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Spatial Multi-Criteria Decision Analysis for Sustainable Urban Expansion: A Case Study of Trincomalee, Sri Lanka

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I. Introduction

Rapid urbanization shapes the global environment. United Nation projections show that 68% of the population will live in cities by 2050, causing land demand, infrastructure stress, and environmental risks. In Trincomalee, accelerated growth, infrastructure deficits, and pressure on forests, wetlands, and coastal areas create planning gaps. This study applies an AHP-based multi-criteria suitability approach to support Trincomalee's development plan by generating fine-grained, empirically derived suitability maps, overcoming limitations in current macro-level zoning and setting the foundation for a more systematic evaluation of future expansion needs. Although several studies in Sri Lanka have explored urban growth, a clear gap remains in district-level, high-resolution suitability assessments that integrate both environmental sensitivity and development priorities. To respond to this gap, this study develops an AHP-based GIS model aimed at identifying the most appropriate locations for sustainable urban expansion in Trincomalee. The outcomes offer practical value for planners by providing transparent, evidence-based spatial guidance that supports responsible land allocation, reduces conflicts with sensitive landscapes, and strengthens long-term, climate-resilient development planning.

II. Literature Review

Especially in rapidly growing regions, urban expansion faces significant challenges in sustainable urban development and spatial planning. The integration of the Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA), in such a case, the Analytical Hierarchy Process (AHP) is very applicable for land suitability analysis and prediction of urban growth. In various case studies globally, including Sri Lanka and other Asian contexts, AHP has been recognized as a prominent method for weighting multiple criteria while achieving robust results. For the countries that have experienced rapid urbanization and have limited socioeconomic datasets, a morphological approach is suitable to predict urban boundaries, focusing on spatiotemporal urban margins, which does not require a lot of data to work well [1]. Such techniques are useful for planners to delineate trajectories and plan for infrastructure provision [1], [3], [5].

To identify optimal residential sites through weighted overlay modeling of accessibility, physical, and social factors, the suitability analysis integrating with AHP and GIS is very effective in the residential development in Sri Lanka [2]. Processing of Landsat and Sentinel satellite data with machine learning algorithms such as Random Forest (RF) provides accurate results for analysis of urban growth variations [3]. Systematically weighing land, social infrastructure, physical infrastructure, economic, and environmental parameters is very important for strategic site selection [4]. Successful validation of GIS and MCDA methods shows that such frameworks can outperform conventional manual planning by achieving greater precision and speed [3].

As recent advances have merged remote sensing, machine learning, and scenario-based suitability modeling can enhance the accuracy of future predictions. A good example for the increment of prediction accuracy is the integration of spatial simulation models, such as CA (Cellular Automata, Markov, and neural networks), and clustering algorithms for dynamic spatial zoning and zoning benefit evaluation [3] [5]. Taken together, previous studies consistently highlight that integrating GIS, MCDA, and spatial simulation techniques provides a reliable foundation for producing accurate and practical urban expansion assessments.

III. Materials and Methods

A. Study Area

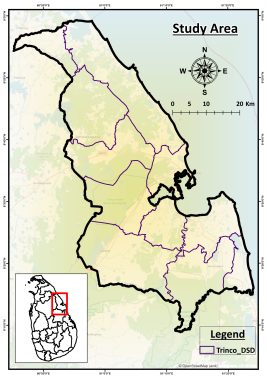

Fig. 1. Study Area Map - Trincomalee District

The study area is the Trincomalee district. As illustrated in Fig. 1, the district is located on the East coast of Sri Lanka. It has 11 Divisional Secretariats (DS) Divisions and more than 200 Grama Niladari (GN) Divisions. Extent of the district is 2,727 km², with a population of 442,465. Due to the significant population increase over the past decade, the district demonstrates a growing need for effectively planned urban expansion.

B. Factor Selection and Data Preprocessing

Ten key factors were selected, including land use/land cover, slope, road accessibility, distance to towns and essential facilities, environmentally sensitive areas, flood frequency, soil type, building density, and the urban heat island effect. These factors were chosen because they collectively capture the physical suitability, infrastructure potential, and environmental constraints that typically influence sustainable urban expansion in fast-growing districts. All datasets were obtained from widely used and openly accessible sources such as OpenStreetMap, SRTM DEM, Sentinel-1 SAR, Landsat 8, and Survey Department land-use and soil layers. Each dataset was projected to the Kandawala coordinate system with 10 m spatial resolution. They were then reclassified into five classes, where Class 1 represents the highly suitable category, while Class 5 denotes the not suitable category.

C. AHP-Based Weight Derivation

The Saaty's 9-scale AHP method was applied to derive the influence of each factor for the MCDA. With the help of four experts, all factors were systematically compared, and a pairwise comparison matrix was developed. From this matrix, weights were derived while maintaining an acceptable consistency ratio of 4.3%.

D. Weighted Overlay and Extraction of Suitable Areas

The reclassified raster layers were combined with their respective weights derived from AHP. As a result, the urban expansion suitability raster was generated. The resulting layer was further classified into five classes according to the suitability score, and only the suitable and highly suitable classes (i.e., class 2 and class 1) were extracted for further analysis to identify the potential zones for urban expansion.

E. Results and Discussion

A suitability map of urban expansion in Trincomalee was produced using the AHP-based MCDA method. While Land use/ Land cover, distance to facilities, and distance to existing towns and villages were prioritized at the top, building density and the UHI effect were ranked lowest. The resulting suitability raster shows that 256 km² of the area is highly suitable. In terms of area coverage, 8.76%, 20.93%, and 25.60% are classified as highly suitable, suitable, and moderately suitable, respectively. Kantale, Seruwila, and Gomarankadawala DS Divisions show the highest mean suitability. Similarly, Verugal, Anaithivu, and Uppooral GN Divisions show high potential. Overall, the district spatially exhibits the capability for new town development.

Seven potential zones with different areas were generated over the highly suitable areas. Among these, based on their extent, cumulative suitability score, and land use coverage (using accurately developed Survey Department land use data), Zones 1, 7, and 6 were identified as the most appropriate for urban expansion. Zones 2, 3, and 5 were excluded due to the presence of restricted wetland and forest areas. Google imagery was also used to validate these results. The findings provide a strong, evidence-based classification to support sustainable urban planning. Fig. 2. shows the suitability map and the seven proposed zones.

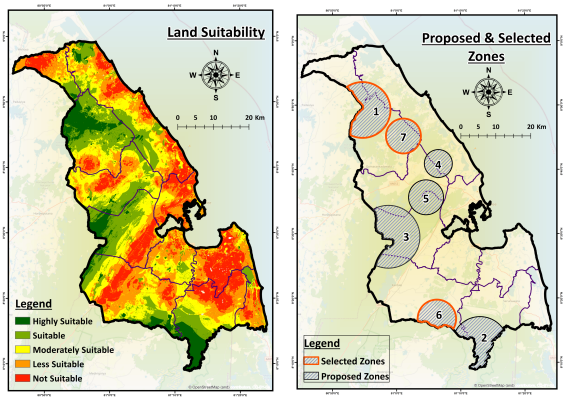

Fig. 2. Suitability Map and Proposed & Selected Zones Map

IV. Conclusion

This study demonstrates that the AHP-based MCDA approach is effective for identifying suitable zones for urban expansion in the Trincomalee District. Using freely available datasets, a detailed suitability layer was developed, revealing that approximately 790 km² of the district is suitable for development, with land use, accessibility, and proximity to social infrastructure emerging as the most influential factors. Among the seven delineated zones, Zones 1, 7, and 6 show the strongest practical potential, supported by validation using Survey Department land-use data and Google Earth imagery. A key limitation of the study is the use of only four experts for the AHP comparison and the reliance on secondary datasets, which may introduce minor uncertainties, though these do not alter the overall spatial patterns and are acknowledged as areas for refinement. Future research should incorporate field verification, population characteristics, and scenario-based land-use simulations to enhance predictive accuracy and further support sustainable, long-term urban planning in the Trincomalee District.

References

[1] J. J. Arsanjani, M. Helbich, and A. J. Mousivand, "A Morphological Approach to Predicting Urban Expansion," Transactions in GIS, vol. 18, no. 2, pp. 219-233, May 2013, doi: https://doi.org/10.1111/tgis.12031.

[2] H. K. G. M. Madurika and G. P. T. S. Hemakumara, "GIS based analysis for suitability location finding in the residential development areas of Greater Matara Region," International Journal of Scientific & Technology Research, vol. 6, no. 2, pp. 99-105, Feb. 2017. [Online]. Available: http://www.ijstr.org/final-print/feb2017/Gis-based-analysis-for-suitability-location-finding-in-the-residential-development-areas-of-greater-matara-region.pdf

[3] Y. Zhou, T. Wu, and Y. Wang, "Urban expansion simulation and development-oriented zoning of rapidly urbanising areas: A case study of Hangzhou," Science of The Total Environment, vol. 807, p. 150813, Feb. 2022, doi: https://doi.org/10.1016/j.scitotenv.2021.150813.

[4] N. Withanage, "A GIS -Multi-Criteria Decision Analysis To Find Suitable Sites For Residential Development: A Case From Kandy MC, Sri Lanka," International Journal of Spatial, Temporal and Multimedia Information Systems, vol. 1, no. 1, p. 1, 2021, doi: https://doi.org/10.1504/ijstmis.2021.10044016.

[5] E. Sahin, Muzaffer Can Iban, and Suleyman Sefa Bilgilioglu, "Remote Sensing-Enabled Urban Growth Simulation Overlaid with AHP-GIS-Based Urban Land Suitability for Potential Development in Mersin Metropolitan Area, Türkiye," Applied Sciences, vol. 14, no. 8, pp. 3484-3484, Apr. 2024, doi: https://doi.org/10.3390/app14083484.