Integration of GIS, Shannon Entropy and Multi-Criteria Decision Making for Hospital Site Selection

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Summary

In this study, a hybrid methodology consisting of geospatial information systems (GIS), Shannon Entropy (SE) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is proposed for a hospital site selection problem in Tehran, Iran. SE was used for determining the objective weights of the employed criteria which can model the existing uncertainty in the decision criteria. TOPSIS is a multi-criteria decision making (MCDM) method. According to the results obtained from implementing the SE, the distance from existing hospitals criterion had the highest weight in the optimum hospital site selection. The findings of the research have proved the suitability of using the integration of SE and TOPSIS for the optimum hospital site selection.

Key Words: GIS-based MCDM, Optimum Site Selection Process, Shannon Entropy, TOPSIS.

1. Introduction

Ever increasing urban population, expansion of urban sprawl and increasing urban land value, has led more pressure on urban areas especially in mega cities in providing appropriate access to urban services such as health services for all the citizens. Hospitals are the most important centers of health services which directly impacts the health of the citizens. One of the most essential factors in the hospital's optimum performance is selecting its best location (Chatterjee and Mukherjee, 2013). Today, the lack of open space in megacities and the diversity of land uses, have made it more difficult to plan to establish new service centers in these areas. Building a new hospital requires a lot of time and money, so it is impossible to build a hospital anywhere without the right decision-making process. In the optimum hospital site selection process, the conditions, limitations and available resources should be considered. The existence of several criteria that may be inconsistent or interdependent makes it challenging to determine the appropriate locations to assign to a particular land use (Witlox et al., 2009). In other words, it is difficult to consider the internal relationships of these criteria (Witlox et al., 2009). MCDM is one of the most popular methods in the site selection problems. GIS applications in the site selection problems are very widespread due to their capabilities in spatial data fusion, spatial optimization techniques and managing land use and land cover data capabilities. Integration of GIS and MCDM is a very powerful method to the location selection process.

Adali and Tus (2019) have used the combination of CRITIC[1] objective weighting method with three MCDM methods including TOPSIS, EDAS[2], and CODAS[3], in order to locate the hospital in Turkey. Senvar et al. (2016) have used a combination of Hesitant Fuzzy Sets and TOPSIS technique to locate the hospital in Istanbul. Sahin et al. (2019) have used Analytical Hierarchical Process (AHP) method to locate a hospital in Turkey. Vahidnia et al. (2009) have used a combination of GIS and fuzzy AHP to locate a hospital in Tehran. Zandi and Palavani (2021) have used the integration of Analytical Network

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[1] Criteria Importance Through Intercriteria Correlation
[2] Evaluation Based on Distance from Average Solution
[3] Combinative Distance-based Assessment

Process (ANP), CRITIC, VIKOR and EDAS, in order to locate a hospital in Tehran (Zandi and Pahlavani, 2021). According to the previous studies in the hospital site selection, subjective weighting methods have usually been used. Research on the integration of Objective weighting methods with GIS and the MCDM approaches has been dramatically increased especially in the last decade.

2. Methodology

This study aims to determine a hospital optimum location in District 5 of Tehran, capital of Iran. To achieve this objective, GIS was used to produce and analyze the required data. SE objective weighting method was implemented to determine the decision criteria weights. TOPSIS method was employed to rank the candidate sites and find optimum site for construction of the hospital in the study area. Figure (1) illustrates the proposed methodology.

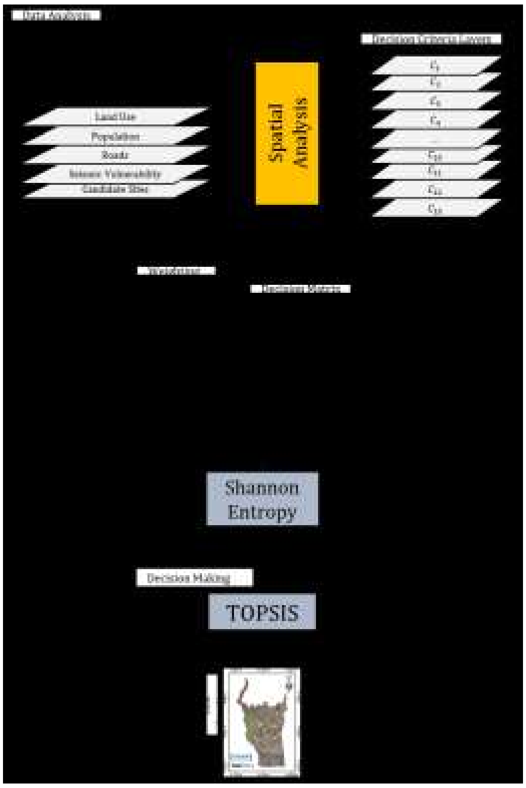

Figure 1 Research Methodology

2.1. Shannon Entropy

Shannon Entropy (SE) method is a function of probability distribution and a parameter to measure the uncertainty in the employed criteria. The weights of the criteria in this method are determined based on the amount of scatter and turbulence in each decision matrix criterion. The following steps are performed to determine decision criteria weights by SE. The steps undertaken in this research are as follows (Lin, 1991, Bromiley et al., 2004):

Step 1: Formation of decision matrix.

$$X_{n\times m} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \qquad (1)$$

Step 2: Normalization of the decision matrix.

$$r_{ij} = \frac{r_{ij}}{\sum_{i=1}^{n} r_{ij}} \tag{2}$$

Step 3: Determination of the degree of convergence of the values of each criterion (E_j).

$$E_j = -k\left(\sum_{i=1}^{m} r_{ij}, \ln(r_{ij})\right) \tag{3}$$

If the number of alternatives is equal to *n*, the constant *k* value is calculated using Equation (4).

$$k = \frac{1}{\ln(n)} \tag{4}$$

Step 4: Calculation of the weights of the criteria.

$$D_j = 1 - E_j \tag{5}$$

$$W_j = \frac{D_j}{\sum_{j=1}^{n} D_j} \tag{6}$$

2.2. TOPSIS

In TOPSIS decision-making method, the appropriate alternative is the one that has the least distance from the positive ideal solution (PIS) and the largest distance from the negative ideal solution (NIS). In this method, the best alternative is the one that is the closet to the ideal answer. This decision strategy expresses the simplicity and comprehensibility of this very popular method. This method was proposed by Hwang and Yoon (1981). The following computational steps describe the implementation of this method:

Step 1: Formation of the decision matrix using Equation (1).

Step 2: Normalization of the decision matrix using Equation (7).

$$r_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{n} r_{ij}}} \tag{7}$$

Step 3: Calculation of the weighted normal matrix using Equation (8).

$$t_{ij} = r_{ij} \times w_j \tag{8}$$

Step 4: Determination of the set of PIS (S^+) and the set of NIS (S^-) in such a way that the PIS contains each criterion's best values and the NIS contains the worst values of each criterion.

Step 5: Calculation of the value of the positive and negative separation measures for each alternative using Equations (9 and 10).

$$d_i^+ = \sqrt{\sum_{j=1}^{m} (t_{ij} - t_j^+)^2} \tag{9}$$

$$d_i^- = \sqrt{\sum_{j=1}^{m} \left(t_{ij} - t_j^-\right)^2} \tag{10}$$

In the above-mentioned, t_j^+ and t_j^- are equal to the positive and negative ideal solutions in the criterion X_j, respectively.

Step 6: Calculation of the relative closeness to the ideal solution using Equation (11).

$$C_i = \frac{d_i^-}{d_i^+ + d_i^-} \qquad (11)$$

Step 7: Ranking the alternatives in descending the order to select the best alternative which has the highest relative closeness.

3. Implementation

3.1. Study area and data

In this study, District 5 of Tehran mega city has been selected as the study area. District 5 with an area of 54 Km^2 and 850,000 people is the second largest and most populated district of Tehran. This district is located in the northwest of Tehran. Figure (2) illustrates the study area. In this study, 12 criteria including seismic vulnerability (C_1), population density (C_2), distance from main roads (C_3), distance from industrial areas (C_4), distance from business centers (C_5), distance from religious centers (C_6), distance from sports centers (C_7), distance from cultural centers (C_8), distance from educational centers (C_9), distance from green spaces (C_{10}), distance from healthcare centers (C_{11}) and distance from existing hospitals (C_{12}), were used to locate the new hospital. These criteria have been selected according to experts' opinions and literature review (Vahidnia et al., 2009, Adali and Tuş, 2019, Şahin et al., 2019). The decision criteria layers using the land use map of Tehran provided by Municipality of Tehran (http://www.tehran.ir), seismic vulnerability map produced in one of our previous research (Sheikhian et al. (2017), population distribution map obtained through internet, and roads network map provided by Open Street Map (http://www.openstreetmap.org), have been prepared in the GIS environment. Decision layers are prepared using Euclidean distance and kriging interpolation tools in the GIS environment. Figure (3) represents the criteria map used in this research. Three constraints with a minimum area of 3,500 square meters, suitable access to the main roads, and barren land have been considered to select the candidate sites. Figure (4) shows the selected candidate sites distribution.

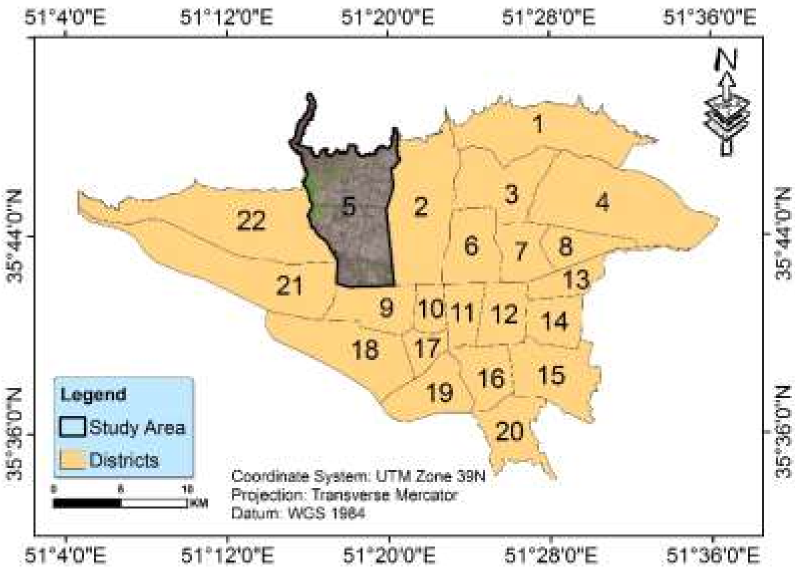

Figure 2 Study area.

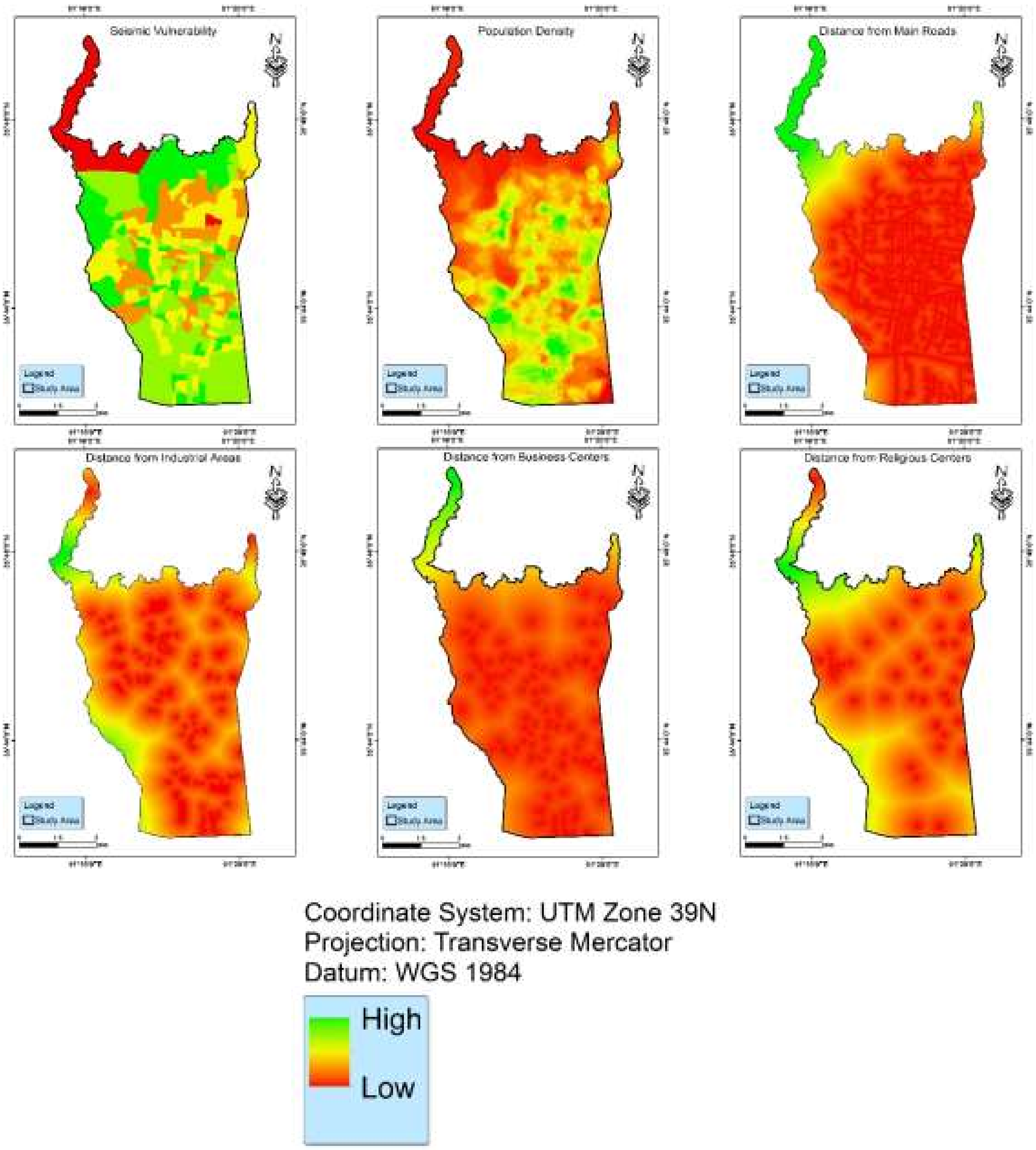

Figure 3 The Employed Criteria Layers

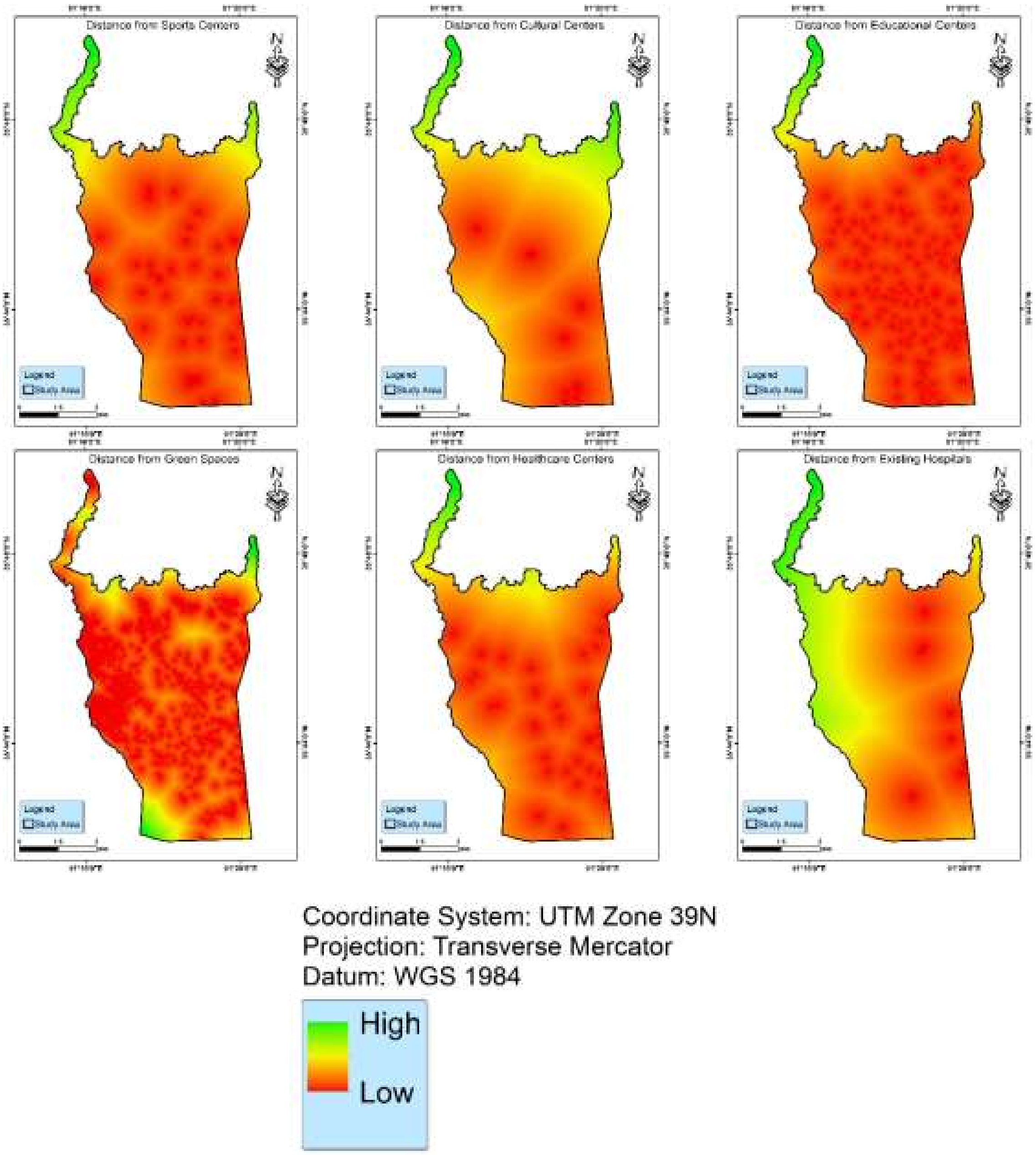

Figure 3 The Employed Criteria layers (Cont.).

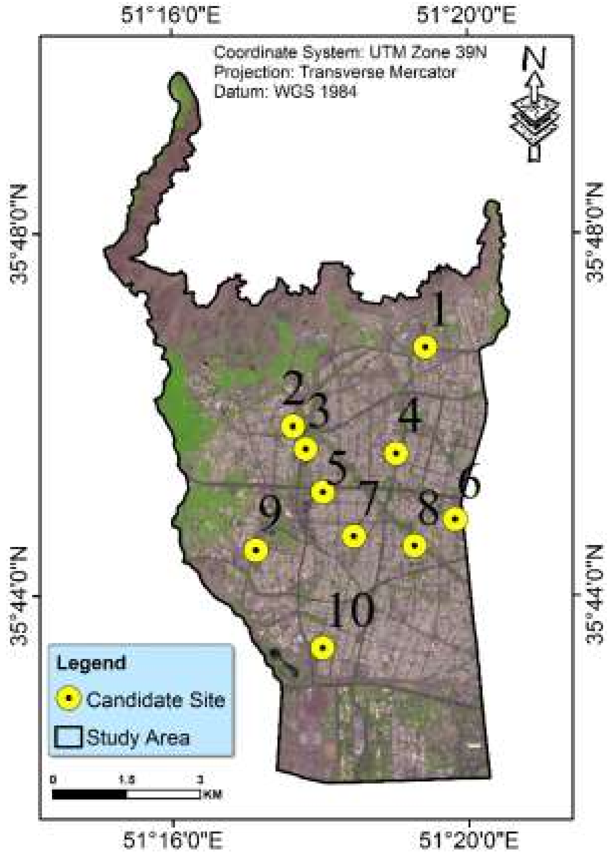

Figure 4 The Candidate sites

3.1. Shannon Entropy results

In this section, considering the ten candidate sites, the weights of the decision criteria have been determined. By performing the SE weighting method in Section 2.1, the weights of the criteria were obtained according to Table 1. In order to calculate the weights of the criteria, the SE is programmed in the Python language. It is verified that the criteria of distance from existing hospitals (C_{12}) and distance from green spaces (C_{10}) had the highest and lowest weights, respectively.

Table 1. SE weighting results

Criterion	**Weight**
C_1	0.0381
C_2	0.0683
C_3	0.1009
C_4	0.0882
C_5	0.1186
C_6	0.0471
C_7	0.0644
C_8	0.1163
C_9	0.1245
C_{10}	0.0327
C_{11}	0.0687
C_{12}	0.1324

3.2. TOPSIS results

In this section, the ranking of the candidate sites by considering the weights vector obtained from Shannon Entropy by TOPSIS technique has been done. By implementing TOPSIS method explained in Section 2.2, the candidate sites' ranking results have been obtained according to Tables 2 using the integration of SE and TOPSIS (SE-TOPSIS) methods. In order to calculate the ranks of the candidate sites, TOPSIS is programmed using the Python language. According to Table 2, the best sites for constructing a new hospital were sites No. 6, 10, and 3, respectively. The results of SE-TOPSIS ranking were illustrated in Figure (5).

Table 2. SE-TOPSIS results

Site	D^+	D^-	Ci	Rank
1	0.1424	0.0619	0.3029	10
2	0.1002	0.0970	0.4921	7
3	0.0720	0.1183	0.6216	3
4	0.0903	0.0903	0.5001	6
5	0.1001	0.0960	0.4897	8
6	0.0575	0.1334	0.6987	1
7	0.1116	0.1051	0.4851	9
8	0.0870	0.1163	0.5719	4
9	0.1023	0.1039	0.5041	5
10	0.0702	0.1196	0.6301	2

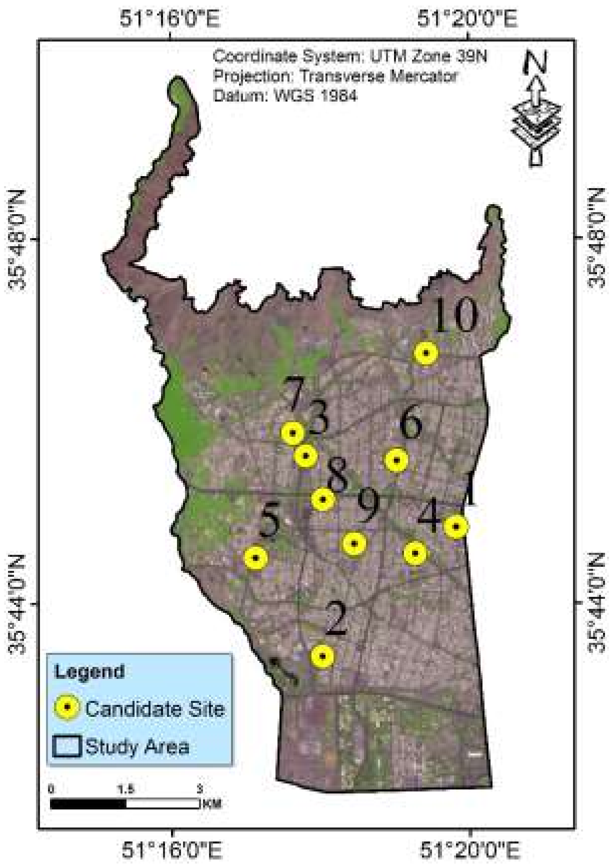

Figure 5 SE-TOPSIS results.

4. Conclusions

In this study, GIS was used for the spatial data analysis of optimum hospital sites selection in District 5 of Tehran mega city. SE was used to determine the objective weights of the decision criteria. TOPSIS MCDM method was used to rank candidate sites for the hospital site selection. Shannon entropy method has assisted to model the uncertainty in the criteria, and has calculated the criteria objective weights without using the experts' opinions. According to the obtained results using SE, the criteria of distance from existing hospitals (C_{12}) and distance from green spaces (C_{10}) have the highest and lowest weights, respectively. In most previous researches, which have used some subjective weighting methods such as AHP and ANP, the distance from existing hospitals has the highest weight compared to other criteria. Of course, the weights obtained are depended on the selected candidate sites, and as the candidate sites change, the weights may also change. In addition, TOPSIS is used as a MCDM method to determine optimum hospital site selection. In this method, the best alternative is the one that has the shortest distance from the best ideal solution and the longest distance from the worst ideal solution. This decision strategy expresses the simplicity and comprehensibility of this very popular method. Furthermore, the best sites for constructing a new hospital were sites No. 6, 10, and 3, respectively. The results may change by modifying the weighting or the MCDM methods. The important point is that combining objective weighting methods and MCDM is a suitable way to solve the optimum site selection problems. It is suggested that objective weighting methods be compared with subjective weighting methods such as the AHP in future research. It is also suggested to integrate the weighting method used in this research with other MCDM methods such as Complex Proportional Assessment of alternatives (COPRAS) and CODAS.

5. Bibliography

Iman Zandi works as a MSc. Student at the GIS Department, School of Surveying and Geospatial Engineering, College of Engineering, University of Tehran, Iran. His research interests are in GIS-based MCDM, urban planning, spatial planning, data mining and knowledge discovery and uncertainty modeling.

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