Site Suitability Analysis for a Multi-Speciality Hospital Development in Indore

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Abstract

The selection of optimal multi-speciality hospital sites selection is a critical multi-criteria decision-making challenge in rapidly urbanizing regions especially Indore, directly impacting public health infrastructure and a need of a multi-speciality hospital in this city. Amid rising urban population densities, the demand for new medical facilities underscores the need for meticulous site selection.

This paper presents a geospatial approach integrating Geographic Information Systems with multi-criteria decision-making techniques to identify suitable locations for new hospitals in Indore, India. The methodology overcomes limitations of subjective decision-making by providing a data-driven, objective framework . . Existing hospitals and Primary Health Centres were digitized and mapped in QGIS, revealing non-uniform coverage across the city. This includes urban factors like access to transportation networks like railways and bus ; and socio-economic aspects including population density, existing healthcare distribution, and other super speciality hospital.

The research develops a spatial model using geospatial datasets to automate and prioritize potential hospital sites, systematically evaluating criteria such as population density and infrastructure to enhance accessibility and optimize our model. Ultimately, it equips urban planners with evidence-based insights to improve healthcare provision, promote sustainable development, and address spatial inequalities in developing regions. By tackling challenges like limited land availability and high costs in urbanizing areas, this GIS-based approach ensures strategic placement for maximum public benefit and operational efficiency offering governments and entrepreneurs a competitive edge through a new statistical model called Equitable Accessibility–Dominance Index (EADI). This non-linear, non-compensatory formulation robustly evaluates proximity, balance, and vulnerability, tackling healthcare complexities like distance to existing centres, service quality, and transport connectivity. And finally we got the best site by means of calculation and considering all the necessary factors.

Keywords: GIS, EADI, mapping, network analysis, geospatial

Introduction

Accessibility to healthcare is crucial for societal advancement, yet disparities persist globally. Geospatial techniques aid in assessing and addressing these gaps, ensuring equitable distribution of services.

Methods like GIS facilitate identifying underserved regions and optimizing facility placement. In India, despite progress, healthcare inequality persists. Indore City, the largest city and commercial hub of Madhya Pradesh, India, was selected as the study area (as shown in Figure 2) owing to its rapid urbanisation, substantial population growth, and pronounced spatial disparities in healthcare access, where peripheral and underserved regions face long travel distances to facilities [1], [2], [3], [4]. This context exemplifies the broader challenges in Indian urban centres, where existing infrastructure inadequately serves expanding demographics, necessitating data-driven site selection to enhance equity and efficiency [5], [6], [7], [8]. The analysis focuses on the city's administrative boundaries, incorporating key layers such as population density, road networks, and land use to identify optimal hospital locations [9]. To address this, geographic information systems combined with multi-criteria decision analysis, such as the Analytical Hierarchy Process, offer a robust framework for objectively evaluating potential hospital locations [5], [6].

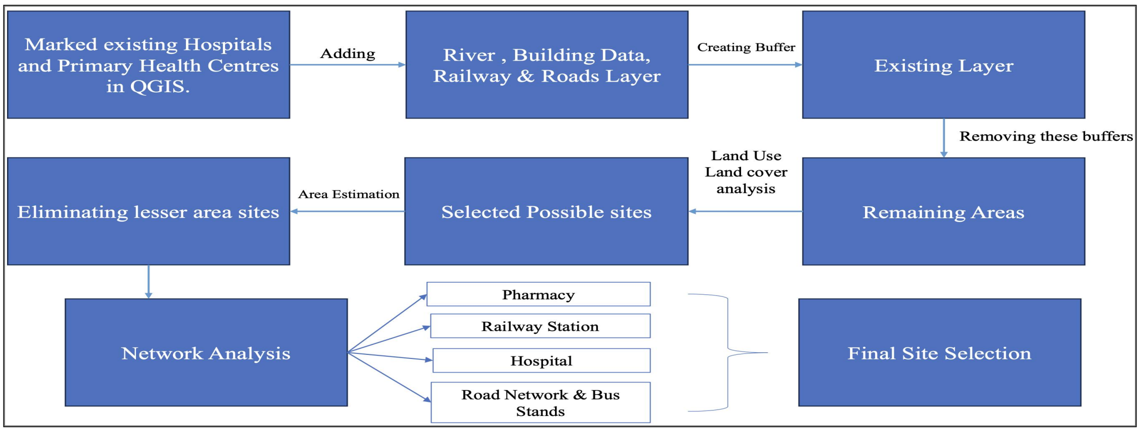

Figure 1: Flowchart illustrating the complete process.

This integrated approach allows for the systematic consideration of diverse factors, ranging from population density and existing healthcare infrastructure to environmental considerations and economic viability, thereby providing a data-driven basis for site selection [1], [6], [9]. This methodology enables the identification and ranking of suitable sites for new hospitals, thereby supporting the strategic planning and development of national health infrastructure [5]. Such an approach aids in mitigating spatial discrepancies in healthcare access, particularly in regions where existing facilities are poorly distributed or insufficient to meet demand [1]. This comprehensive evaluation is particularly vital in urban areas facing rapid expansion, as well as in underserved rural regions, where the judicious placement of medical facilities can significantly reduce health disparities and enhance public welfare [2], [9]. The continuous expansion of the country's population amplifies the demand for new healthcare facilities, yet existing public and private services often cater to specific societal segments, excluding underprivileged communities [6]. Consequently, leveraging advanced spatial analytical techniques becomes imperative to identify optimal locations that serve all demographic groups, ensuring equitable access to medical care [3].

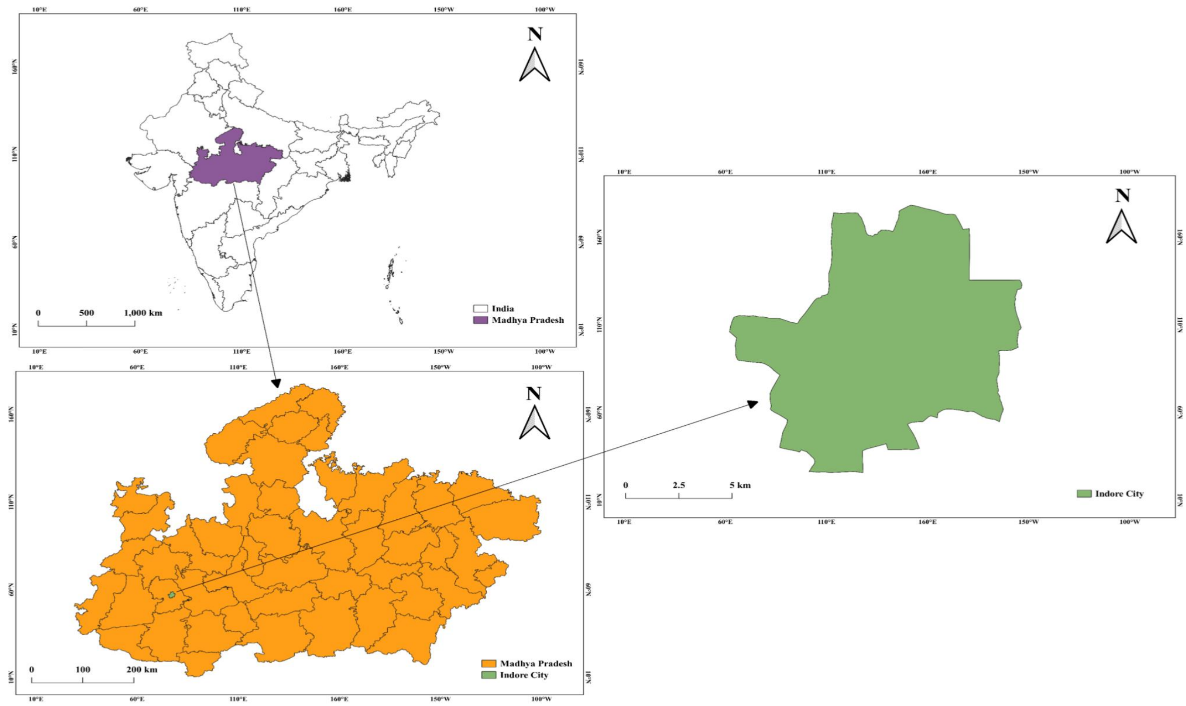

Figure 2: Map of the study area – Indore City, Madhya Pradesh, India, delineating the spatial extent analysed for hospital site suitability using GIS techniques.

Literature Review

A review of pertinent literature underscores the significance of robust site suitability analyses for healthcare infrastructure, particularly in mitigating the spatial mismatch between population needs and service availability [10].

Evaluating the equality of access to health services across different geographical areas necessitates a rigorous analysis of multiple criteria, including proximity to existing health centres and hospitals, the quality of services provided, connectivity to primary road networks, and the distribution patterns of healthcare facilities [4]. This holistic assessment is crucial for understanding the present landscape and for strategically planning future interventions to enhance healthcare accessibility [11]. Previous research highlights the significance of travel time, facility size, regional physical conditions, available utilities, and natural features in optimizing healthcare services and site selection [12]. These criteria often guide the development of site selection models, which can range from heuristic approaches to more sophisticated GIS-integrated multi-criteria decision-making frameworks [13]. The integration of Multi-Criteria Decision Making methods with GIS is widely recognized for its ability to create a problem-solving environment for spatially referenced data, facilitating effective ranking of alternatives based on multiple criteria [14]. This integration offers a robust framework for assessing potential hospital sites by considering a multitude of factors, thereby enhancing the objectivity and transparency of the decision-making process [15]. This systematic approach is particularly valuable for urban policymakers seeking to develop sustainable and equitable healthcare infrastructure by identifying optimal sites for new facilities, ultimately improving healthcare accessibility for all residents [4], [16]. This ensures that new facilities are strategically located to address current service gaps and anticipate future demands arising from demographic shifts and urban growth [6], [17].

Furthermore, analysing existing healthcare infrastructure distribution through methods like nearest neighbour analysis and service area analysis can reveal spatial inequities and inform strategic placement to bridge identified gaps [8], [17]. Moreover, the strategic incorporation of location-allocation and accessibility models within GIS provides a sophisticated approach to optimize the distribution of public service resources, balancing equity and efficiency in urban planning for healthcare [18]. This integrated approach is particularly vital for enhancing the resilience and responsiveness of health systems in emergencies by identifying optimal locations for rapid deployment of medical resources [19]. Such models enable planners to evaluate various scenarios for service provision, taking into account factors like population density, travel impedance, and existing healthcare infrastructure [18]. This comprehensive evaluation is essential for guiding decision-makers in developing sustainable healthcare infrastructure that effectively addresses both current needs and future challenges [9], [20]. The combination of Geographic Information Systems and Multi-Criteria Decision Analysis offers a powerful toolset for identifying optimal locations for new healthcare facilities [21], [22]. This integration is particularly advantageous because it allows decision-makers to incorporate their value judgments into spatial decision support systems, facilitating a more nuanced and context-aware selection process [23].

Methodology

Access to healthcare is a multifaceted concept encompassing availability, affordability, acceptability, and geographical accessibility. While affordability and acceptability represent non-spatial dimensions, geographical accessibility and availability incorporate spatial elements that can be effectively analysed using Geographic Information Systems [4]. The present study employs QGIS to explore suitable sites for a new hospital in Indore City by first assessing the existing distribution of healthcare facilities.

Existing hospitals and Primary Health Centres were digitized and mapped in QGIS to evaluate spatial distribution patterns. The analysis revealed non-uniform coverage across the city, with residents in underserved areas required to travel long distances for adequate treatment [1]. To identify potential sites, additional layers were incorporated: a river layer with buffers to exclude flood-prone zones; a Land Use Land Cover map prioritizing barren and agricultural fallow lands near settlements for cost-effective development and proximity to populations [2]; and road networks to ensure connectivity [9].

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These overlays generated candidate sites, refined by network analysis to evaluate accessibility. Shortest-path distances were calculated from proposed sites to nearest healthcare centres, pharmacies, multispecialty hospitals, bus stands, and the railway station [5]. Factors across all features were quantified, yielding an accumulation score to rank sites and select the optimum location [6].

Network analysis was conducted to quantify accessibility from candidate sites. Starting with sites identified through overlay analysis of the aforementioned layers, shortest path distances were calculated to the nearest healthcare centres, pharmacies, and two multispecialty hospitals [5]. Bus stand data was imported to determine proximity to public transport, followed by analysis of distances to the railway station. Factors for all features were computed, culminating in an accumulation factor to rank sites and identify the optimal location for the new hospital [6]. This methodology allowed for a comprehensive evaluation of various spatial criteria, ensuring that the final site selection maximizes accessibility and minimizes travel burden for the largest possible population [2], [6]. The methodology employed integrates spatial and non-spatial data using Geographic Information Systems with multi-criteria decision-making to provide a comprehensive framework for selecting optimal hospital sites, thereby bridging gaps between infrastructure coverage and healthcare disparities [1], [24]. The following are the step wise process:

Data Acquisition and Pre-Processing

The initial stage involved gathering diverse geospatial datasets, including administrative boundaries, land use/land cover classifications, demographic information, existing healthcare facility locations, and transportation networks from authoritative sources such as government agencies and satellite imagery providers. These datasets underwent rigorous pre-processing, including georeferencing, projection transformations, and data cleaning, to ensure spatial accuracy and compatibility for subsequent analyses.

Spatial datasets, including existing hospitals and primary health centres, rivers, buildings, railways, roads, land use, and land cover, were acquired from authoritative sources[2], [9] and imported into QGIS[1]. All layers were then reprojected to a common coordinate reference system to ensure spatial consistency and accurate overlay analysis[14].

Mapping of Existing Healthcare Facilities

Existing hospitals and Primary Health Centres were spatially mapped using QGIS to evaluate current healthcare coverage, identify spatial distribution patterns, and delineate exclusion zones around already serviced regions (as shown in the figure 3). This analysis revealed non-uniform coverage and clustering tendencies across the city, with underserved areas requiring long travel distances for treatment, thereby informing the strategic placement of new facilities to bridge identified gaps and prevent overlap [1], [8], [17].

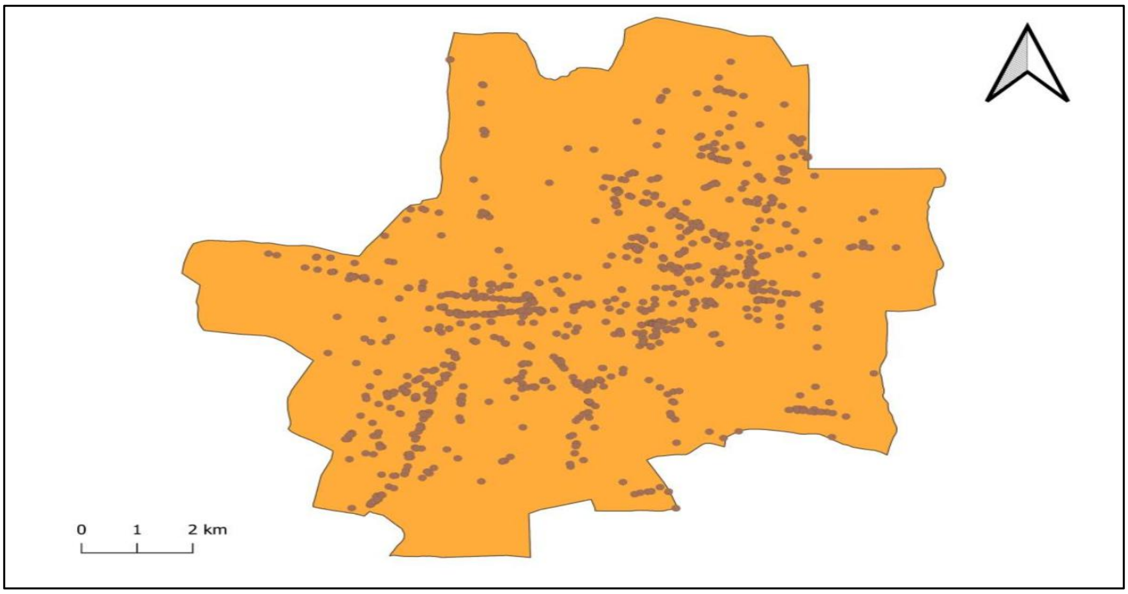

Figure 3: Spatial Distribution of Existing Hospitals and Primary Health Centres

Integration of Physical and Infrastructure Layers

River networks, building footprints, railway lines and stations, and road networks—digitized from authoritative spatial datasets [1], [2], [9]—were overlaid(as shown in figure 4 and 5) onto the base layers using QGIS spatial analysis tools [14]. This integration delineated key constraints: rivers for environmental hazards like flood risks; building footprints to exclude densely developed urban areas; railways and stations for safety setbacks due to noise, vibration, and accident proximity; and road networks to evaluate connectivity and accessibility [5], [19]. Collectively, these overlays refined the candidate sites by incorporating multifaceted physical and infrastructural limitations influencing overall suitability [21].

Land Use Land Cover maps, derived from high-resolution satellite imagery such as Sentinel-2A via supervised classification, were incorporated to identify suitable land parcels that minimize development costs and maximize accessibility to target populations [6], [25].

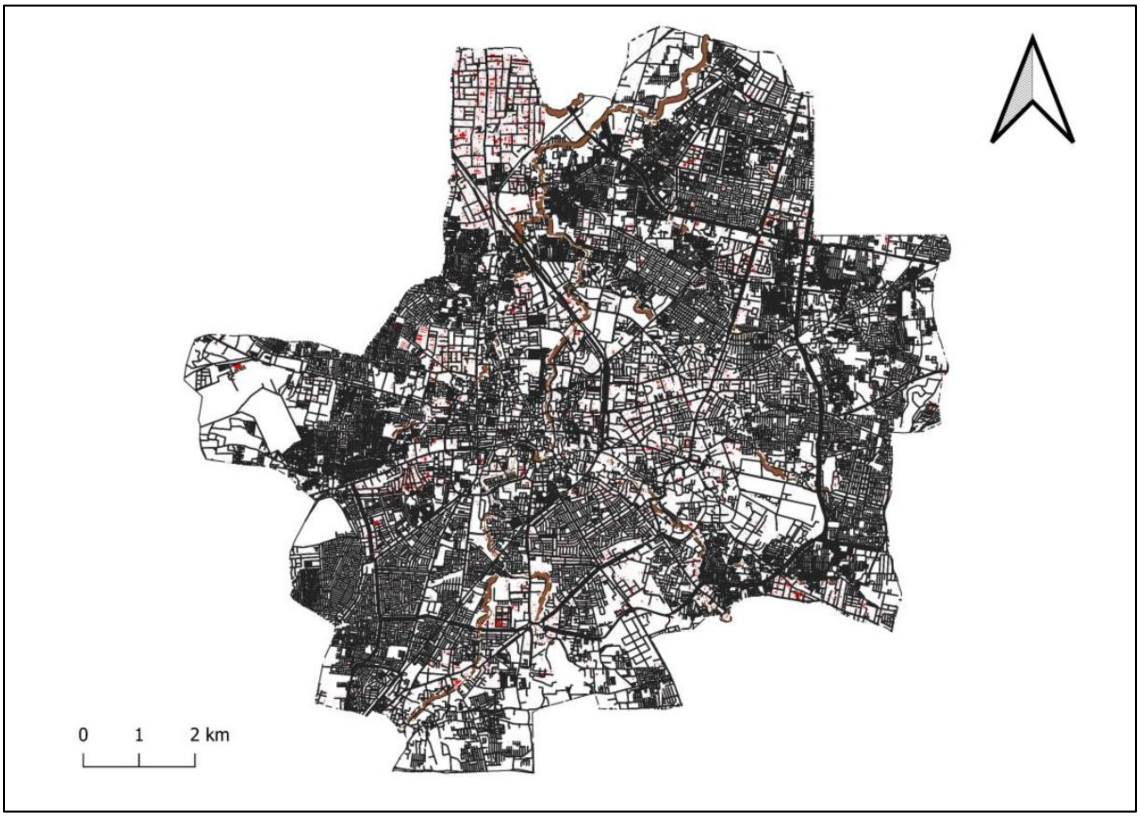

Figure 4: All the selected part to be removed to identify the free area available for the hospital.

Figure 5: All the removed area that were previously selected to identify the free area available for the hospital.

Buffer Generation and Constraint Removal

Buffer zones were created around existing healthcare facilities, rivers, railways, and major roads to identify restricted areas [2], [17]. These buffered regions were removed from the study area using spatial overlay (as shown in Figure 6) and erase operations to retain only feasible land parcels [14]. This process is crucial for identifying suitable land parcels by systematically excluding areas with pre-existing infrastructure or environmental constraints, thereby streamlining the subsequent multi-criteria analysis for optimal site selection [26]. Moreover, these exclusion zones help ensure that the new hospital sites do not infringe upon sensitive ecological areas or create undue burdens on existing infrastructure, thus promoting sustainable urban development [5].

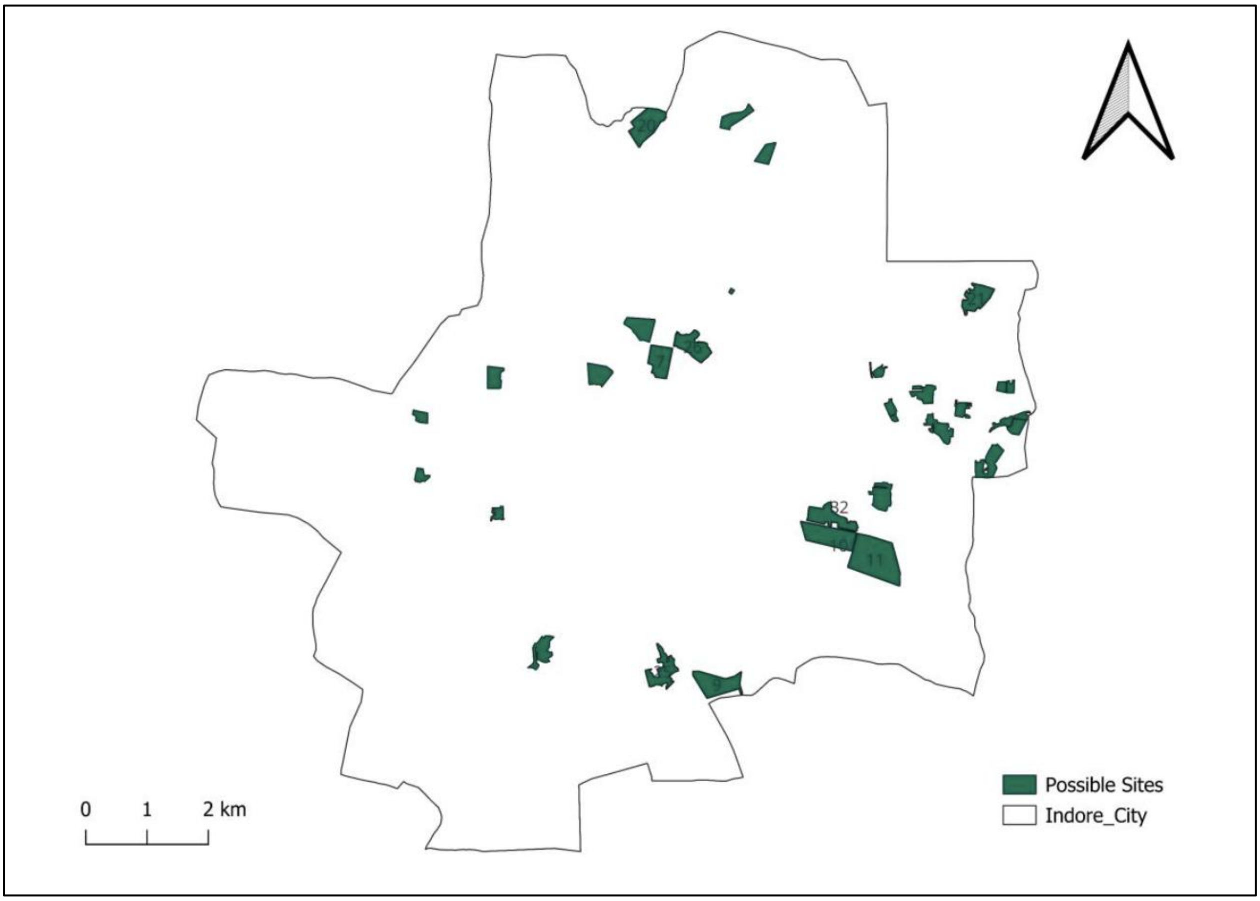

Figure 6: Manually selecting the free area available for the hospital.

Land Use and Land Cover Analysis

Land use and land cover (LULC) classification was performed to identify suitable land categories. Only land-use classes compatible with healthcare facility development were retained, while unsuitable classes such as water bodies and dense built-up areas were excluded. This selective process optimizes resource allocation by focusing on barren or agricultural fallow lands near population centres, thereby minimizing acquisition and development costs [27].

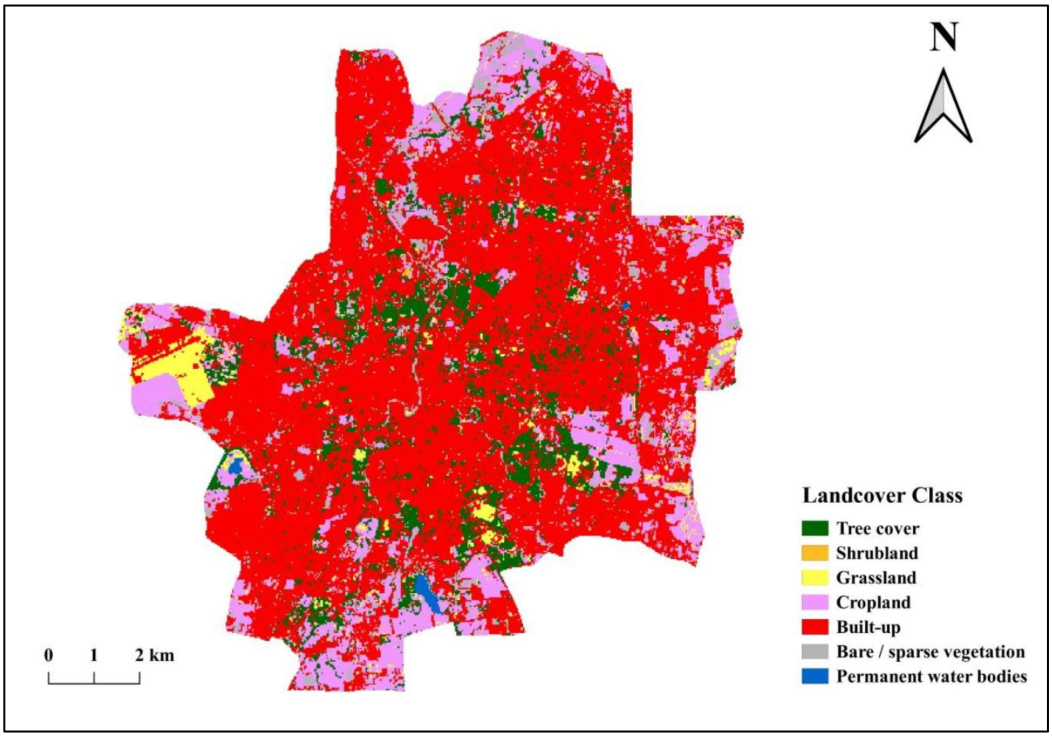

Figure 7: Land use and land cover (LULC) classification for making the final selection.

Area Estimation and Threshold Filtering

The remaining area were analysed to estimate their required surface area. Parcels smaller than the minimum required area for healthcare infrastructure development were eliminated from further consideration. This filtering step ensures that only economically viable and physically adequate sites capable of accommodating necessary medical facilities, future expansions, and supporting infrastructure are carried forward for more detailed evaluation [6].

This meticulous approach guarantees that selected sites not only meet immediate operational needs but also offer sufficient flexibility for future growth and adaptation to evolving healthcare demands.

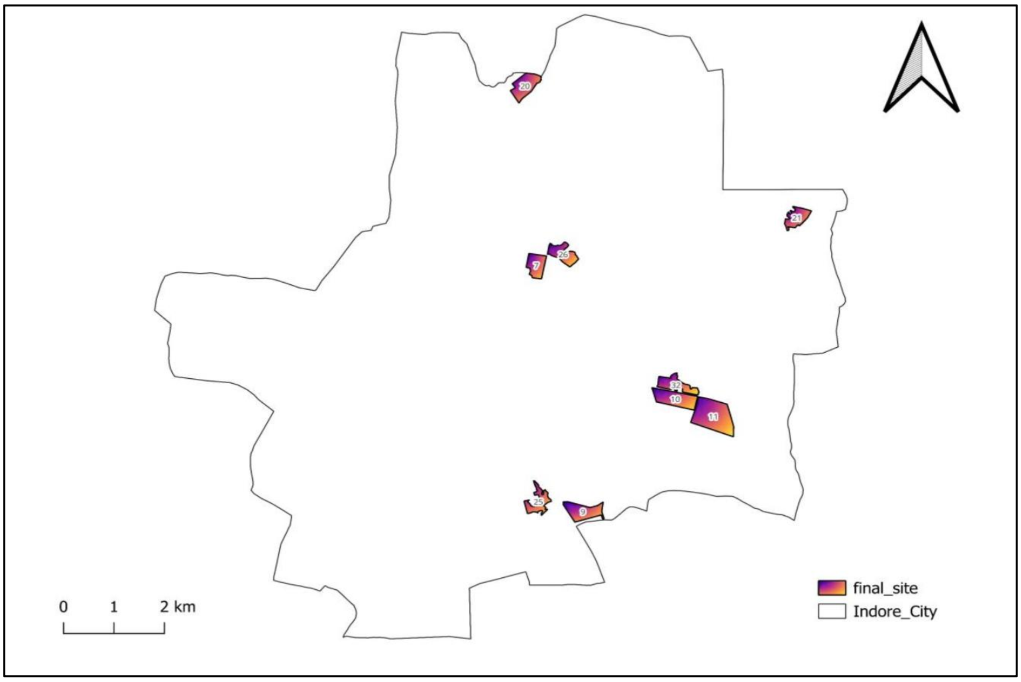

Figure 8: The final selection based on the LULC and area considerations.

Proximity and Network Analysis

Network analysis was conducted to identify nearby pharmacies and railway stations, enhancing functional support and accessibility. Additionally, road network analysis was performed to evaluate connectivity and travel efficiency from surrounding areas to the candidate sites. This detailed analysis aids in pinpointing locations that maximize patient access while minimizing travel times, a critical factor for emergency services [2].

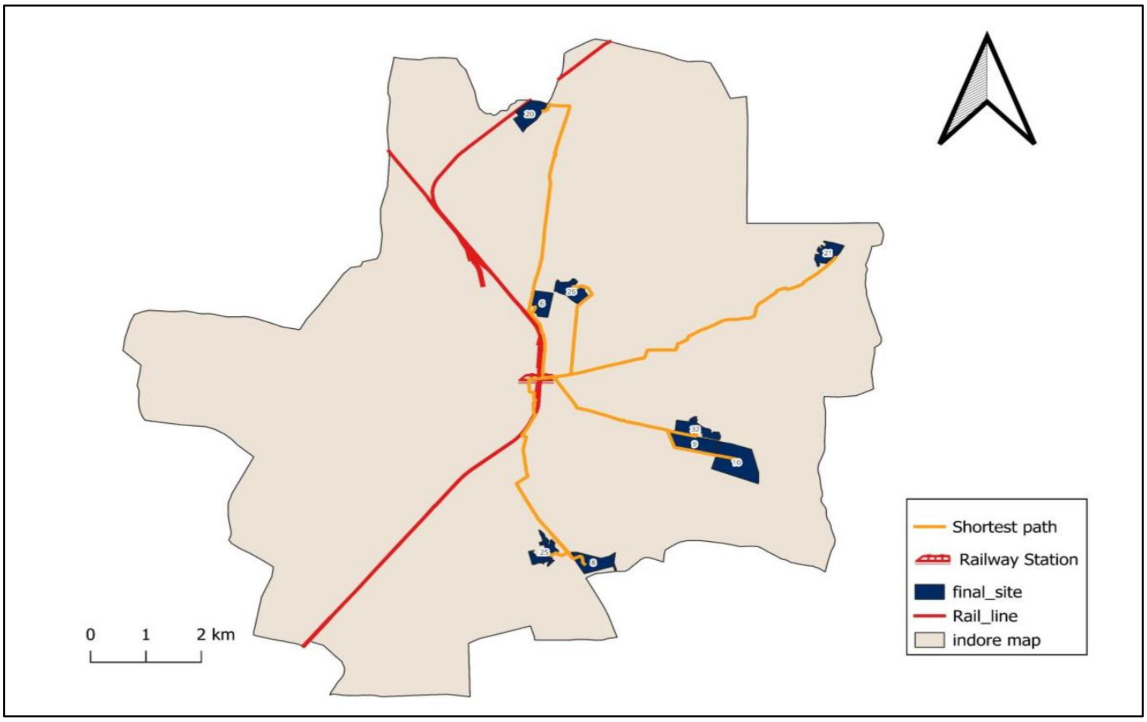

Figure 9: Network analysis to find the shortest distance connecting all the sites.

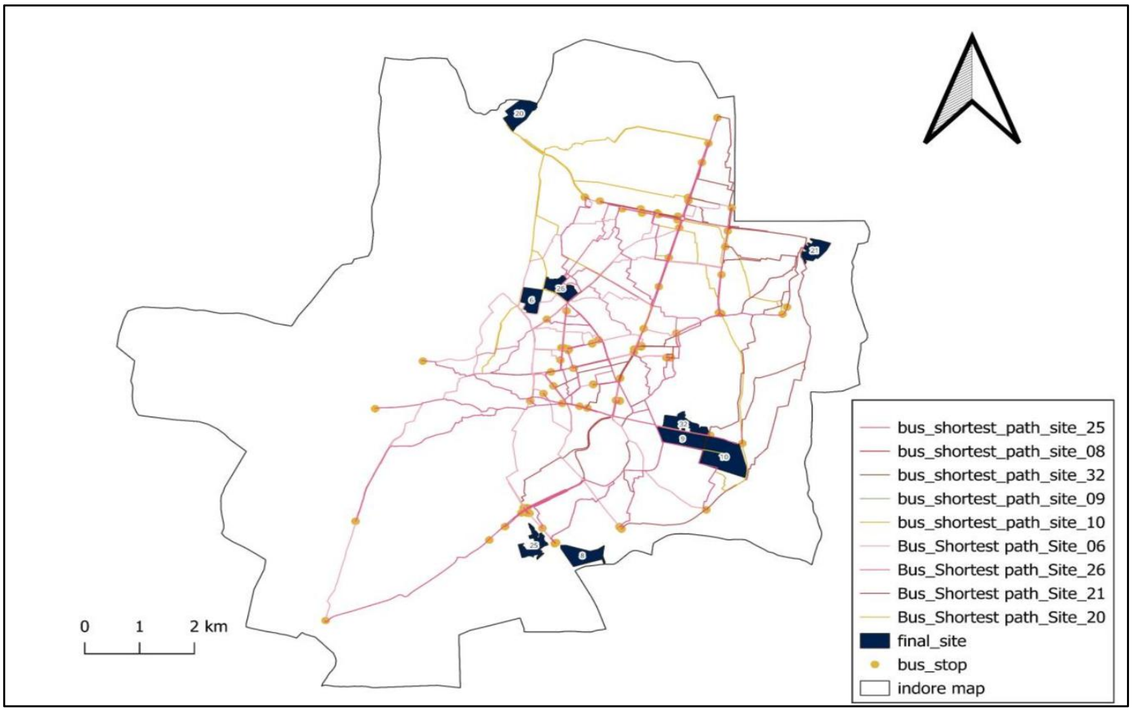

Figure 10: Network analysis to find the shortest distance from all the bus routes connecting to all the sites.

Final Site Selection

The final site was selected based on integrated multi-criteria evaluation, considering spatial constraints, land suitability, adequate area, and network accessibility. The selected location represents the most optimal site for establishing a new healthcare facility within the study area. This comprehensive methodology ensures that the chosen site not only meets essential spatial and infrastructural requirements but also contributes to equitable healthcare provision and sustainable urban planning [6]. Now we are ready to proceed for the calculation after successfully isolation the area for further calculation.

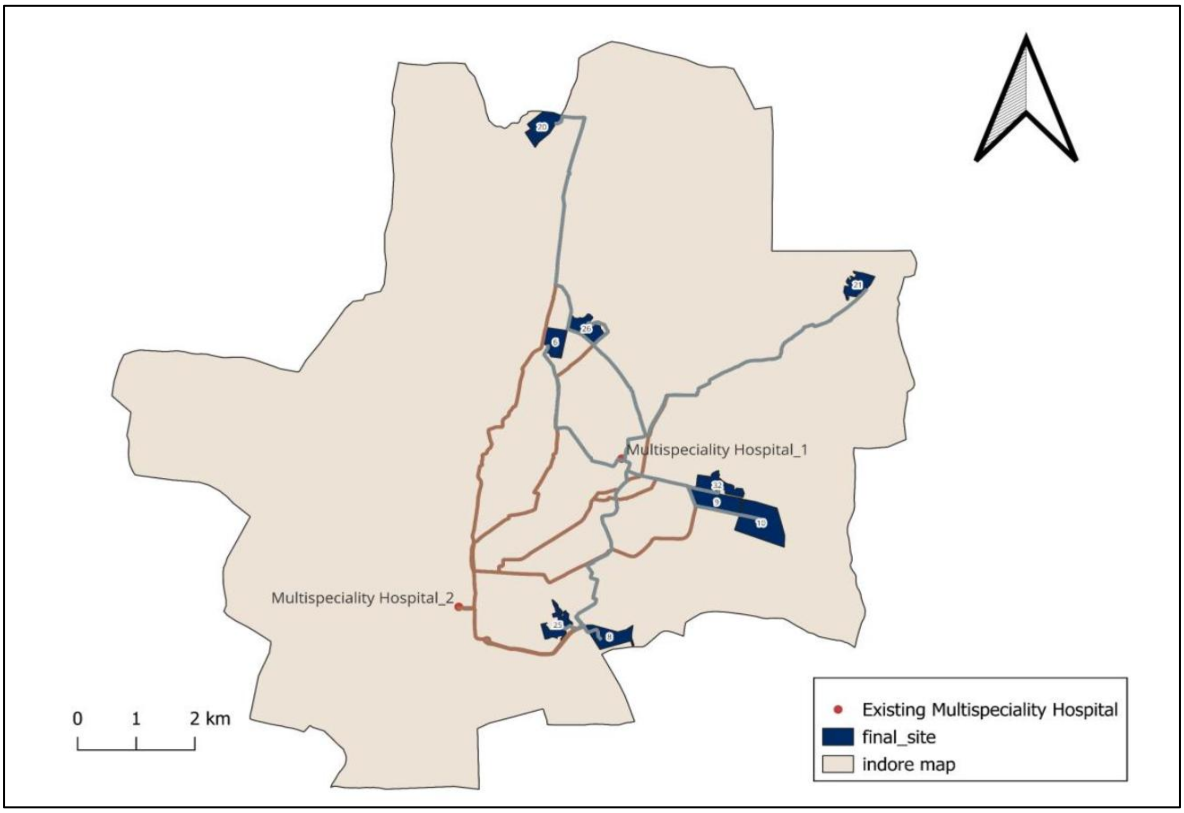

Figure 11: Network analysis to find the shortest distance connecting all the sites to the Multi-speciality existing hospital.

Classification Criteria

In this study, the selection criteria were classified based on their functional role in healthcare planning and spatial equity. Beneficial-when-close (cost-type) criteria include proximity to pharmacies and health care facilities, railway stations, and bus stands, where shorter distances are preferred to ensure rapid access, convenience, and effective connectivity for patients and emergency services. Conversely, beneficial-when-far (benefit-type) criteria include distance from existing multi-speciality hospitals, where greater distances are desirable to minimize service overlap and to extend healthcare coverage to underserved regions. This dual classification enables a context-aware normalisation strategy that aligns spatial analysis with real-world healthcare distribution objectives, thereby promoting improved spatial equity and balanced service accessibility.

Results

The Equitable Accessibility–Dominance Index is proposed as a novel GIS-based model for healthcare site selection. It addresses limitations of traditional multi-criteria methods—such as weighted sum models, AHP, and multiplicative indices—which prioritize proximity and allow compensation across criteria, often yielding spatially imbalanced results. Unlike these compensatory approaches, EADI ensures equitable access by integrating three key dimensions: overall accessibility strength, equity across essential facilities, and penalties for weak or distant links. This non-linear, non-compensatory formulation robustly evaluates proximity, balance, and vulnerability, tackling healthcare complexities like distance to existing centres, service quality, and transport connectivity.[4]. This approach also accounts for the complex interplay of multiple criteria and stakeholders, which is characteristic of the ill-structured decision problem of healthcare facility site selection [13].

Site No.	Pharmacy & Health Care (km)	MS Hospital 1 (km)	MS Hospital 2 (km)	Railway (km)	Bus Stand (km)
6	0.303	6.261	3.254	2.165	2.201
8	1.049	3.516	4.610	5.121	5.653
9	1.374	6.098	2.200	3.662	1.701
10	1.137	6.986	2.997	4.459	2.297
20	1.868	11.086	8.267	7.305	2.224
21	0.465	10.769	6.040	6.558	2.895
25	1.397	3.161	4.737	4.993	5.901
26	0.506	7.334	3.676	3.009	1.043
32	1.391	6.367	2.162	3.624	4.197

Table 1: Table to note the shortest distance from the new selected site .

Normalisation

The proposed normalisation approach is scientifically robust as it aligns spatial analysis with fundamental healthcare equity principles by explicitly distinguishing between accessibility-driven and coverage-driven criteria. By rejecting the conventional assumption that closer proximity is always preferable, the method avoids artificial bias and more accurately reflects real-world healthcare planning objectives. The use of dual-behaviour normalization—treating certain criteria as beneficial when close and others as beneficial when distant—allows heterogeneous spatial relationships to be modelled within a single, coherent framework. This context-sensitive normalisation not only improves the realism and interpretability of the results but also significantly strengthens the methodological novelty and analytical depth of the proposed Equitable Accessibility–Dominance Index (EADI).

For Beneficial-when-Close Criteria for Lower distance offering the higher suitability:

$$\mathrm{F}_{\mathrm{ij}}^{\mathrm{close}} = \frac{\mathrm{D}_{\mathrm{j}}^{\mathrm{min}}}{D_{ij}}$$

Where, D_{ij} = distance from site ii to facility jj and D_j^{min}= minimum observed distance for criterion jj

For Beneficial-when-Far Criteria where Higher distance offering higher suitability:

$$\mathrm{F}_{\mathrm{ij}}^{far} = \frac{D_{ij}}{D_j^{max}}$$

Where, D_j^{max} = maximum observed distance among all sites for that hospital

This normalization approach ensures that all criteria, regardless of their intrinsic directional preference, contribute proportionally to the overall suitability score.

Normalized Factors

Let normalized factors already computed be:

$$\mathrm{F_i} = \left[\left\{\mathrm{F_{i1}^{close}}, \mathrm{F_{i2}^{far}}, \mathrm{F_{i3}^{far}}, \mathrm{F_{i4}^{close}}, \mathrm{F_{i5}^{close}}\right\}\right]$$

Where $\mathrm{F_{i1}^{close}}$ represents the normalized suitability factor for proximity to Pharmacy and Health Care facilities, $\mathrm{F_{i2}^{far}}$ and $\mathrm{F_{i3}^{far}}$correspond to the normalized factors for distance from the first and second multi-speciality hospitals (MS Hospital 1 and MS Hospital 2) respectively, reflecting the preference for greater separation to reduce service overlap, and $\mathrm{F_{i4}^{close}}$ and $\mathrm{F_{i5}^{close}}$ denote the normalized factors for proximity to the railway station and main bus stand, where shorter distances enhance accessibility and connectivity.

with $\left(0 < \mathrm{F_{ij}} \leq 1 \right)$

Formulation

This Empirical Formula is a normalisation ensures that all factors contribute equitably to the site selection process, preventing any single criterion from dominating the evaluation due to scale differences.

$$\mathrm{EADI_i} = \frac{\left(\sum_{j=0}^{5} F_{ij}\right)^2}{\left(1 + \sqrt{\frac{1}{5}\sum_{j=0}^{5} \left(\mathrm{F_{ij}} - \overline{F_i}\right)^2}\right)\left\{1 + \max\left(F_{ij}\right) - \min\left(F_{ij}\right)\right\}} = \frac{\left(\sum_{j=0}^{5} F_{ij}\right)^2}{(1+\sigma_i)(1+\Delta_i)}$$

where:

$\sum_{j=0}^{5} \mathrm{F_{ij}}$ is Accessibility Strength Term, measures overall closeness to essential services.

$\sigma_\mathrm{i} = \sqrt{\frac{1}{5}\sum_{j=0}^{5} \left(\mathrm{F_{ij}} - \overline{F_i}\right)^2}$ is Equity (Dispersion) Term, which penalizes sites with uneven accessibility (large variation across services).

$\Delta_i = \max\left(F_{ij}\right) - \min\left(F_{ij}\right)$ is Dominance Penalty Term, ensures no single facility dominates the suitability score.

Interpretation

A higher Equitable Accessibility–Dominance Index (EADI) value indicates a more suitable site for healthcare facility development. To achieve a high EADI score, a site must demonstrate close proximity to all essential facilities, maintain balanced accessibility across multiple service types, and avoid extreme weaknesses in any single criterion. Consequently, the index favours locations that provide equitable and uniformly distributed access rather than excelling in only one or two dimensions.

Calculation

The calculation of suitability scores incorporated weighted criteria, such as proximity to main roads, population density, and distance from existing healthcare facilities, to objectively rank potential sites [6], [10], [27]. This multi-criteria decision analysis framework, often integrated with Geographic Information Systems, allows for the systematic evaluation of various factors influencing site suitability, thereby enhancing the objectivity and transparency of the selection process [1]. The Analytic Hierarchy Process and Ordered Weighted Averaging operator were frequently employed to determine criteria weights and aggregate suitability scores, classifying results into distinct suitability levels [14].

Rank	Site No.	F1 (Pharmacy)	F2 (Hosp-1)	F3 (Hosp-2)	F4 (Rail)	F5 (Bus)	EADI
1	**26**	0.599	0.662	0.445	0.720	1.000	**6.38**
2	6	1.000	0.565	0.394	1.000	0.474	5.81
3	21	0.652	0.971	0.731	0.330	0.360	4.55
4	**20**	0.162	**1.000**	**1.000**	0.296	0.469	**3.45**
5	10	0.266	0.630	0.363	0.486	0.454	3.16
6	9	0.221	0.550	0.266	0.591	0.613	3.08
7	32	0.218	0.574	0.262	0.597	0.249	2.24
8	8	0.289	0.317	0.558	0.423	0.185	2.03

9	25	0.217	0.285	0.573	0.434	0.177	1.77

Table 2:Table to presents the top nine most suitable sites for a new healthcare facility, ranked by their Equitable Accessibility–Dominance Index (EADI) values.

Limitations

The proposed formulation is intentionally non-reducible to conventional multi-criteria decision-making frameworks. It cannot be expressed as a weighted sum, product model, AHP, TOPSIS, or any classical MCDM index, as it incorporates non-linear interactions, dispersion-based penalties, and dominance constraints that prevent compensatory behaviour among criteria. While this enhances robustness and equity in site selection, it may limit direct comparability with traditional models and requires additional computational steps for interpretation and validation.

Discussion

This multi-criteria decision analysis approach, integrated with Geographic Information Systems, allows for a comprehensive evaluation of diverse decision factors, ensuring a holistic assessment of site suitability for healthcare facilities [1], [4], [13]. This methodology incorporates both qualitative and quantitative factors, providing a robust framework for complex decision-making processes [28]. Furthermore, the Analytical Hierarchy Process was utilized to assign objective weights to the various criteria, facilitating a flexible aggregation procedure for generating composite suitability maps [6], [9]. This methodological approach, combining GIS with AHP, has proven effective in identifying optimal locations for critical infrastructure, such as hospitals, by integrating diverse spatial and thematic data [9], [10].

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The proposed normalization strategy and the Equitable Accessibility–Dominance Index (EADI) in capturing both accessibility and spatial equity. Site 26 emerges as the highest-ranked location primarily due to its excellent proximity to key transportation nodes, including the main bus stand and railway station, combined with balanced accessibility across all evaluated services. This indicates strong overall connectivity and operational feasibility. In contrast, Site 20 achieves the maximum possible score for both hospital-distance criteria, highlighting its superior potential for reducing service overlap and extending healthcare coverage to underserved regions. Although its overall EADI value is marginally lower due to comparatively weaker proximity to pharmacies and transport infrastructure, Site 20 represents the most effective option for strategic hospital decongestion and spatial equity enhancement. These findings underscore the importance of policy-driven normalization and validate the proposed EADI framework as a robust and context-aware decision-support tool for healthcare facility site selection.

Conclusion

The findings from this study confirm the viability of applying GIS-based multi-criteria suitability analysis for healthcare facility site selection, aligning with similar successful applications in infrastructure planning [29]. The Analytic Hierarchy Process played a pivotal role in objectively assigning weights to various criteria, ensuring that the final site suitability maps accurately reflected the nuanced priorities of urban, environmental, and economic factors [6], [9], [28]. This integrated methodology thus provides a transparent and robust framework for systematically evaluating and prioritizing potential sites, ultimately facilitating informed decision-making in urban planning and healthcare infrastructure development [6], [31].

The study further reveals that healthcare service development often follows linear patterns along historical avenues, indicating a need for future planning to address spatial accessibility disparities and promote sustainable urban growth [32].

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