Science Frontiers
2024, Vol. 5, No. 3, pp. 102-109
https://doi.org/10.11648/j.sf.20240503.11

Review Article

Review on Potential Urban Development Site Selection Using Geospatial-Based Multi-Criteria Decision Analysis (MCDA) Techniques in the Context of Ethiopia

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Abstract

This review paper provides a comprehensive assessment of the opportunities and challenges in leveraging geospatial-based technologies, particularly Multi-Criteria Decision Analysis (MCDA) techniques, to enhance the effectiveness of urban development site selection in Ethiopia. The overarching findings highlight several critical focus areas for improvement. Firstly, the review emphasizes the need to strengthen the availability, quality, and accessibility of geospatial data through the development of robust data infrastructures and innovative data collection methods. Secondly, it recommends adopting a more inclusive and collaborative approach to stakeholder engagement, coupled with targeted capacity-building initiatives to enhance the technical skills and knowledge of urban planners, GIS experts, and local stakeholders. Thirdly, the paper suggests incorporating advanced spatial modeling and simulation techniques to capture the dynamic nature of urban growth patterns, as well as integrating climate change impact assessments and disaster risk analyses into the decision-making framework. Fourthly, it emphasizes the importance of strengthening institutional and organizational frameworks to promote cross-sectoral collaboration, data sharing, and integrated decision-making processes. Finally, the review underscores the significance of designing user-friendly and customizable Spatial Decision Support Systems (SDSS) that cater to the specific needs and constraints of the Ethiopian urban development context. The review concludes that the use of geospatial-based MCDA approaches holds immense potential in addressing Ethiopia's complex urban development challenges, as it enables a comprehensive evaluation of suitability factors and the exploration of alternative urban development strategies.

Keywords

Analytical Hierarchy Process, GIS, Suitability Analysis, Urban Growth

1. Introduction

Ethiopia has experienced rapid urbanization, with its urban population growing from 14.1% in 2000 to 21.2% in 2020, and projected to reach 35% by 2030 [28, 25]. This growth, driven by rural-to-urban migration, natural population increase, and economic development [9], has led to the expansion of informal settlements, infrastructure deficiencies, and environmental degradation in major cities [24]. To accommodate the growing urban population and promote sustainable development, there is a growing interest in using geospatial-based multi-criteria decision analysis (MCDA) tech-

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Received: 2 July 2024; **Accepted:** 23 July 2024; **Published:** 30 August 2024

niques to guide the urban site selection process [9]. MCDA can help address land use conflicts and improve urban planning and management, supporting informed decision-making and increasing transparency in the decision-making process [10].

Rapid urbanization in Ethiopia has increased land demand for development, leading to occupation of environmentally sensitive areas and conversion of agricultural land due to limited suitable land [23]. Balancing urban development with environmental protection and ensuring the availability and accessibility of essential infrastructure have become major challenges, which can be addressed through the integration of geospatial data and advanced technologies [23, 1].

Addressing the needs and concerns of diverse stakeholders, including local communities and vulnerable populations, is essential for equitable and inclusive urban development, and emerging participatory mapping and crowd sourcing technologies can facilitate this process [1]. However, fragmented institutional responsibilities, limited coordination, and weak enforcement of urban planning regulations pose significant challenges, which can be addressed through advancements in GIS-based decision support systems and cloud-based platforms [23].

The lack of comprehensive and up-to-date geospatial data can hinder the effective application of site selection techniques, but recent developments in cloud-based GIS platforms, crowd sourcing initiatives, and satellite-based data collection have improved data availability and quality [24, 1]. To address these challenges and complexities, the integration of geospatial-based multi-criteria decision analysis (MCDA) techniques with recent advancements in technology has gained significant attention in the context of urban development site selection in Ethiopia, enabling more comprehensive, evidence-based, and inclusive decision-making processes for sustainable urban development [24]. The integration of geospatial data and MCDA techniques has emerged as a promising approach for addressing the complex challenges of urban development site selection in Ethiopia [23]. Recent studies have highlighted the potential of geospatial-based MCDA in the Ethiopian context, including comprehensive evaluation of factors [24], spatial analysis and visualization [10], stakeholder engagement and participatory approaches [1], scenario-based evaluation and trade-off analysis [24], and improved coordination and collaboration [1].

2. Urbanization Trends and Challenges in Ethiopia

Ethiopia has experienced rapid urbanization in recent decades, with the urban population growing at a faster rate than the national average. According to recent estimates, the country's urban population has increased from 16.2% in 2010 to 21.2% in 2020, and it is projected to reach 30% by 2030 [29]. This rapid urban population growth is driven by both natural increase and rural-to-urban migration, with the latter contributing significantly to the expansion of urban centers [10]. Factors contributing to rural-to-urban migration include the search for better economic opportunities, access to social services, and the desire for a higher standard of living [24].

Major urban centers, such as Addis Ababa, Dire Dawa, and Hawassa, have experienced the most significant population growth, attracting migrants from various parts of the country [1]. The rapid urbanization has led to the physical expansion of urban areas, with many cities experiencing sprawling growth and the development of informal settlements on the urban periphery [9]. The expansion of urban areas has often outpaced the capacity of local governments to provide basic infrastructure, affordable housing, and essential services, leading to the growth of informal settlements and unplanned development [10].

The rapid urbanization in Ethiopia has brought about a range of challenges, including the need for improved urban planning, investment in infrastructure, access to affordable housing, and the provision of basic services [24]. However, urbanization also presents opportunities for economic growth, employment generation, and the improvement of living standards, provided that the challenges are effectively addressed [9]. The Ethiopian government has recognized the importance of managing urbanization and has implemented various policies and strategies to promote sustainable urban development [1, 13].

2.1. Drivers and Challenges Associated with Urban Growth

The drivers of urban growth in Ethiopia are multifaceted. The pursuit of better economic opportunities, such as employment and higher incomes is a significant driver of rural-to-urban migration [11]. The availability of better access to social services, such as healthcare and education, also attracts people to urban centers [19, 21]. Ethiopia's high population growth rate and young, mobile population further contribute to rapid urbanization [27]. Government policies and investments in urban development, such as industrial parks and road networks, can also stimulate urban growth [17]. However, this rapid urban growth has brought about significant challenges. Rapid expansion has led to the encroachment of urban areas onto agricultural and rural lands, causing conflicts between different land use interests [30]. The development of informal settlements and unplanned growth has exacerbated these land use conflicts, particularly in urban peripheries [22]. Local governments have struggled to keep pace, failing to provide adequate infrastructure, transportation, water, and affordable housing [22], leading to the proliferation of informal settlements with limited access to basic services [11, 18]. Rapid urbanization has also resulted in environmental degradation, including the loss of green spaces, increased air pollution, and the conversion of agricultural and natural lands [30, 22].

2.2. Existing Urban Planning Policies, Regulations, and Initiatives in Ethiopia

Ethiopia has made efforts to develop urban planning policies and implement various initiatives to manage the challenges of rapid urbanization. The Urban Development Policy (2005) aims to guide the sustainable development of urban centers, emphasizing balanced regional development, efficient land use, and the provision of basic services [6]. The Growth and Transformation Plans (2010-2020) have recognized the need for effective urban planning and management, setting targets for improving urban infrastructure, housing, and service delivery [21]. The Urban Land Lease Proclamation (2011) regulates the lease and administration of urban land, aiming to promote efficient land use and prevent speculation, though it has been criticized for its limited consideration of informal settlements and existing land users [22, 7].

The Integrated Housing Development Program (2005) aims to provide affordable housing and improve living conditions, though it has faced criticism for its limited impact on addressing the needs of the urban poor [11]. Several cities have launched urban renewal and redevelopment programs to revitalize their centers, though these initiatives have struggled to balance economic development, social inclusion, and environmental sustainability [17].

Ethiopia has also started exploring the implementation of smart city concepts, focusing on improving infrastructure, service delivery, and governance through digital technologies, with pilot projects in cities like Addis Ababa, Bahir Dar, and Kombolcha [7]. While Ethiopia has made efforts to address rapid urbanization, the effectiveness of these policies and initiatives has been limited, and more comprehensive and inclusive approaches are needed to ensure sustainable urban development [24, 21].

3. Geospatial Data and Techniques for Urban Site Selection

Geospatial data and techniques have become crucial for urban site selection in Ethiopia. Satellite data enables analysis of land cover, sprawl, and site suitability for planning and decision -making [7, 17]. Aerial and drone-acquired imagery have complemented satellite data, enabling detailed mapping of urban features and informal settlements to identify micro-level characteristics essential for site selection [30, 6, 14]. Digital Elevation Models (DEMs) from Shuttle Radar Topography Mission (SRTM) and Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) have been used to assess terrain characteristics like slope, drainage, and accessibility of potential sites [7, 11].

GIS-based spatial analysis has integrated various datasets to map and evaluate factors like land use, infrastructure, environmental constraints, and socioeconomic conditions [21, 6]. Remote sensing techniques, such as image classification and change detection, have analyzed urban land cover, monitored growth, and identified potential sites, including informal settlements and underutilized land [7, 17, 11]. Multi-Criteria Decision Analysis (MCDA) frameworks integrated with Geographic Information System (GIS) have developed comprehensive site selection models, considering various factors to prioritize suitable sites [21, 30]. However, further integration with local knowledge and stakeholder engagement is needed to ensure sustainable and inclusive urban development [22].

3.1. The Data Requirements, Availability, and Quality Issues

Geospatial data and techniques are crucial for urban site selection in Ethiopia. Satellite data enables analyzing land cover, sprawl, and site suitability for planning and decision-making [7, 17]. Aerial and drone-acquired imagery have complemented satellite data, enabling detailed mapping of urban features and informal settlements to identify micro-level characteristics essential for site selection [30, 6]. Digital Elevation Models (DEMs) from SRTM and ASTER have been used to assess terrain characteristics like slope, drainage, and accessibility of potential sites [11, 17].

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3.2. Advantages and Limitations of Using Geospatial Data for Urban Site Selection

Satellite imagery and GIS data provide a comprehensive overview of spatial characteristics, enabling the identification of suitable locations based on different factors [7, 30]. Geospatial analysis techniques, such as suitability mapping and multi-criteria decision analysis, can systematically evaluate and compare potential sites, leading to more informed and evidence-based decision-making [22, 6, 7]. Furthermore, geospatial data can monitor and evaluate the impacts of urban development, informing future planning and ensuring more sustainable development [21, 30].

However, the availability and quality of geospatial data can be limited, affecting the reliability and accuracy of the site selection process [7, 16]. Effective utilization requires technical expertise and adequate resources, hindering widespread adoption [21]. Additionally, geospatial data alone may not provide a complete picture, and integration with other

data sources can be challenging [7]. Addressing data availability, building technical capacity, and fostering cross-sectoral collaboration can enhance the application of geospatial approaches in urban planning [22, 6].

4. Multi-Criteria Decision Analysis (MCDA) for Urban Site Selection

4.1. Commonly Used MCDA Methods

The Analytic Hierarchy Process (AHP) is a structured approach for decision-making that involves pairwise comparisons of criteria to determine their relative importance [21, 17]. AHP has been used in various urban development site selection studies in Ethiopia, such as identifying suitable locations for urban expansion [7] and evaluating the suitability of sites for industrial development [11]. For instance, [7] used AHP to integrate spatial and socioeconomic factors in selecting optimal sites for urban expansion in Addis Ababa, while [11] applied AHP to assess the suitability of sites for industrial development in Mekelle.

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a compensatory MCDA method that ranks alternatives based on their proximity to the ideal solution [22, 30]. TOPSIS has been employed in urban development site selection studies in Ethiopia, such as identifying suitable locations for urban expansion [22] and evaluating the suitability of sites for public facilities [30].

The Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) is an outranking MCDA method that allows for the ranking of alternatives based on their pairwise comparisons [21, 6]. PROMETHEE has been applied in urban development site selection studies in Ethiopia, such as identifying suitable locations for urban growth [21] and evaluating the suitability of sites for residential development [6]. The choice of a specific MCDA method depends on the decision-making objectives, the available data, and the preferences of the decision-makers [12].

4.2. Criteria and Factors Considered in the MCDA Process

In the context of urban development site selection in Ethiopia, recent studies have highlighted the key criteria and factors considered in the MCDA process. These factors encompass environmental, social, economic, and infrastructure-related aspects [7, 21, 22]. Environmental factors include the evaluation of land use and land cover patterns [7, 21], topography and slope [11, 30], hydrology and drainage [6, 17], and environmental sensitivity [7]. Social factors consider population distribution and growth [30], accessibility and proximity to amenities [21], and land tenure and ownership [17]. Economic factors assess the proximity to economic hubs [22], land value and market demand [30], and the cost of development [7]. Infrastructure-related factors encompass the assessment of the transportation network [6], utility infrastructure [30, 22], and the availability and quality of urban services [7, 21].

4.3. The weighting and Prioritization of the MCDA criteria

The weighting and prioritization of MCDA criteria for urban development site selection in Ethiopia have been influenced by stakeholder involvement, expert opinion, analytical methods, and regional or local context and others [6, 11]. The AHP has been widely used to determine the weights of MCDA criteria, with researchers prioritizing factors such as environmental conditions, land cover, and topography [7, 17]. Some studies have employed entropy-based methods to assign weights, considering the inherent information content of the criteria [21, 22], where infrastructure-related factors, such as road accessibility, have been prioritized [21, 26].

Researchers have often conducted sensitivity analyses to assess the robustness of the MCDA results and the impact of different weighting schemes on the final site selection [11, 30], highlighting the importance of infrastructure-related factors [30]. Finally, the weighting and prioritization can be influenced by the specific regional or local context, such as data availability, land use patterns, and development priorities [17, 22].

4.4. Integration of Geospatial-based MCDA Techniques

The integration of geospatial data and MCDA techniques has been crucial for urban development site selection. Researchers have utilized various geospatial data sources, such as satellite imagery, digital elevation models, and infrastructure data, to inform the MCDA process [7, 21]. MCDA techniques have been coupled with Geographic Information Systems (GIS) to perform spatial analysis and generate suitability maps for urban development [30, 22].

Some studies have integrated MCDA with spatial optimization algorithms to identify the optimal urban development sites, considering both the MCDA criteria and spatial constraints [6, 17]. Stakeholder involvement has been important, with researchers incorporating local knowledge and preferences through participatory mapping approaches [11, 17]. Additionally, efforts have been made to develop web-based decision support systems that integrate geospatial data, MCDA techniques, and user-friendly interfaces to facilitate the urban development site selection process [7, 21]. Overall, the integration of geospatial data and MCDA has enabled evidence-based decision-making in urban planning, supporting the identification of optimal sites for urban development in Ethiopia while considering various environmental, infrastructure, and socioeconomic factors.

4.5. Critical analysis of the strengths, limitations, and challenges

The workflow to integrate geospatial data and MCDA techniques for urban development site selection includes data collection and pre processing from various sources, such as satellite imagery, digital elevation models, and infrastructure databases [7, 30]. The MCDA criteria are identified, and their weights are determined through stakeholder engagement, expert opinion, or analytical methods like the Analytical Hierarchy Process (AHP) [6, 11]. GIS-based spatial analysis techniques, such as overlay analysis and proximity analysis, are used to generate suitability maps [21, 22]. Finally, the MCDA techniques, including TOPSIS, PROMETHEE, or weighted sum, are integrated with the spatial analysis to produce the final site selection [21, 17]. Researchers have leveraged a range of software tools, including GIS software, specialized MCDA software, and web-based decision support systems, to facilitate the geospatial-based MCDA process [7, 21]. Advanced computational approaches, such as scripting languages, spatial optimization algorithms, and cloud-based computing platforms, have also been employed to enhance the integration and analysis of geospatial data and MCDA [30, 7, 21].

5. Case Studies and Best Practices

Recent case studies from Ethiopia, India, Vietnam, and Indonesia have demonstrated the application of geospatial-based multi-criteria decision analysis (MCDA) for identifying suitable locations for urban development. In Ethiopia, [7] used GIS and MCDA techniques, incorporating criteria like land use, slope, and proximity to roads and water bodies, to select urban development sites in Bahir Dar. The study highlighted the benefits of the geospatial-based MCDA approach in enhancing transparency and supporting informed decision-making for urban planning.

A case study from Kolkata, India, by [4] applied a similar geospatial-based MCDA approach, using criteria such as proximity to infrastructure and environmental factors, and the PROMETHEE method. The study emphasized the importance of integrating GIS and MCDA for holistic decision-making and the need for stakeholder engagement. In Hanoi, Vietnam, [15] used the Analytic Network Process (ANP), a geospatial-based MCDA technique, to select urban development sites based on factors like land use, infrastructure, and environmental considerations. The study highlighted the advantages of the geospatial-based MCDA approach in addressing the complex and multi-dimensional nature of urban development site selection.

Similarly, a case study from Semarang, Indonesia, by [20] integrated GIS and MCDA to identify suitable urban development sites in the coastal area, considering criteria such as flood risk, proximity to roads, and environmental factors. The study underscored the importance of incorporating both spatial and non-spatial decision factors in the MCDA process and the need for effective stakeholder engagement. Here is a summary of 10 recently published articles that have used geospatial-based MCDA for urban development site selection in developing country contexts (Table 1).

Table 1. *Geospatial-based MCDA for urban development site selection used by different researchers.*

Year	Study area	Methodology	Key findings	Limitations
2	Bahir Dar, Ethiopia	Integration of GIS and TOPSIS MCDA	Highlighted the benefits of geospatial-based MCDA in increasing transparency and supporting informed decision-making	1) Limited consideration of stakeholder preferences 2) Subjectivity in criteria weighting
4	Kolkata, India	Geospatial MCDA using PROMETHEE method	Identified suitable urban development sites based on proximity to infrastructure, land cover, and environmental factors	1) Need for more extensive stakeholder engagement 2) Computational complexity for large-scale analysis
15	Hanoi, Vietnam	Geospatial-MCDA using AHP	Identified suitable urban development sites considering land use, infrastructure, and environmental factors	1) Limited consideration of local community preferences 2) Challenges in scaling up the approach
14	Semarang, Indonesia	GIS-based MCDA	Emphasized the importance of incorporating both spatial and non-spatial decision factors in the MCDA process	1) Need for more comprehensive stakeholder engagement 2) Subjectivity in criteria weighting
11	Addis Ababa, Ethiopia	GIS-based MCDA using TOPSIS and VIKOR	identified suitable sites for urban expansion and infill development in Addis Ababa	1) Limited consideration of socioeconomic factors 2) Challenges in data integration and

Year	Study area	Methodology	Key findings	Limitations
				updating
18	Kathmandu Valley, Nepal	GIS-based MCDA using AHP and ELECTRE	Emphasized the importance of stakeholder engagement in the MCDA process	Need for more comprehensive consideration of social and economic factors
13	Dhaka, Bangladesh	GIS-based MCDA using AHP	Highlighted the potential of GIS-based MCDA in supporting sustainable urban planning	Limited consideration of dynamic spatial factors and future growth scenarios
16	Kumasi, Ghana	GIS-based MCDA using TOPSIS	Demonstrated the applicability of geospatial-based MCDA in the African context	Need for more extensive validation and sensitivity analysis
19	Kumasi, Ghana	GIS-based MCDA using Fuzzy AHP	Emphasized the use of fuzzy logic to address the uncertainties in the MCDA process	Challenges in transferring the methodology to other contexts
8	Bandung, Indonesia	GIS-based MCDA using AHP	Highlighted the potential of geospatial-based MCDA in supporting sustainable urban planning	Subjectivity in criteria weighting and stakeholder preferences

As indicated in the above Table, the application of geospatial-based multi-criteria decision analysis (MCDA) for urban development site selection in developing countries has yielded valuable lessons. The integration of GIS and MCDA has increased transparency and supported informed decision-making in diverse contexts. Successful approaches have involved using various MCDA methods and emphasizing stakeholder engagement to provide insights and enhance legitimacy. Common factors considered include accessibility, land use, environmental sensitivity, and infrastructure proximity. However, areas for improvement include more comprehensive stakeholder engagement, integrating dynamic spatial factors and future growth scenarios, and addressing data availability and quality issues.

6. Future Directions and Recommendations

To improve the application of geospatial-based MCDA for urban development site selection in the Ethiopian context, the following recommendations are proposed:

1. Enhance data availability and quality by developing comprehensive geospatial data infrastructures and databases at national and local levels to improve data accessibility and reliability.
2. Adopt a more inclusive and collaborative stakeholder engagement approach, ensuring meaningful participation of local communities, marginalized groups, and decision-makers to better capture diverse perspectives.
3. Integrate dynamic spatial factors and future growth scenarios into the MCDA process to support long-term, sustainable urban planning.
4. Strengthen institutional and organizational frameworks to promote cross-sectoral collaboration, data sharing, and integrated decision-making for urban development.
5. Foster interdisciplinary collaboration among urban planners, GIS experts, environmental scientists, and other relevant stakeholders to enhance the comprehensive and holistic nature of the geospatial-based MCDA process

7. Conclusion

The review paper provides a comprehensive assessment of the key focus areas that require attention to enhance the effectiveness of geospatial-based urban development site selection in the Ethiopian context. Firstly, it highlights the need to strengthen the availability, quality, and accessibility of geospatial data through the development of robust data infrastructures and innovative data collection methods, laying the foundation for more informed decision-making processes. Secondly, the paper recommends adopting a more inclusive and collaborative approach to stakeholder engagement, ensuring the meaningful participation of local communities, marginalized groups, and decision-makers, alongside targeted capacity-building initiatives to enhance the technical skills and knowledge of urban planners, GIS experts, and local stakeholders. Thirdly, the review suggests incorporating advanced spatial modeling and simulation techniques to capture the dynamic nature of urban growth patterns, as well as developing robust future growth scenarios to support long-term, sustainable urban planning, while also integrating climate change impact assessments and disaster risk analyses into the decision-making framework. Fourthly, the paper underscores the importance of strengthening institutional and organizational frameworks to promote cross-sectoral collaboration, data sharing, and integrated decision-making processes, as well as designing user-friendly to the specific needs

and constraints of the Ethiopian urban development context.

Abbreviations

GIS	Geographic Information System
MCDA	Multi-Criteria Decision Analysis
ANP	Analytic Network Process
AHP	Analytical Hierarchy Process
DEMs	Digital Elevation Models
SRTM	Shuttle Radar Topography Mission
ASTER	Advanced Space Borne Thermal Emission and Reflection Radiometer

Acknowledgments

The author, Mr. Adimasu, would like to acknowledge the researchers and government agencies that have published the various geospatial datasets, urban planning reports, and MCDA-related studies in Ethiopia and other countries, without which this review paper would not have been possible.

Author Contributions

Adimasu Tafesse Gontte is the sole author. The author read and approved the final manuscript.

Funding

No funding source for this study.

Data Availability Statement

Desktop review methods was applied to analyses the published articles and similar topics that are available in internet. The author did not generate or collect any primary data for this study. All the information and analyses presented are based on a thorough review of the existing literature related to the title of the study.

Conflicts of Interest

The author declares no conflicts of interest.

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Biography

Adimasu Tafesse Gontte is a senior lecturer at Wollega University, Geography and Environmental Studies Department. He acquired his B. A degree in Geography and Environmental Studies from Wollega University in 2019, and Master's Science in Geographic Information Science and Remote Sensing from Hawassa University in 2023. He currently serves as a lecturer at Wollega University.