrastructure locations [1]. Second, spatial modeling operations provide quantitative analysis methods such as buffer zone threshold delineation, transportation network capacity assessment, and resource distribution heterogeneity detection. Finally, spatial cognition support translates abstract indicators into visual forms like heat maps and 3D terrain models, significantly enhancing decision-making efficiency. This technology fully realizes the closed-loop transformation from raw geographic data to spatial decision knowledge .

2.2 Coupling relationship between population spatial distribution and public service resource allocation

Geographic Information Systems (GIS) fundamentally constitute an integrated technical framework for spatial data collection, management, analysis, and visualization. Their core value lies in profoundly revealing the distribution patterns and associative mechanisms of geographic phenomena, far exceeding the scope of traditional cartography. Key technological advantages are concentrated in the following aspects: First, at the heterogeneous data integration level, GIS enables the unified georeferencing and spatial overlay of demographic statistics, land use types, transportation network data, and infrastructure point locations. Second, spatial modeling operations provide quantitative analysis methods such as buffer zone threshold delineation, transportation network capacity assessment, and resource distribution heterogeneity detection. Finally, spatial cognition supports transforming abstract indicators into visual forms like heat maps and 3D terrain models, significantly enhancing decision-making efficiency. This technology fully realizes the closed-loop transformation from raw geographic data to spatial decision knowledge.

2.3 GIS technology as the methodology for achieving precise alignment

Geographic Information Systems (GIS) provide the technical framework for resolving spatial mismatches between population and resources. Its methodology fundamentally involves spatial simulation and regulatory experimentation of complex urban systems. At the foundational level, it implements a refined reconstruction of population distribution. By integrating mobile signaling activity intensity, building 3D contours, and land use classification features through kernel density estimation algorithms, it constructs a 100-meter grid-based dynamic population surface model. This model overcomes the limitations of administrative unit statistical thresholds, precisely identifying tidal flows along commuting corridors and diurnal demand fluctuations in aging communities, providing sub-block-level decision benchmarks for educational and healthcare resource allocation. At the core dimension, it advances a multimodal measurement system for facility service efficiency, integrating a four-dimensional spatial analysis technology chain: ① A real-time traffic flow semantic analysis engine deconstructs time-varying patterns of road capacity; ② A multimodal transfer topology network model quantifies time losses during transfers; ③ A spatial accessibility index for barrier-free facilities assesses coverage gaps for vulnerable groups. By calculating the spatio-temporal effective service radius of facilities like schools and hospitals with millimeter-level precision, the spatial coordinates and population scale of existing service blind spots are precisely located [2].

3 The limitations of traditional population analysis and resource allocation methods

3.1 Traditional statistical data fails to reveal micro-level population distribution patterns

The aggregated administrative district data relied upon by traditional resource allocation paradigms suffers from deep structural flaws. Its spatial homogenization logic forcibly flattens gradient differentiation within regions, resulting in specific information losses: inaccurate spatial localization of micro-density peaks within large residential areas; absence of dynamic monitoring mechanisms for linear settlement belts evolving along transportation axes; masking of diurnal population tidal fluctuations caused by work-residence separation; and systematic filtering of spatial demand signals from special groups. These data flaws generate an administrative center polarization effect in resource allocation during planning practice, manifesting in governance challenges such as: public service vacuums in densely commuted industrial new towns; accelerated population aging in old urban districts with lagging elderly-friendly facility provision; and educational resource shortages in high-density development zones near transit hubs [3]. The root cause lies in the mismatch between spatial statistical units and the scale of residents' daily life spheres, preventing genuine demands emerging during urban spatial reproduction from being reflected in governance decisions. The solution requires reconstructing a micro-data collection system based on human activity trajectories, shifting population statistical units from static administrative divisions to dynamic behavioral geographic grids.

3.2 Decision-making lacks scientific assessment of spatial accessibility and service coverage

Traditional facility service effectiveness evaluations suffer from dual methodological disconnects. Their conceptual framework rests on two flawed assumptions: geometric spatial proximity equates to service accessibility, and static facility capacity substitutes for sustained service quality. This paradigm severely overlooks the multifaceted mechanisms of spatial friction: the exponential increase in detour costs due to road network topology defects; cumulative energy dissipation from vertical topography; time fragmentation losses from multimodal transfer mismatches; and invisible access barriers constructed by socioeconomic barriers. Cognitive gaps and technological limitations jointly cause systemic divergence between planning logic and real-world experience [4]. This manifests in spatial justice issues such as service islands in mountainous urban canyon villages and structural deficiencies in emergency access networks within high-density built-up areas. This necessitates rebuilding an evaluation paradigm grounded in residents' spatiotemporal behavior, incorporating psychologically perceived distance into spatial resistance modeling frameworks.

3.3 Lack of dynamic simulation and visualization support in planning processes

The existing planning system faces an iterative crisis, with technical carriers still confined to two-dimensional paper maps, incapable of simulating the four-dimensional spatiotemporal coupling of population flows and facility services. Decision-making mechanisms remain dominated by an empiricist paradigm, severely lacking quantitative decision support tools for multi-objective collaborative optimization. Evaluation feedback systems suffer significant institutional time lags, hindering timely responses to work-residence spatial restructuring triggered by industrial upgrading. This induces four-fold governance contradictions: significant transportation hubs experience failed public participation due to inadequate visualization; emerging tech parks exacerbate work-residence separation through lagging basic education infrastructure; aging-friendly renovations in historic districts face delays, creating a vicious cycle with rapid population aging; and commercial service gaps in ecological resettlement areas trigger return migration waves. At its core, this reflects a generational gap between instrumental rationality and the complexity of spatial governance, creating a resonance of temporal and spatial mismatches between public service provision and demand in rapidly urbanizing regions.

4 Application pathways for optimizing population analysis and resource allocation using GIS technology

4.1 Achieving detailed population mapping through spatial interpolation and multi-source data fusion

Addressing the spatial inaccuracy of traditional demographic data requires multi-scale conversion techniques within Geographic Information Systems (GIS). The fundamental approach involves downscaling street-level statistics to sub-block units using geographically weighted regression algorithms, leveraging spatial proxy variables such as land cover types and built environment density. More advanced implementations require integrating multidimensional spatiotemporal data: using census data as the spatial baseline, incorporating three dynamic information sources—mobile device location heatmaps, building outline vector datasets, and satellite nighttime light remote sensing imagery—to develop a spatially adaptive allocation algorithm. This algorithm effectively identifies differences in commuter population distribution patterns between day and night, generating regularly updated community-level population density distribution maps. This technical architecture ensures precise representation of micro-scale population spatial heterogeneity while meeting the timeliness requirements for dynamic monitoring of public service demand, providing high-precision decision-making support for educational resource allocation and healthcare facility siting.

4.2 Scientific evaluation of facility accessibility using buffer zone and network analysis methods

Scientifically evaluating the effectiveness of public service resource allocation requires establishing a multidimensional assessment model. Fundamental analysis employs multi-ring buffer zones to identify facility coverage gaps, such as detecting service blind spots in parks. The core technological breakthrough relies on constructing a multi-factor weighted road network model: comprehensively considering elements like road connectivity topology, public transportation transfer convenience, and natural environmental resistance along walking paths to simulate residents' spatio-temporal barriers to healthcare services [5]. The core implementation step spatially couples the generated accessibility grid with population distribution matrices, yielding evaluation outcomes including: dynamic population carrying capacity within each facility's service area, spatial distribution maps of uncovered populations, and regional public service supply equilibrium metrics .

4.3 Building a visualized decision support system to optimize spatial layout

An intelligent decision-making hub system is required to optimize planning response mechanisms. The system framework incorporates a three-tier functional architecture: a foundational data platform integrates dynamic spatiotemporal population sequences, spatial attribute databases of existing facilities, urban commuting network topology models, and future land development plans to establish a four-dimensional geographic information index [6]. The analysis module layer incorporates spatial optimization decision algorithms, supporting multidimensional planning objectives such as maximizing service coverage and enhancing accessibility for vulnerable groups. The visual interaction layer employs immersive 3D scenarios: as planners adjust proposed facility locations within the geographic space, the system instantly generates dynamic cloud maps of changing coverage areas, pie-chart analyses of beneficiary group structures, and gradient renderings of service pressure during peak hours. This real-time simulation mechanism translates abstract planning parameters into intuitive spatial semantics, significantly enhancing major municipal engineering planning proposals' scientific credibility and public trustworthiness .

5 Conclusion

Geographic Information System (GIS) technology, leveraging its spatial computing core and visualization mechanisms, provides a methodological foundation for addressing the governance challenge of spatial mismatches between urban population distribution and public service resources. This technology drives a paradigm shift in resource allocation through three breakthroughs: at the micro level, it deconstructs spatial heterogeneous patterns of population distribution; at the meso level, it quantifies the actual accessibility of facility services; and at the macro level, it establishes dynamic decision-response mechanisms. This technological empowerment enables urban administrators to transcend the limitations of traditional static management models, achieving a systematic restructuring of public service delivery patterns within the spatial dimension.

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