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GIS-Based Multi-Criteria Evaluation for Hospital Site Selection: A Systematic Literature Review (2010–2025)

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Abstract **Original Research Article**

Hospital site selection is a complex spatial decision-making process that significantly influences healthcare accessibility, service efficiency, emergency response, and equitable resource distribution. Increasing population growth, rapid urbanization, and environmental challenges have made conventional site selection approaches inadequate for addressing multiple and often conflicting planning criteria. Consequently, the integration of Geographic Information Systems (GIS) with Multi-Criteria Evaluation (MCE) techniques has emerged as an effective decision-support framework for healthcare facility planning. This study presents a systematic literature review of GIS-based MCE applications for hospital site selection published between 2010 and 2025. Relevant studies were identified through major scientific databases using predefined inclusion and exclusion criteria. The selected literature was analysed to examine theoretical foundations, methodological approaches, spatial datasets, decision criteria, weighting techniques, validation procedures, and emerging technological developments. The review shows that the Analytic Hierarchy Process (AHP) remains the most widely applied weighting method, although Fuzzy AHP, TOPSIS, ELECTRE, PROMETHEE, VIKOR, and hybrid approaches are increasingly adopted to improve decision accuracy. Frequently used spatial criteria include population density, road accessibility, land use, topography, environmental constraints, infrastructure, and proximity to existing healthcare facilities. Despite the demonstrated effectiveness of GIS–MCE in supporting evidence-based hospital planning, considerable methodological differences exist regarding criteria selection, weighting procedures, validation methods, and data quality. Emerging technologies such as machine learning, artificial intelligence, remote sensing, and cloud-based GIS present new opportunities for enhancing spatial decision-making. The review concludes that more standardized methodological frameworks, stronger validation procedures, and greater integration of advanced analytical techniques are required to improve the reliability and applicability of GIS-based hospital site selection models, particularly in rapidly urbanizing and data-constrained regions.

Keywords: Geographic Information Systems (GIS); Hospital site selection; Multi-Criteria Evaluation (MCE); Multi-Criteria Decision Making (MCDM); Healthcare planning; Spatial decision support.

1. Introduction

Healthcare infrastructure plays a fundamental role in improving population health, reducing mortality rates, promoting social equity, and supporting sustainable economic development. Among healthcare facilities, hospitals represent

the highest level of specialized medical care and serve as essential components of national healthcare systems. The strategic location of hospitals determines not only the accessibility of healthcare services but also the efficiency of emergency response, referral systems, resource allocation, and healthcare delivery. Consequently, selecting suitable locations for hospitals has become an increasingly important issue for governments, urban planners, public health professionals, and decision-makers worldwide (World Health Organization [WHO], 2021).

Hospital site selection is inherently a complex spatial decision-making process involving numerous interrelated factors that frequently conflict with one another. Decision-makers must simultaneously consider population distribution, accessibility, transportation infrastructure, land-use compatibility, environmental quality, natural hazard exposure, topography, land acquisition costs, public utilities, future urban growth, and government planning policies. Optimizing one factor often compromises another; for example, centrally located sites may maximize accessibility but involve substantially higher land acquisition costs, whereas peripheral locations may provide larger land parcels but reduce service accessibility for densely populated communities (Malczewski & Rinner, 2015). Consequently, hospital location planning cannot rely on a single decision criterion but instead requires systematic evaluation of multiple variables within an integrated decision-support framework.

Historically, healthcare facility planning was guided by classical location theories, including Central Place Theory, Gravity Models, and Location-Allocation Models. These theories established the conceptual basis for understanding how healthcare services should be spatially distributed relative to population demand (Christaller, 1933; Lösch, 1954). While these theoretical models contributed significantly to the development of spatial planning, they were developed before the emergence of modern geospatial technologies and therefore could not effectively accommodate the large number of environmental, socio-economic, and infrastructural variables now available through digital spatial databases.

The rapid development of Geographic Information Systems (GIS) has fundamentally transformed healthcare planning by enabling the integration, management, visualization, and analysis of spatial information from multiple sources. GIS allows planners to combine demographic data, transportation networks, land-use maps, digital elevation models, satellite imagery, environmental datasets, and healthcare service information within a common spatial framework (Longley et al., 2015). Through spatial overlay analysis, network analysis, buffering, proximity analysis, interpolation, and suitability modelling, GIS provides decision-makers with objective tools for identifying optimal hospital locations and evaluating healthcare accessibility across different geographical contexts.

Despite the analytical capabilities of GIS, determining the suitability of hospital sites remains a multi-criteria problem because different stakeholders often assign different levels of importance to individual decision factors. Multi-Criteria Evaluation (MCE) techniques address this challenge by providing structured procedures for integrating quantitative and qualitative criteria into a single decision model. MCE enables planners to evaluate competing alternatives based on predefined objectives while accounting for stakeholder preferences, uncertainty, and conflicting priorities (Malczewski, 2006). As a result, the integration of GIS and MCE has become one of the most widely adopted approaches for hospital site selection and broader healthcare infrastructure planning.

Among the available MCE techniques, the Analytic Hierarchy Process (AHP) developed by Saaty (1980) remains the most frequently applied due to its structured pairwise comparison framework and consistency assessment. However, advances in decision science have led to the application of additional methods such as Fuzzy AHP, TOPSIS, ELECTRE, PROMETHEE, VIKOR, Weighted Linear Combination (WLC), and hybrid decision models. These approaches enable researchers to

accommodate uncertainty, expert judgment, and multiple stakeholder perspectives while improving the robustness of spatial decision-making (Ishizaka & Nemery, 2013). Recent studies have also integrated machine learning algorithms, remote sensing data, cloud-based GIS platforms, and artificial intelligence techniques to improve predictive accuracy and automate suitability modelling processes.

During the last fifteen years, research on GIS-based hospital site selection has increased substantially due to advances in geospatial technologies, greater availability of open spatial datasets, and increasing demand for equitable healthcare services. Studies conducted across Asia, Africa, Europe, the Middle East, and North America have demonstrated that GIS–MCE approaches can significantly improve healthcare accessibility by identifying underserved areas, optimizing resource allocation, and supporting evidence-based planning decisions. Nevertheless, considerable variation exists in the criteria employed, weighting methods, spatial datasets, and validation procedures adopted by different researchers. These methodological differences make it difficult to compare findings directly and highlight the need for a comprehensive synthesis of current knowledge.

In addition, many existing reviews focus primarily on either GIS applications or individual decision-making techniques without comprehensively examining their integration for hospital site selection. Few reviews critically evaluate methodological strengths and limitations, compare weighting approaches, or identify emerging technological trends such as artificial intelligence, machine learning, cloud GIS, and big spatial data analytics. Addressing these gaps is important for advancing both research and professional practice in healthcare infrastructure planning.

1.1 Aim of the Review

The aim of this paper is to critically review and synthesize the existing literature on GIS-based multi-criteria Evaluation techniques applied to hospital site selection between 2010 and 2025. The review evaluates theoretical foundations, methodological developments, spatial analytical techniques, weighting procedures, validation approaches, and emerging technologies to provide a comprehensive understanding of current practices and future research directions.

1.2 Objectives of the Review

The specific objectives of this review are to:

1. Examine the theoretical foundations underpinning hospital site selection and spatial decision-making.
2. Review the role of Geographic Information Systems in healthcare infrastructure planning.
3. Analyse the major Multi-Criteria Decision-Making (MCDM) techniques employed in hospital site selection.
4. Identify the spatial, environmental, socio-economic, demographic, and infrastructural criteria commonly used in GIS-based suitability analyses.
5. Compare methodological approaches, weighting strategies, validation methods, and outcomes reported in studies published between 2010 and 2025.
6. Identify research gaps, methodological limitations, and emerging trends that can inform future hospital site selection research.

1.3 Scope of the Review

This review focuses on peer-reviewed journal articles, conference proceedings, and technical reports published between 2010 and 2025 that explicitly integrate GIS with Multi-Criteria Evaluation or Multi-Criteria Decision-Making methods for hospital or healthcare facility site selection. The review covers methodological frameworks, spatial datasets, decision criteria, weighting techniques, validation procedures, and case study findings from developed and developing countries. Studies that focus solely on healthcare accessibility without incorporating spatial suitability modelling are discussed only where they provide methodological insights

relevant to hospital site selection.

1.4 Methodology

This study adopted a **systematic literature review (SLR)** approach to critically synthesize existing knowledge on the application of Geographic Information Systems (GIS) and Multi-Criteria Evaluation (MCE) techniques in hospital site selection. The review followed internationally accepted systematic review principles to ensure transparency, reproducibility, and comprehensive coverage of relevant literature.

A structured search was conducted across major scholarly databases, including **Scopus, Web of Science, ScienceDirect, SpringerLink, Google Scholar, IEEE Xplore, and PubMed**. The search covered studies published between **2010 and 2025** using combinations of keywords such as *hospital site selection*, *healthcare facility location*, *Geographic Information Systems (GIS)*, *Multi-Criteria Evaluation (MCE)*, *Multi-Criteria Decision Making (MCDM)*, *Analytic Hierarchy Process (AHP)*, *Fuzzy AHP*, *TOPSIS*, *VIKOR*, *ELECTRE*, *PROMETHEE*, and *spatial decision support systems*.

Studies were included if they (i) focused on hospital or healthcare facility site selection, (ii) integrated GIS with one or more MCE/MCDM techniques, (iii) were published in peer-reviewed journals, conference proceedings, or reputable technical reports, and (iv) were written in English. Studies that addressed healthcare accessibility without spatial suitability analysis, duplicate publications, editorials, and non-scholarly documents were excluded. The selected studies were reviewed and analysed using **thematic content analysis**. Information extracted included study location, research objectives, GIS techniques, decision criteria, weighting methods, validation procedures, datasets, key findings, methodological strengths, limitations, and identified research gaps. Comparative analysis was then undertaken to identify common methodological trends, emerging technologies, and opportunities for future research. The findings were synthesized narratively and presented through summary tables and a conceptual framework illustrating the integration of GIS and MCE in hospital site selection.

2. Theoretical Foundations of Hospital Site Selection

The selection of an appropriate hospital location is underpinned by several spatial, economic, and geographical theories that explain how services should be distributed to maximize accessibility, efficiency, and equity. Before the advent of Geographic Information Systems (GIS) and Multi-Criteria Evaluation (MCE), healthcare planners relied primarily on classical location theories to determine the optimal placement of public facilities. These theories established the conceptual basis for understanding the relationship between population distribution, travel distance, service demand, and resource allocation. Although they were developed decades before modern geospatial technologies, they continue to influence contemporary healthcare planning and provide the theoretical foundation upon which GIS-based decision-support systems have evolved (Malczewski & Rinner, 2015).

Modern hospital site selection extends beyond these traditional theories by integrating spatial analysis, environmental assessment, socio-economic considerations, and stakeholder preferences within GIS-based Multi-Criteria Decision-Making (MCDM) frameworks. Consequently, understanding these theories is essential for appreciating the evolution of healthcare facility planning and the rationale behind contemporary GIS–MCE models.

2.2 Central Place Theory

Central Place Theory (CPT) was developed by the German geographer Walter Christaller in 1933 to explain the spatial distribution of settlements and public services. Christaller proposed that settlements naturally develop in a hierarchical pattern, with larger urban centres providing more specialized services while smaller settlements offer only basic services. According to the theory, higher-order services,

such as tertiary hospitals, are located in larger population centres because they require larger catchment populations to remain economically viable (Christaller, 1933).

The theory assumes an isotropic surface characterized by uniform population distribution, equal transportation costs in all directions, and rational consumer behaviour. Under these assumptions, settlements form hexagonal service areas that minimize travel distances while maximizing service coverage. Although these assumptions rarely exist in reality, the theory remains one of the most influential frameworks in regional planning and public service distribution.

Application to Hospital Site Selection

Central Place Theory provides an important conceptual framework for understanding the hierarchical organization of healthcare systems. Healthcare services are generally structured into primary, secondary, and tertiary levels, each serving different population sizes and geographical areas. Primary healthcare centres provide routine medical services within local communities, whereas secondary hospitals serve larger districts, and tertiary hospitals offer specialized services that attract patients from extensive catchment areas (Guagliardo, 2004).

In hospital planning, CPT suggests that highly specialized hospitals should be located within major urban centres where sufficient population demand exists, while smaller healthcare facilities should be distributed across rural communities to maximize accessibility. This hierarchical organization enables healthcare systems to allocate resources efficiently while reducing unnecessary duplication of expensive medical infrastructure.

2.3 Gravity Model

The Gravity Model originated from Newton's Law of Universal Gravitation and was later adapted to explain interactions between geographical locations. Reilly (1931) first applied gravity principles to retail trade, and the concept was subsequently extended to transportation planning, migration analysis, healthcare accessibility, and service utilization.

The Gravity Model assumes that interaction between two locations increases with population size but decreases as travel distance or travel time increases. In healthcare planning, hospitals with greater capacity, more specialized services, and better medical equipment attract patients from wider geographical areas than smaller facilities.

Application in Healthcare Planning

The Gravity Model has become one of the most widely used approaches for evaluating healthcare accessibility because it recognizes that accessibility depends not only on physical distance but also on the attractiveness and capacity of healthcare facilities (Joseph & Phillips, 1984).

Modern GIS software incorporates gravity-based accessibility models through network analysis, allowing researchers to estimate travel times, service catchment areas, and patient flows. These analyses help identify underserved communities, evaluate healthcare equity, and optimize hospital placement.

For example, a hospital equipped with advanced diagnostic facilities, specialized surgeons, and intensive care units is likely to attract patients from neighbouring districts despite longer travel distances. Conversely, small community hospitals mainly serve nearby populations.

3. Geographic Information Systems in Healthcare Planning and Multi-Criteria Evaluation Methods

The rapid advancement of Geographic Information Systems (GIS) has revolutionized healthcare planning by providing sophisticated tools for acquiring, managing, analysing, and visualising geographically referenced data. Unlike traditional planning methods that relied heavily on manual mapping and descriptive statistics, GIS enables decision-makers to integrate multiple spatial datasets into a unified analytical environment where complex

relationships between population distribution, transportation networks, environmental conditions, land use, and healthcare infrastructure can be examined simultaneously (Longley et al., 2015).

In healthcare planning, GIS has evolved from a simple mapping tool into a comprehensive spatial decision-support system capable of modelling healthcare accessibility, identifying underserved populations, evaluating emergency response capabilities, monitoring disease distribution, and supporting strategic infrastructure development. The increasing availability of high-resolution satellite imagery, digital elevation models (DEMs), open geospatial databases, remote sensing products, and cloud-based GIS platforms has significantly improved the precision and efficiency of healthcare facility planning (Chang, 2021).

Because hospital site selection involves numerous conflicting spatial, environmental, economic, and social criteria, GIS alone cannot determine the optimal location. Consequently, GIS is commonly integrated with Multi-Criteria Evaluation (MCE) techniques, enabling planners to combine spatial analysis with structured decision-making procedures. This integration has become one of the most widely adopted approaches for healthcare facility location planning worldwide.

3.2 Geographic Information Systems in Healthcare Planning

3.2.2 Evolution of GIS in Healthcare Planning

The application of GIS in healthcare began primarily with disease mapping and epidemiological surveillance. During the 1990s and early 2000s, researchers increasingly used GIS to analyse disease outbreaks, healthcare accessibility, environmental health risks, and emergency response systems (Cromley & McLafferty, 2012).

3.3 Spatial Criteria Used in Hospital Site Selection

Hospital location decisions require consideration of numerous criteria representing physical, environmental, socio-economic, and infrastructural conditions. Although specific criteria vary between studies, the literature consistently identifies several core factors.

Table 1: Spatial Criteria Used in Hospital Site Selection

Criterion Category	Typical Variables	Importance
Demographic	Population density, population growth, age distribution	Determines healthcare demand
Accessibility	Roads, travel time, public transport	Improves patient access
Environmental	Flood zones, wetlands, pollution, protected areas	Ensures environmental safety
Topographical	Elevation, slope, terrain	Influences construction suitability
Infrastructure	Electricity, water supply, telecommunications	Supports hospital operations

Existing Facilities	Distance from hospitals and clinics	Reduces duplication and improves coverage
Land Characteristics	Land use, ownership, availability, cost	Determines feasibility
Socio-economic	Income level, poverty, urbanisation	Indicates healthcare needs

3.4 Multi-Criteria Evaluation (MCE)

3.4.1 Concept of MCE

Multi-Criteria Evaluation refers to a collection of decision-support techniques that facilitate the systematic evaluation of alternatives based on multiple, often conflicting, criteria (Malczewski & Rinner, 2015). Rather than relying on a single factor, MCE enables decision-makers to integrate quantitative measurements and qualitative judgments into a transparent analytical framework.

In hospital site selection, MCE supports decisions by assigning relative importance (weights) to different criteria and combining them to produce suitability scores. This approach is particularly valuable because hospital planning involves trade-offs among accessibility, cost, environmental sustainability, equity, and future development.

3.6 Integration of GIS and Multi-Criteria Evaluation

The integration of GIS and MCE represents one of the most significant advances in healthcare facility planning. GIS provides spatial analysis capabilities, while MCE offers structured decision-making procedures for weighting and combining diverse criteria. Together, these technologies enable planners to evaluate environmental suitability, accessibility, socio-economic conditions, infrastructure availability, and healthcare demand within a single analytical framework.

Compared with traditional planning methods, GIS–MCE integration offers several advantages:

i. Simultaneous evaluation of multiple spatial criteria.

ii. Transparent and reproducible decision-making.

iii. Improved visualisation through suitability maps.

iv. Efficient scenario analysis and sensitivity testing.

v. Support for participatory planning involving multiple stakeholders.

These advantages explain why GIS–MCE has become the dominant methodological framework for hospital site selection in the past decade.

The role of Geographic Information Systems and Multi-Criteria Evaluation methods in contemporary hospital site selection. GIS provides powerful capabilities for managing and analysing spatial data, while MCE enables the systematic evaluation of multiple decision criteria. The integration of these approaches has transformed healthcare planning by supporting evidence-based, transparent, and reproducible site selection processes. Among the available decision-making methods, AHP remains the most widely applied, although Fuzzy AHP, TOPSIS, ELECTRE, PROMETHEE, VIKOR, and Weighted Linear Combination are increasingly adopted depending on the planning context. The next chapter reviews empirical studies published between 2010 and 2025, comparing methodological approaches, decision criteria, weighting techniques, and key findings from different regions of the world.

4. Empirical Review of GIS-Based Hospital Site Selection Studies

Empirical studies on hospital site selection using Geographic Information Systems (GIS) and Multi-Criteria Evaluation (MCE) have expanded significantly between 2010 and 2025. These studies demonstrate a global shift from traditional heuristic decision-making toward spatially explicit, data-driven, and multi-criteria decision-support systems. Across different regions, researchers consistently apply GIS–MCE frameworks to identify optimal hospital locations, improve healthcare accessibility, and support equitable distribution of health services.

A synthesis of the literature reveals that despite geographical differences, most studies follow a similar methodological structure: selection of criteria, standardization of spatial data, weighting using Multi-Criteria Decision-Making (MCDM) techniques, integration using GIS overlay models, and validation through sensitivity analysis or comparison with existing hospital locations.

4.3 Empirical Studies by Region

4.3.1 Asia

Asian studies form the largest body of GIS-based hospital site selection research. In countries such as Iran and India, researchers frequently use AHP and GIS overlay techniques to evaluate environmental, demographic, and infrastructural criteria. Commonly applied factors include population density, road accessibility, land use, slope, and proximity to existing healthcare facilities.

Studies consistently show that urban expansion and uneven healthcare distribution are major drivers for hospital site optimization. Many studies report that existing hospitals are often clustered in central urban zones, leaving peripheral and rural areas underserved. GIS–MCE models are therefore used to identify new hospital sites that improve spatial equity.

A recurring limitation in Asian studies is the heavy reliance on expert judgment in weighting criteria, with limited validation against real healthcare outcomes.

4.3.2 Europe

European studies tend to emphasize methodological rigor and advanced spatial modelling techniques. Researchers frequently integrate GIS with location–allocation models, network analysis, and accessibility indices such as the Two-Step Floating Catchment Area (2SFCA) method.

Unlike many Asian studies, European research often prioritizes healthcare equity and accessibility rather than purely physical suitability. There is also greater use of sensitivity analysis and validation techniques to test model robustness.

However, European studies are less focused on rapid urban expansion compared to developing regions, making their models sometimes less transferable to rapidly growing cities in Africa and Asia.

4.3.3 Africa

African studies on hospital site selection are increasing but remain comparatively limited. Most research focuses on addressing severe healthcare accessibility gaps in both rural and peri-urban areas.

GIS–MCE applications in Africa commonly identify significant spatial inequalities in healthcare provision. Studies consistently show that rural populations are disproportionately far from existing hospitals, with poor road infrastructure further limiting accessibility.

The most common limitation in African studies is data scarcity, particularly regarding high-resolution population data, updated road networks, and environmental layers. Despite this, GIS-based models are widely recognized as valuable tools for guiding healthcare infrastructure development.

4.3.4 Middle East

Middle Eastern studies, particularly in Iran, Saudi Arabia, and Iraq, show strong adoption of GIS–AHP frameworks. These studies often integrate environmental constraints such as flood

risk, land stability, and seismic vulnerability due to regional geographic conditions.

A key feature of this region is the integration of disaster risk reduction into hospital site selection models, reflecting the importance of emergency preparedness. Many studies also emphasize strategic urban planning aligned with national development goals.

4.3.5 Americas

In North and South America, GIS-based hospital location studies tend to focus on healthcare accessibility, emergency response optimization, and urban service distribution. In the United States, advanced spatial analytics such as network-based service area modeling and optimization algorithms are widely used.

Latin American studies often focus on addressing healthcare inequality in rapidly urbanizing cities. Similar to African contexts, disparities between urban and rural healthcare access remain a major concern.

4.4 Comparative Summary of Empirical Studies

The table below summarizes key characteristics of representative GIS–MCE hospital site selection studies

Table 2: Comparative Sumarry

Region	Common Methods	Key Criteria	Strengths	Limitations
Asia	AHP, GIS overlay	Population, roads, slope, land use	Extensive case studies	Subjective weighting
Europe	GIS + 2SFCA, network analysis	Accessibility, equity	Strong validation	Less focus on rapid growth
Africa	AHP, WLC	Accessibility, infrastructure	Identifies inequality	Data limitations
Middle East	AHP, Fuzzy AHP	Environmental risk, slope	Disaster-focused planning	Limited standardization
Americas	GIS optimization, network models	Emergency response, accessibility	Advanced modelling	Unequal data quality

4.6 Synthesis of Empirical Evidence

The empirical literature confirms that GIS–MCE is highly effective for hospital site selection, particularly in identifying suitable areas and highlighting spatial inequalities in healthcare access. However, the effectiveness of these models depends heavily on data quality, weighting methodology, and validation techniques.

A major conclusion across studies is that hospital site selection is not purely a spatial problem but a socio-spatial decision-making process influenced by demographic change, policy priorities, and environmental risks. This reinforces the need for integrated, multi-dimensional modelling approaches.

4.7 Transition to Critical Analysis

While empirical studies demonstrate the

usefulness of GIS–MCE frameworks, they also reveal significant methodological inconsistencies and limitations. These include subjective weighting systems, limited validation procedures, lack of uncertainty modelling, and insufficient integration of emerging technologies such as machine learning and big data analytics.

5. Critical Discussion, Research Gaps, Conceptual Framework, and Conclusion

5.1 Critical Discussion of GIS–MCE Approaches

The synthesis of literature on GIS-based Multi-Criteria Evaluation (MCE) for hospital site selection reveals a strong methodological convergence toward integrated spatial decision-support systems. Across studies conducted between 2010 and 2025, GIS–MCE frameworks have consistently demonstrated their usefulness in addressing complex healthcare planning problems involving multiple conflicting criteria such as accessibility, cost, environmental constraints, and population demand.

However, despite their widespread application, several critical methodological issues persist. First, most studies rely heavily on the Analytic Hierarchy Process (AHP) for weight derivation. While AHP is widely used due to its simplicity and interpretability, it remains fundamentally subjective because it depends on expert judgment. This introduces bias and reduces reproducibility across different studies and geographical contexts (Saaty, 1980; Malczewski & Rinner, 2015).

Second, many GIS–MCE studies employ static models that fail to account for temporal dynamics such as population growth, urban expansion, climate change, and evolving healthcare demand. As a result, hospital site selection outputs often reflect current conditions rather than future scenarios, limiting their long-term planning value.

Third, validation of suitability models remains weak. A significant proportion of studies validate results visually or through expert opinion rather than empirical healthcare utilization data or post-implementation evaluation. This limits the ability to assess the real-world accuracy of GIS-based recommendations.

Finally, although advanced techniques such as Fuzzy AHP, TOPSIS, and machine learning have been introduced, their integration into unified frameworks remains limited. Many studies apply these methods in isolation rather than combining them into hybrid models that can better handle uncertainty and complexity.

5.2 Research Gaps Identified in the Literature

Based on the reviewed literature, the following key research gaps are identified:

5.2.1 Over-reliance on Subjective Weighting Methods

Most studies depend on expert-driven weighting approaches such as AHP, which introduce subjectivity and limit reproducibility. There is a need for more objective weighting techniques such as entropy-based weighting or machine learning-based feature importance estimation.

5.2.2 Lack of Temporal and Predictive Modelling

Existing studies are predominantly static and do not incorporate predictive modelling of population growth, urban expansion, or healthcare demand changes. This limits their applicability for long-term healthcare infrastructure planning.

5.2.3 Limited Integration of Advanced Analytics

Although GIS technology has advanced significantly, most hospital site selection studies do not fully integrate artificial intelligence, deep learning, or big spatial data analytics, which could significantly improve decision accuracy.

5.2.4 Weak Validation Frameworks

Many studies lack robust validation using real-

world healthcare outcomes such as patient distribution, hospital utilization rates, or post-construction performance evaluation.

5.2.5 Insufficient Consideration of Climate and Disaster Risks

Only a limited number of studies integrate climate change impacts, flood risk, seismic vulnerability, and environmental sustainability into hospital site selection models, despite their increasing importance.

5.2.6 Limited Stakeholder Participation

Most models are expert-driven, with minimal involvement of community stakeholders, healthcare workers, or policymakers in the decision-making process.

5.3 Conceptual Framework for GIS–MCE Hospital Site Selection

Based on the reviewed literature, a comprehensive conceptual framework for hospital site selection can be proposed. The framework integrates spatial data analysis, decision criteria, and multi-criteria evaluation techniques within a GIS environment.

5.3.2 Conceptual Flow

Input Data → GIS Processing → Criteria Standardization → Weighting (MCE) → Overlay Analysis → Suitability Mapping → Decision Output

This framework ensures transparency, flexibility, and adaptability across different geographic contexts.

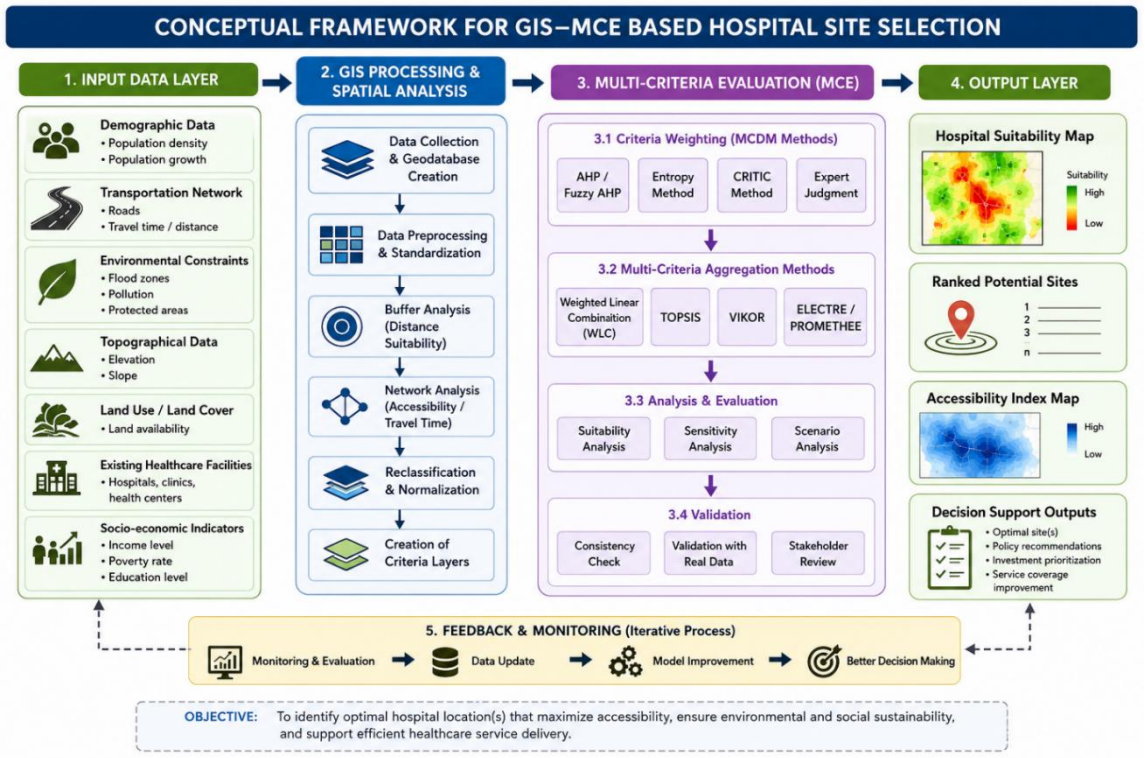

Figure 1: Conceptual Framework

5.4 Implications for Healthcare Planning

The integration of GIS and MCE has significant implications for healthcare infrastructure development. First, it improves evidence-based planning by replacing subjective decision-making with structured analytical models.

Second, it enhances healthcare equity by identifying underserved populations and optimizing facility distribution. Third, it supports efficient allocation of limited healthcare resources, particularly in developing countries where infrastructure constraints are significant.

Furthermore, the integration of emerging technologies such as artificial intelligence, machine learning, and remote sensing offers opportunities for real-time decision-making and predictive healthcare planning.

Table 3: Summary of Key GIS–MCE Hospital Site Selection Studies, Identified Gaps, and Justification for Current Study

Author(s) / Study Area	Methods Used	Key Focus / Contribution	Identified Gaps	Justification for Current Study
Malczewski (2006)	GIS–MCE overview	Foundational review of GIS-based decision analysis	Conceptual; not healthcare-specific; outdated dataset	Need for updated healthcare-focused GIS–MCE synthesis (2010–2025)
Guagliardo (2004)	Accessibility models (GIS)	Healthcare accessibility measurement	Limited integration with decision-making models	Need integration of accessibility + MCE for hospital siting
Saaty (1980)	AHP	Introduced structured weighting method	Highly subjective; inconsistency in expert judgment	Need hybrid weighting (AHP + objective methods)
Luo & Wang (2003)	Spatial accessibility (2SFCA)	Healthcare access measurement framework	Does not optimize hospital location directly	Need combined accessibility + suitability modelling
Church & Murray (2009)	Location–allocation models	Optimization of facility location	Ignores environmental & socio-economic complexity	Need multi-criteria spatial decision integration
Asian GIS–MCE studies (Iran, India, China)	AHP + GIS overlay	Hospital suitability mapping	Heavy reliance on subjective weights; weak validation	Need more objective weighting + validation with real data
European studies	GIS + network analysis + 2SFCA	Emphasis on accessibility and equity	Less focus on rapidly growing urban contexts	Need adaptable models for dynamic urban growth areas
African studies	GIS–AHP + overlay analysis	Identification of healthcare inequality	Poor data availability; limited high-resolution datasets	Need robust methods usable under data-scarce conditions
Middle East studies	GIS–AHP, Fuzzy AHP	Environmental + disaster-sensitive siting	Limited integration of socio-economic dynamics	Need integrated socio-economic + environmental framework

Global recent studies (2015–2025)	Hybrid GIS–MCE (TOPSIS, VIKOR, ANN)	Advanced hybrid decision-making models	Fragmented approaches; lack of unified framework	Need comprehensive GIS–MCE conceptual framework
Recent machine learning GIS studies	ML + spatial modeling	Predictive suitability modelling	Limited interpretability; weak policy integration	Need interpretable hybrid GIS–MCE–ML frameworks
COVID-era studies	GIS accessibility mapping	Emergency healthcare planning	Short-term focus; not long-term planning oriented	Need long-term sustainable hospital planning models

5.5 Conclusion

This study has provided a comprehensive review of GIS-based multi-criteria Evaluation methods for hospital site selection between 2010 and 2025. The review demonstrates that hospital site selection is a complex spatial decision-making problem that requires the integration of multiple criteria including demographic, environmental, infrastructural, and socio-economic factors.

The findings show that GIS–MCE frameworks are highly effective tools for supporting healthcare planning and improving accessibility. However, existing studies are limited by subjective weighting methods, weak validation approaches, lack of temporal analysis, and limited integration of advanced computational techniques.

Future research should focus on developing hybrid models that integrate GIS, machine learning, and big data analytics to improve predictive accuracy and reduce uncertainty. In addition, more robust validation frameworks and participatory decision-making approaches are required to ensure that hospital site selection models are both scientifically sound and socially relevant.

Overall, GIS-based MCE represents a powerful and evolving methodology that will continue to play a critical role in healthcare infrastructure planning, particularly in rapidly urbanizing and resource-constrained environments.

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