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EVALUATION OF THE DEVELOPMENT POTENTIAL OF ULAANBAATAR USING GIS BASED ON LOCAL EXPERTS' EXPERIENCE

1. Introduction

Ulaanbaatar is the capital city of Mongolia. It consists of only 0.3% of land area of the country, yet as of 2023, 48.9% of the population live in the capital city. Although the amount of land per capita (3.7 persons/per ha) in the capital city is large, based on the geographical location of the city and the hilliness of the land, there are 35,200 hectares of land suitable for urban sprawl, which is a residential area. However, during its development, the city has become a monocentric structure, and the lack of development of other areas of the city has become one of the main reasons for the current traffic congestion and the inconvenience of living in the city. Therefore, developing other parts of the city as sub-centers is the key to reducing burden on the city center.

2. Study Contribution

According to the literature review, spatial multi-criteria analysis method is traditionally used for deciding the suitable location for large-scale new industrial sites and new cities, for example, finding the most appropriate site with desired conditions defined by the selection criteria (Rikalovic, Ilija, & Djordje, 2014). It is also applied to small-scale facilities such as hospitals, schools, and other social infrastructure, for instance, using an integrated framework to evaluate the equity of urban public facilities (M, Sliuzas, & Flacke, 2014)

Furthermore, quantitative data-based evaluation of a city is conducted using various methodologies to assess the potential, strengths, and weaknesses of a city. For example, in studies such as Japan power cities: Profiling urban attractiveness (Hiroo, 2023), and City development index (B, Batsukh, & Norovsambuu, 2021). This study will employ a comprehensive approach that integrates location-evaluating spatial analysis and qualitative data-based evaluation techniques, based on local experts' experience, to find the appropriate sub-city center location. This approach aims to bridge the gap between large-scale and small-scale studies of a similar nature in urban planning efforts.

3. Study Objective

In recent years, the urban planning sector in Ulaanbaatar has focused on addressing urban development congestion based on recommendation from both international and local experts. To achieve this, the city needs to develop as polycentric structure. Several locations have been proposed for sub-city centers, and building new satellite cities, even relocating the capital city to new location in considered based on mostly economic and census data recommended locations for the sub-center based on economic and census data (Urban Planning and Research Institute, 2024).

This study aims to fill the gap by evaluating the most suitable location for sub-centers using not only economic and census quantitative data, but also spatial analysis based on local experts' judgement.

The objectives of this study are to (1) identify and analyze the key attributes and factors that are critical for evaluating optimal locations, and (2) develop an expert system capable of determining the most suitable locations based on these identified criteria. To achieve the objective, the Analytical Hierarchy Process (AHP) was applied. This method enables the prioritization and weighting of the criteria and factors for identifying the optimal location. The pairwise comparisons informed by local experts' judgment. Participants included municipal staff and academic experts in Mongolia's urban planning sector. Weighted Linear Combination (WLC) method was employed to overlay and integrate these factors with Geographic Information System (GIS) platform.

4. Methodology & Study process

4.1. Selecting criteria and factors:

Previous, similar studies conducted have typically focused on assessing the best location for public facilities like schools, hospitals, parks, landfills, or potential building development sites rather than the location of urban centers or sub-centers. Since this study aims to evaluate suitable locations for development as sub-city centers, the criteria required in this context are derived from the methodology and criteria structure of previous studies within 5 main criterions of environmental conditions, accessibility, social infrastructure, engineering infrastructure, and economy. These five criteria were selected because they reflect important factors that contribute to the balanced decentralization of Ulaanbaatar, which faces challenges such as overconcentration in the central region, limited infrastructure in the peripheral areas, environmental characteristics, and socio-economic inequality among districts. Furthermore, they are also a broad set of indicators that can be used to assess the development potential of any other urban area.

Since, the Weighted Linear Combination (WLC) is selected as site selection and resource evaluation on Geographic Information System (GIS) the factors used for site selection process must be not only quantitative, but also available as spatial data.

4.2. Data Collection:

The Weighted Linear Combination (WLC) is selected as site selection and resource evaluation on Geographic Information System (GIS) the factors used for site selection process must be not only quantitative, but also available as spatial data.

To ensure reliable results, most of the data used in this study were collected from official government database, only the residential property value data is generated from real estate platform due to lack of data in government data set. In Table 2, list of factors and the base data used in the study were presented with the spatial data type and data source.

4.3. Analytical hierarchical process (AHP):

AHP is applied in several studies for site selection for its ability to incorporate experts' judgement and prioritize criteria based on pairwise comparisons to obtain the weights (R.W.Saaty, 1987) of hierarchical structured factors. In this study, to properly assess the urban development condition and environment in Ulaanbaatar, Mongolia, it relied solely on assessments by domestic experts in the field of urban planning and development in the country.

The expert questionnaire used in this study was developed based on the AHP multi-criteria decision-making methodology, which allows determining the relative importance of selected criteria and factors based on their pairwise comparison evaluation. In total, the questionnaire consisted of 61 (10 criteria level, 51 factor level) pairwise comparison questions within 5 main criteria and 24 factors.

- Criteria 1, Environmental condition including 4 factors have 6.
- Criteria 2, Accessibility including 7 factors have 21.
- Criteria 3, Social infrastructure including 4 factors have 6.
- Criteria 4, Infrastructure including 3 factors have 3.
- Criteria 5, Economy including 6 factors have 15 pairwise comparison.

The measurement scale ranges from one to five, where one implies that the two factors are equally important, number 5 implies that one factor is extremely important that the other factor in a pairwise matrix.

Table 1: Score for the importance of variable

Importance scale	Definition of scale
1	Equally important
2	A little important
3	Important
4	Very important
5	Extremely important

Participants gave their ratings according to the rating scale developed by T. Saaty, who laid the foundation for the AHP method (Saaty, 1977), and emphasized that it is easier and more accurate for the human mind to choose between only two alternatives than to evaluate among many alternatives simultaneously.

Result from the pairwise comparisons for n attributes is organized into positive reciprocal n×n matrix S=(s_{ij}) as shown below.

$$S = \begin{pmatrix} 1 & s_{12} & \dots & s_{1n} \\ 1/s_{12} & 1 & \dots & s_{2n} \\ \dots & \dots & \dots & \dots \\ 1/s_{1n} & 1/s_{2n} & \dots & 1 \end{pmatrix}$$

Equation 1: Positive matrix reciprocal of pairwise comparisons for n attributes.

To check the consistency of estimated weight values, the consistency ratio (CR) and consistency index (CI) are calculated with Equation 6 and Equation 7 (Saaty, 1980).

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Equation 2: Consistency index

$$CR = \frac{CI}{RI}$$

Equation 3: Consistency ratio

4.4. Weighted Linear Combination (WLC):

Weighted Linear Combination (WLC) is a widely used in site selection, land use suitability and resource evaluation analysis based on geographic information system (GIS) decision rules (Malczewski, 2000). In this method, all the selected factor layers are combined according to their relative importance, as determined by the AHP result as outlined previous section (Younes Noorollahi, 2015).

The geographic data that corresponding to each 24 selected factors used in this study collected from reliable, government sources. Depending on the nature of the data, the layers were prepared in different forms including point, polygon, and line etc. As first step of the data preparation, all the geographic data were converted into raster format using various GIS tools, depending on the characteristics and formats of the original dataset.

After all the layers are normalized into common scale and format of data, to combine and create the suitability map for weights derived from AHP were used to represent relative importance of each factor in Table 17. Equation for combining the normalized layers using WLC is as shown Equation 8. This process performed in a GIS using “raster calculator” tool.

$$S = \sum_{i=1}^{n} (w_i \times x_i)$$

Equation 4: Weighted Linear Combination.

S: Overall suitability score for each cell.

w_i: Weight of the i^{th} factor.

w_i: Normalized value of the i^{th} factor.

5. Study Result

5.1. Analytical hierarchical analysis result:

The survey was distributed to 60 experts, with responses received from 44 participants. To ensure more reliable and professional results, participants were selected based on their experience in the field, considering factors such as age, work experience, workplace, and education level. Figures 2 and 3 present the resulting weights of the evaluated factors.

The results indicate that infrastructure factors are considered the most important, as they represent the costliest component of new development, particularly in developing countries like Mongolia.

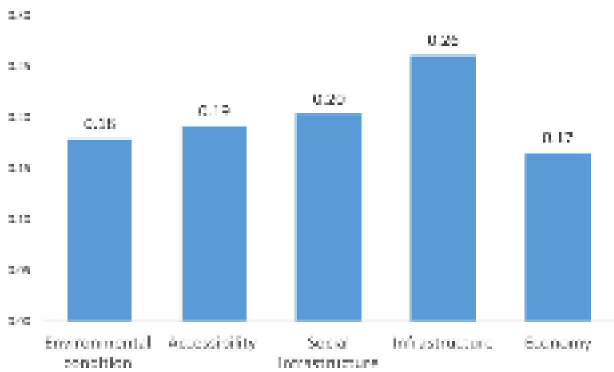

Figure 2: Criteria's weight.

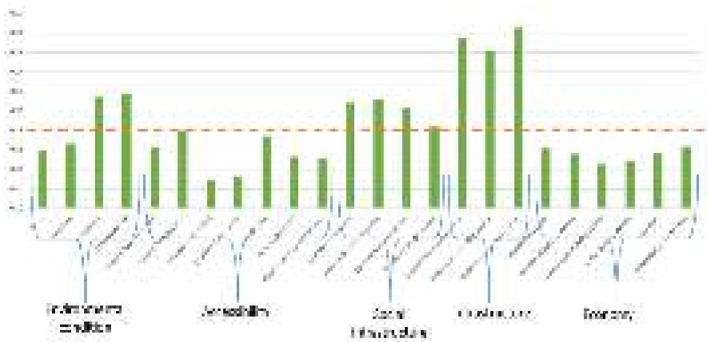

Figure 3: Factors' global weight.

The results of the AHP analysis, the global weighting of all factors included in the infrastructure criterion is evaluated with the highest importance compared to the other criteria. This indicates that the availability and development potential of infrastructure play a decisive role in selecting the location of the sub-city centers. The high assessment of the importance of infrastructure can be attributed to the high technical and economic difficulties and costs required to build new infrastructure.

5.2. Weighted Linear Combination result:

Based on local experts' insights and 24 geographical and quantitative factors, five individual suitability maps

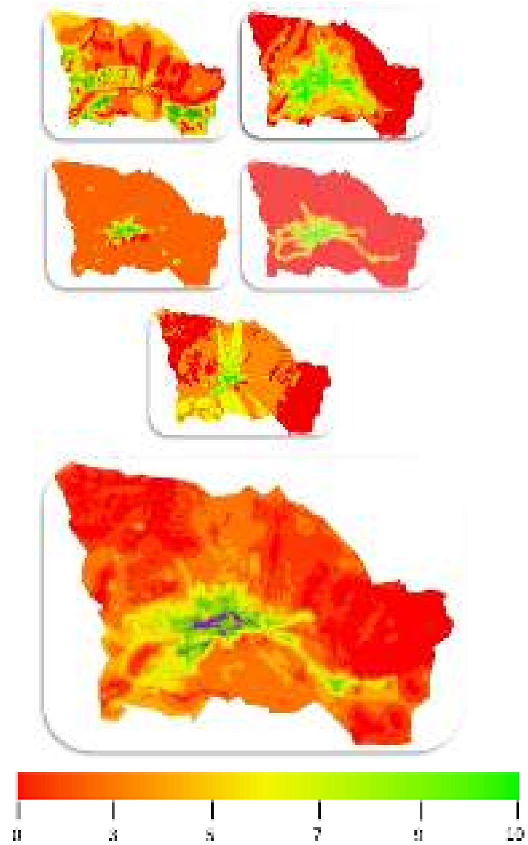

Figure 4: Suitability map. (from the top left, 1.Environment, 2.Accessibility, 3.Social infrastructure, 4.Infrastructure, 5.Economy)

were generated for each criterion, culminating in a final integrated suitability map which shown in *Figure 4.*

5.3. Comparison to current CBD:

The highest scoring areas identified through the analysis are highlighted in purple, while the current Central Business District (CBD) is marked in blue in Figure 5. The spatial distribution of these results reveals that most of the suitable areas for establishing sub-city centers are located outside the existing CBD. These areas are predominantly aligned along major transportation corridors, indicating a strong connection to the city's infrastructure and mobility network. This pattern suggests that accessibility and integration with existing urban systems are significant factors influencing the suitability of these locations.

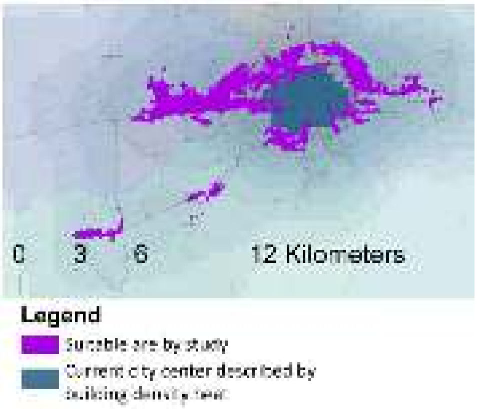

Figure 5: Comparison of suitable area by study to current CBD.

6. Conclusion

The AHP analysis revealed that the infrastructure criterion received the highest global weight among all selected criteria. This finding highlight that the availability and development potential of infrastructure plays an important role in selection optimal locations for sub-city centers in Ulaanbaatar city. The high importance score placed on infrastructure can be related to the technical and economic challenges involved in constructing new infrastructure. Most of the territory of Ulaanbaatar is mountainous, which limits construction potential and increases the cost and complexity of developing networks such as roads, and other engineering systems.

Given these constraints, local experts preferred locations where already existing infrastructure, Figure 29, as this reduces developing costs, accelerates project implementation, and enhances access to services. Thus, the accessibility of existing infrastructure emerged the most influential factor in the site selection process for sub-city centers.

Finally, this analysis provides data-driven, expert-informed guidance for selecting sub-city center locations. It demonstrates that, in a city with limited resources like Ulaanbaatar, existing engineering infrastructure is the most decisive factor. Meanwhile, factors like airport and railway distance, though important at the regional level, play a minimal role in daily urban mobility and are less relevant to sub-city center development. The variation in factor importance across professional disciplines further reinforces the necessity of incorporating diverse stakeholder input in planning decisions. This approach not only improves decision quality but also ensures that urban development strategies are inclusive, practical, and grounded in both spatial data and expert insight.

7. Limitation

Despite the comprehensive nature of this study, several limitations should be acknowledged, as they may affect the interpretation and applicability of the results. These limitations are outlined as follows:

- Congestion Effects Not Considered
- Exclusion of Future Investment Plans
- Reliance on Existing Infrastructure Data
- Limited Expert Participation

8. Future work suggestion

The results of this study, which aims to assess the potential of urban development and identify the most suitable locations for development as sub-urban centers, can be further studied in the following areas to make them more accurate and optimal. These include:

- Reclassifying the values of the factors in accordance with the actual conditions of the city environment and establishing a normalized assessment.
- Determining the characteristic of the sub-center based on the environmental conditions, and socioeconomics of the selected locations.
- Increase public participation in the study and compare it with expert evaluation.