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Different Multi-Criteria Strategies in Hospital Location Ranking using Dempster–Shafer Decision-Level Fusion and Quantifier-guided OWA, A Case Study

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ABSTRACT

This study focused on ranking hospital locations. Accordingly, the Objective weighting methods, Dempster-Shafer Theory (DST), and Quantifier-guided Order Weighting Average (QOWA) were proposed to consider different decision strategies and model the uncertainty in an integrated GIS-based multi-criteria decision making (MCDM) process. The objective weighting methods determine the weights of criteria by solving mathematical models without considering the preferences of experts. The DST fuses information received from two or more sources and this fusion improves reliability and reduces uncertainty in decision making. In this study the QOWA was used because the decision makers will be able to determine the decision risk level according to the decision situation and provide high-low risk solutions to solve the hospital location problem. The results showed that the criteria of seismic vulnerability, population density, and distance from the major roads were the most important criteria for selecting an optimal location for a hospital, respectively. Moreover, the results were compared with the results of four well-known MCDM methods as well as the rankings performed by the experts. The results showed that the rankings performed with different decision strategies of the proposed methodology were closer to experts' opinions compared to the other MCDM methods. According to experts, the Neutral decision strategy (chosen by 46% of the experts) and Pessimistic decision strategy (chosen by 18% of the experts) have shown to be the most suitable decision strategies for selecting an optimal location for a hospital. In the process of spatial planning and urban development, designing different decision-making scenarios and measuring the performance of the proposed scenario is very important and enriches and improves knowledge about results of different decision-making scenarios.

KEYWORDS

Decision Strategies
Dempster–Shafer theory
GIS
MCDM
Objective weighting methods
Quantifier-guided OWA

1. Introduction

The expansion of cities, the increase in population, the spread of diseases, and the aging population have increased the demand for health services. Proper access to the hospital is a basic need of citizens, and hospitals' improper distribution makes it difficult to use health services. The construction of a new hospital requires a lot of time and money, and the hospital's location should be determined to provide adequate access for as many citizens as possible. Usually, the purpose of spatial MCDM is to evaluate multiple spatial options based on a set of criteria (Witlox et al., 2009). Choosing the right and optimal location is a key factor for effectiveness, quality, and justice in healthcare (Daskin & Dean, 2005; Şahin et al., 2019). A hospital should be located in the right place to function properly (Adalı & Tuş, 2019). The problem of location selection includes choosing among two or more locations with a multi-criteria evaluation that is often inconsistent or disproportionate (Witlox et al., 2009). The hospital site selection is a MCDM problem (Adalı & Tuş, 2019; Ahmed et al., 2016). Choosing an optimal hospital location plays a key role in its performance (Sharmin & Neema, 2013). The GIS is used in many fields, such as Spatial Planning and the determination of suitable land and location (Brail &

Klosterman, 2001; Collins et al., 2001). One of the GIS applications in Spatial Planning is to evaluate different spatial options and prepare land suitability maps (Collins et al., 2001; Malczewski, 2004). Nowadays, GIS is used for facilities location selections such as hospitals, renewable energy power plants, and fire stations. Integration of MCDM and GIS improves the efficiency of MCDM in hospital location selection (Alavi et al., 2013).

As the capital of Tehran province and the capital of Iran, Tehran city is considered the most important city in Iran, and in recent decades, has faced population growth and physical development in urban areas. However, the development and spatial distribution of hospital centers have not been proportionating with this urban expansion. Tehran's fifth district is one of the city's most extensive areas, with a population of 850,000 people (ICTOTM, 2019). The authors' field studies and study of land use maps of the fifth district indicate a lack of hospitals' proper distribution. Many parts of this region are much far from existing hospitals. In addition, in the eastern areas of the district and areas closer to the border with the second district, there is a higher density of hospitals than in other areas. However, there is no hospital in the western half of the region, and adjacent areas of the 21st and 22nd districts suffer from severe hospital shortages.

In developed and developing large cities, optimality of location selection of hospitals is necessary. In order to carry out this process, MCDM methods have been used. The integration of MCDM and GIS improves the performance of the location selection process. In most researches, weighting methods based on experts' opinions have been used, and usually, a limited number of criteria are used. This research aims to propose a hybrid methodology based on CRITIC and Shannon's entropy as the objective weighting methods, DST to fuse the weights achieved in the decision level, and QOWA to consider different decision strategies and model the uncertainty. In the present study, to determine an optimal location for the hospital in the fifth district of Tehran, the integration of GIS and MCDM has been used. At first, to perform the mentioned process, the criteria maps used in GIS was prepared. Then, the CRITIC and Shannon's entropy weighting methods have been used to determine the weights of the decision criteria. CRITIC is able to consider the correlations among criteria and Shannon's entropy is able to model the uncertainty in criteria values. In addition, these weighting methods are data-driven and are used to determine the weights of criteria in the absence of experts. In order to fuse the obtained results by two objective weighting methods, DST has been used. DST has been used to model the uncertainty in determining the weights of criteria in decision level. Different decision strategies may be required in the location selection process. However, the methods used in the previous researches may not be feasible in this case. The QOWA method has been used in order to rank the candidate sites. This method has the ability to rank candidate sites with different decision strategies.

The objectives of this research are:

- Investigating the effective criteria in selecting an optimal location for the hospital and determining the most important criteria.
- Implementing CRITIC and Shannon's entropy objective weighting methods in order to weight the criteria.
- Modeling the uncertainty of the weighting process and fusion of the weights obtained by the CRITIC and Shannon's entropy methods using the DST.
- Modeling and comparing different decision strategies by the QOWA method.

The rest of this paper consists of the following parts. The second section is the literature review. The third section describes the study area, the used data, and the preparation of criteria layers. The proposed methodology and the theoretical foundations of the used methods in designing the proposed methodology are briefly described in the fourth section. The fifth section presents the results of the implementation of the proposed methodology. Finally, in the sixth and seventh sections, the discussion and conclusion are presented, respectively.

2. The Related Work

Much research has been done on location selection by MCDM methods. Also, much research has been done with the integration of GIS and MCDM methods. Naturally, there is also much research into selecting an optimal location for the hospital (Ahmed et al., 2016; Alavi et al., 2013; Kim et al., 2015; Moradian et al., 2017; Wissem et al., 2011; Wu et al., 2007). The following are some of the related researches.

Adalı & Tuş (2019) proposed a hybrid MCDM methodology that consists of the CRITIC method for the weighting process and EDAS, TOPSIS and CODAS methods for ranking alternatives to the hospital location selection. Senvar et al. (2016) proposed a combination model based on Hesitant Fuzzy Sets and TOPSIS for hospital location selection. Vahidnia et al. (2009) developed a multi-criteria decision analysis process including GIS and Fuzzy Analytical Hierarchy Process (FAHP) in order to locate hospital site in Tehran, Iran. Mohammadi et al. (2019) had applied the integration of GIS, the Best-Worst method, Dematel-based ANP, VIKOR, and COPRAS in order to hospital site selection in Tehran, Iran. Şahin et al. (2019) used the Analytical Hierarchy Process (AHP) to select the best location for the hospital site in Mugla, Turkey. Zolfani et al. (2020) proposed a gray-based methodology that consists of CRITIC and Combined Compromise Solution (CoCoSo) in order to *select a temporary hospital location for COVID-19 patients in Istanbul.*

Lin & Tsai (2010) proposed an MCDM methodology, including ANP and TOPSIS, for hospital location selection in china. Ahmed et al. (2016) applied the integration of GIS and AHP to determine the most suitable hospital site in Egypt. Kumar et al. (2016) applied the integration of Fuzzy Sets and ELECTRE to select hospital sites in India. Abdullahi et al. (2014) proposed a methodology that consists of GIS, AHP, and OLS for hospital location selection.

Guler & Yomralioglu (2020) proposed a GIS-based MCDM methodology, including GIS, AHP, FAHP, and TOPSIS, to select the most suitable location for the electric vehicle fast-charging station. Noorollahi et al. (2016) proposed a methodology based on GIS and FAHP to analyze land suitability for solar farms in Iran. Wang (2019) used GIS and FAHP for selecting fire station location. Teniwut et al. (2019) used GIS, AHP, and FAHP for location selection of seaweed farming information centers in Indonesia. Some of the other research used FAHP and TOPSIS for biomass and wind energy power plant site selection (Wang et al., 2018; Wang et al., 2019), Fuzzy ANP, and TOPSIS for solid waste energy plant site selection (Wang at al., 2018), integration of Fuzzy ANP and GIS for biomass power plant location selection (Davtalab & Alesheikh, 2018), integration of GIS, OWA, AHP and WLC for landslide susceptibility mapping (Feizizadeh & Blaschke, 2013), integration of GIS, SAW, AHP and CODAS for sanitary landfill location selection (Karakuş et al., 2020), and integration of GIS, AHP and WLC for landfill site selection (Karimi at al., 2019).

According to the mentioned research in this section, it is clear that most previous research in the field of choosing a hospital location used knowledge-driven weighting methods such as ANP and AHP to determine the weights of criteria. Nevertheless, the use of data-driven weighting methods has received less attention. The use of different weighting methods and combining their results in order to model the uncertainty of the weighting process has not been considered in previous research. Furthermore, in choosing an optimal hospital location, there is usually no variety in decision-making strategy, while decision-makers usually need to use different decision strategies. Therefore, in the present study, an attempt has been made to eliminate the weaknesses of previous research by selecting appropriate and practical tools and models for decision-makers.

3. Study area and data set

Tehran is the capital of Iran and is the largest and most populous city in this country. The city covers more than 615 square kilometers and has a population of more than 8.9 million people (ICTOTM, 2019). Tehran consists of 22 districts. The fifth district is the second most populous and large district, and in this research, it has been selected as the study area (Figure 1). With an area of more than 54 square kilometers, the fifth district has a population of more than 850,000 people and consists of seven locales (ICTOTM, 2019). The fifth district is located in the northwest of Tehran and is limited to the north of Tehran's heights from the north to the Ayatollah Ashrafi Isfahani and Mohammad Ali Jinnah highways from the east, to the Karaj special road from the south, and Masileh Kan from the west.

This paper considers the hospitals with the general services and the special treatment centers like ophthalmology centers were not considered in this study. Most of the hospitals in the fifth district of Tehran are located in the south and southeast of the region, and the neighborhoods in the north and west of the region either do not have hospitals or do not have proper access to hospitals. Figure 2 shows the spatial distribution status of fifth district hospitals and the areas that are closest to a hospital (access radius). To find areas close to each hospital, the Thiessen polygons analysis has been used. According to Figure 2, it is observed that the distribution of hospitals in the fifth district is not commensurate with the size and population of the district. According to Figure 2, some hospitals' access radius is minimal, and as a result, some citizens have an easy access to them. By contrast, some other hospitals cover larger access areas and citizens do not have easy access to them. In addition, there is a high hospital density in some parts of the area, and in other parts, there is no hospital at all. All in all, the need to determine an optimal location for the construction of a new hospital is observed to reduce the district's health needs and meet the standards.

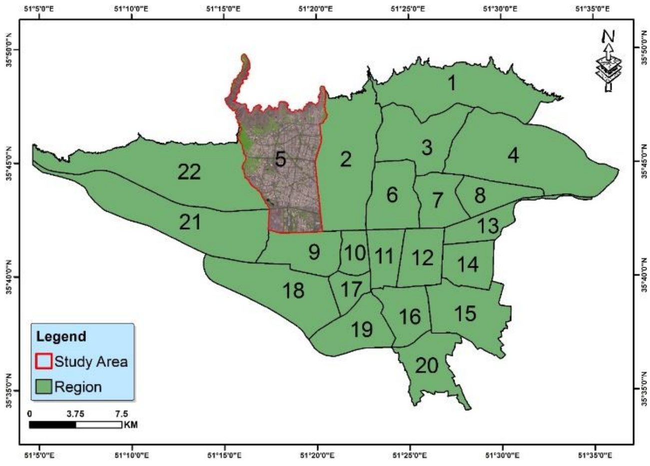

Figure 1. Study area

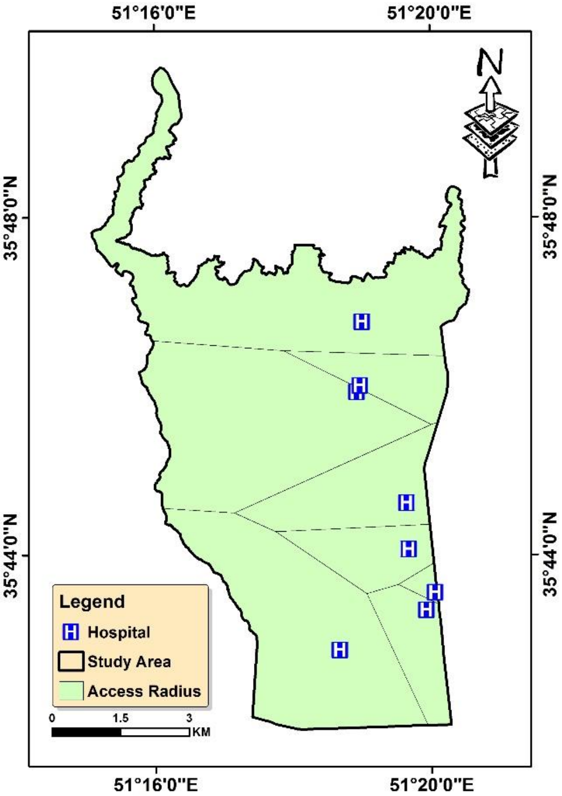

Figure 2. Spatial distribution status of hospitals and those access radius in fifth district

In this study, the integration of GIS and MCDM has been used to determine an optimal location for the hospital in the fifth district of Tehran. The selection of an optimal location for a hospital depends on selected criteria. In order to perform the process of selecting an optimal location for the hospital, at first, the following criteria have been selected. These criteria were selected according to Compatibility of Urban Land Uses (Cheniki et al., 2019; Taleai at al., 2007), literature review (Abdullahi et al., 2014; Adalı & Tuş, 2019; Alavi et al., 2013; Chatterjee & Mukherjee, 2013; Kumar et al., 2016; Sharmin & Neema, 2013; Vahidnia et al., 2009; Wissem et al., 2011; Wu et al., 2007) and the opinions of 50 experts with specialization in GIS, Urban Planning, Spatial Planning, and Urban Engineering. Different Land Use might have High Compatibility, Medium Compatibility, Neutral Compatibility, Medium Incompatibility, or High Incompatibility with hospital Land Use. In this study, the best criteria used in previous research were selected according to Land Use Incompatibility and experts' opinions. These criteria include the distance from residential areas (C_1), distance from cultural centers (C_2), seismic vulnerability (C_3), distance from green spaces (C_4), distance from health centers (C_5), distance from existing hospitals (C_6), distance from industrial areas (C_7), population density (C_8), and distance from major roads(C_9). Table 1 shows the criteria documentation. According to Table 1, The C_2 and C_3 have been used less in previous research. By contrast, C_6, C_8, and C_9, have been used in most previous research. In this study, in addition to the well-known criteria used in the hospital location selection, two criteria that are less used, including C_2 and C_3, have been used.

After selecting the appropriate criteria to determine an optimal location for the hospital, the next step is started, which is preparing the spatial layers to calculate the criteria's values for each candidate site. Raw layers that have been used to prepare the criteria layers include the Tehran's land use layer, population density, main roads, and seismic vulnerability zoning layer. Vulnerability zoning layer is based on the results of (Sheikhian et al., 2017), which was performed using a combination of Granular Computing and Artificial Neural Networks which has a better performance than previous researches (Alinia & Delavar, 2011; Khamespanah et al., 2013; Moradi et al., 2015; Silavi et al., 2006). That study has evaluated seismic vulnerability by considering the following six criteria: 1 - Slope, 2 - The seismic intensity, 3- Buildings constructed before 1966, 4 - The percentage of buildings constructed between 1966 and 1968, 5 - The percentage of buildings with a foundation of weak material with four floors or less, and 6 - the percentage of buildings with a foundation of weak material and more than four floors. Using GIS spatial analyses, the criteria layers have been prepared by calculating the Euclidean distance, as well as performing the interpolation process with the Kriging (Gaetan & Guyon, 2010) method. The criteria maps were shown in Figure 4. In this study, ten candidate sites have been selected for ranking. Candidate sites have been selected, taking into account the appropriate access to the main roads, at least 3500 square meters' area, and barren land. Figure 3 shows the selected sites for ranking.

Table 1. The criteria used in research

Criterion	Reference
Distance from residential areas (C_1)	(Ahadnejad et al., 2015; Alavi et al., 2013; Mohammadi et al., 2019; Parsa Moghadam at al., 2017)
Distance from cultural centers (C_2)	(Ahadnejad et al., 2015)
Seismic vulnerability (C_3)	(Adalı & Tuş, 2019; Zandi et al., 2021)
Distance from green spaces (C_4)	(Ahadnejad et al., 2015; Ahmed et al., 2016; Alavi et al., 2013; Mohammadi et al., 2019; Parsa Moghadam et al., 2017; Soltani et al., 2019; Tripathi et al., 2021)
Distance from health centers (C_5)	(Ahadnejad et al., 2015; Kumar et al., 2016; Mohammadi et al., 2019; Senvar et al., 2016; Soltani et al., 2019; Zandi & Delavar, 2021)
Distance from existing hospitals (C_6)	(Abdullahi et al., 2014; Adalı & Tuş, 2019; Ahadnejad et al., 2015; Halder et al., 2020; Kumar et al., 2016; Mohammadi et al., 2019; Parsa Moghadam et al., 2017; Senvar et al., 2016; Sharmin & Neema, 2013; Soltani et al., 2019; Soltani & Marandi, 2011; Wu et al., 2007; Tripathi et al., 2021)
Distance from industrial areas (C_7)	(Ahadnejad et al., 2015; Alavi et al., 2013; Parsa Moghadam et al., 2017; Sharmin & Neema, 2013; Soltani et al., 2019; Tripathi et al., 2021)
Population density (C_8)	(Abdullahi et al., 2014; Adalı & Tuş, 2019; Ahadnejad et al., 2015; Chatterjee & Mukherjee, 2013; Kumar et al., 2016; Mohammadi et al., 2019; Parsa Moghadam et al., 2017; Şahin et al., 2019; Senvar et al., 2016; Soltani et al., 2019; Soltani & Marandi, 2011; Tripathi et al., 2021; Vahidnia et al., 2009; Wu et al., 2007)
Distance from major roads (C_9)	(Abdullahi et al., 2014; Ahmed et al., 2016; Alavi et al., 2013; Halder et al., 2020; Kumar et al., 2016; Mohammadi et al., 2019; Parsa Moghadam et al., 2017; Senvar et al., 2016; Sharmin & Neema, 2013; Soltani et al., 2019; Soltani & Marandi, 2011; Tripathi et al., 2021; Vahidnia et al., 2009)

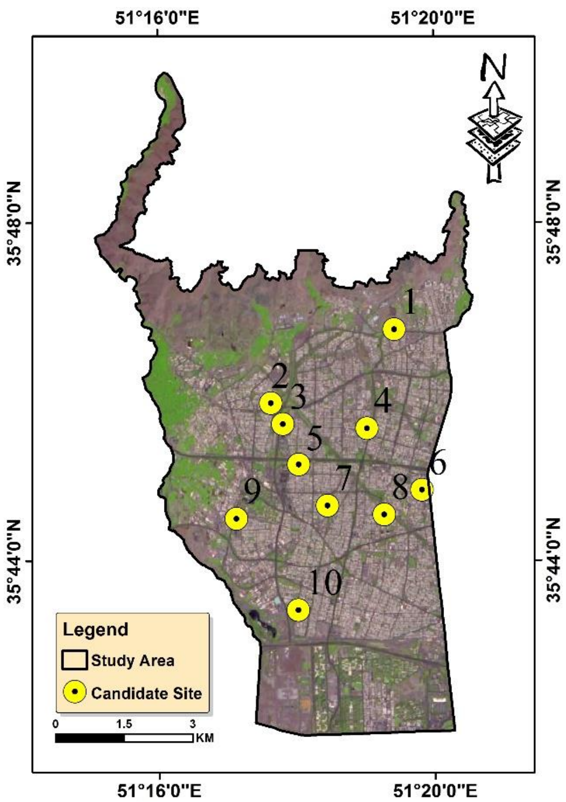

Figure 3. Selected candidate sites for ranking

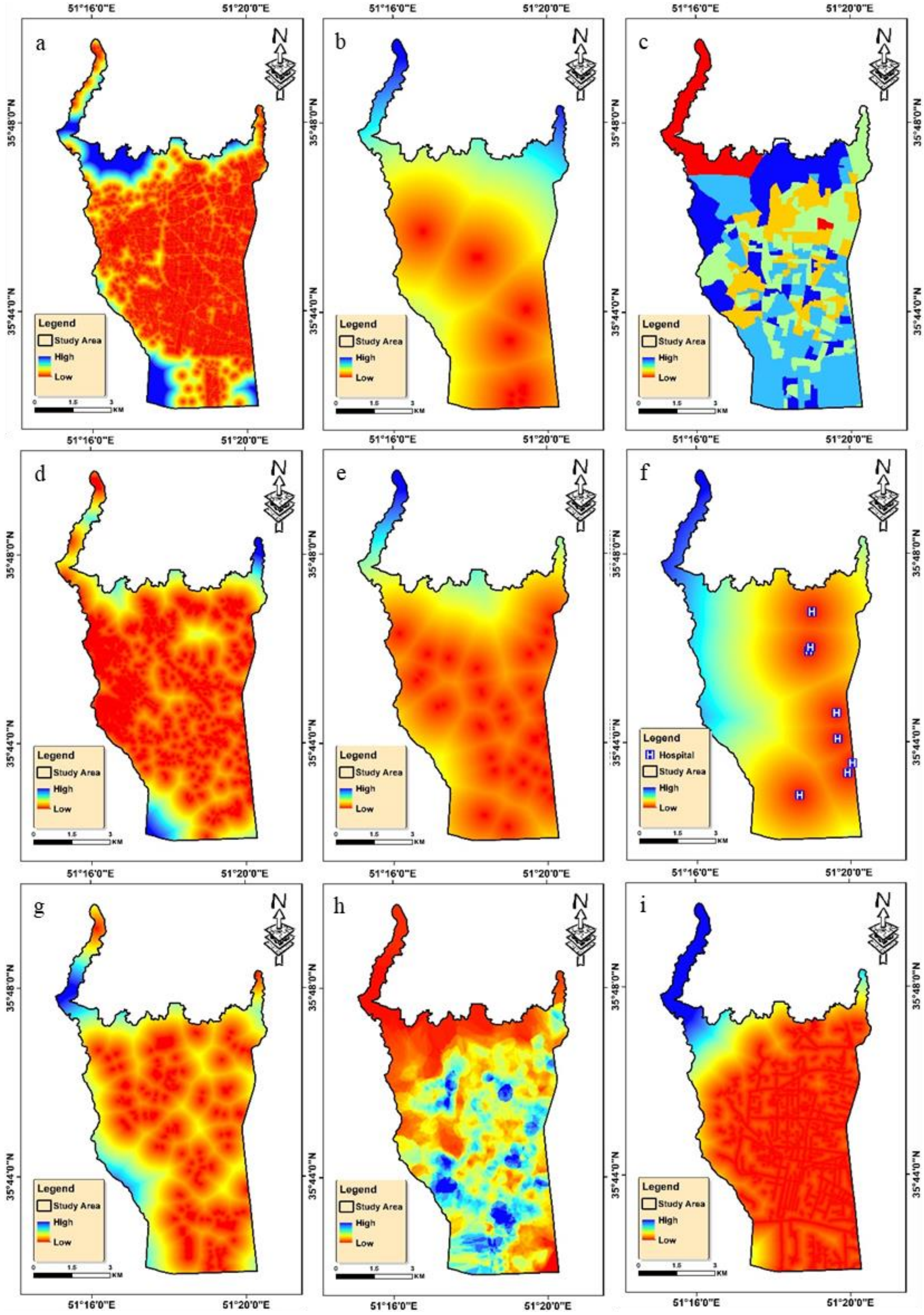

Figure 4. Criteria maps, a) distance from military centers, b) distance from cultural and religious centers, c) seismic vulnerability, d) distance from green spaces, e) distance from health centers, f) distance from existing hospitals, g) distance from industrial

4. Methodology and method justification

The general structure of the present study is shown in Figure 5. The aim is to provide a methodology with the ability to support different decision strategies and model uncertainty. In the first step, the effective criteria in hospital location ranking process were determined using the experts' opinions and the literatures' review. In the next step, the spatial layer of each criterion in the GIS environment was prepared, and the values of the criteria were calculated for each candidate site. Almost all MCDM methods use criteria weights for the decision-making process (information aggregation). Therefore, the weights of the criteria play an essential role in the evaluation of alternatives. As a result, determining the appropriate *weights of the criteria is very important and the results of a MCDM method are largely dependent on the weights of the criteria (Zardari, et al., 2015). One of the ways to obtain the weights of criteria is to use objective weighting methods. In the objective methods of criteria weighting, unlike subjective weighting methods (like AHP and ANP), instead of using experts' preferences to determine the weights of criteria, mathematical models are used (Zardari, et al., 2015). The objective weighting methods determine the weights of criteria by solving mathematical models without considering the preferences of experts (Aalianvari et al., 2012). The use of objective weighting methods, in addition to the mentioned advantages, does not have the problem of inconsistency of experts' opinions, e.g., pairwise comparisons. In the subjective methods, with the increase in the number of criteria or experts, the number of pairwise comparisons increases and as a result, the inconsistency increases.*

Accordingly, the weights of criteria were calculated using the CRITIC and Shannon's entropy methods as they are two well-known objective weighting methods. The weights obtained by the CRITIC method convey all of information from all the criteria participating in the problem (Jahan, et al., 2012). In addition, it provides all information in the decision matrix (Jahan, et al., 2012). The CRITIC method allows the integration of dependent criteria (Jahan, et al., 2012). The obtained weights by CRITIC include existing contrast intensity and conflict in problem structure (Jahan, et al., 2012). The Shannon's entropy method models the uncertainty in the decision matrix. In order to model the uncertainty in the weighting process and to improve its accuracy, the weights obtained by Shannon's entropy and CRITIC methods were combined using DST. MCDM is one of the methods of modeling complex engineering problems (Kahraman, 2008). One of the challenges of decision makers is facing incomplete, ambiguous and uncertain information (Kahraman, 2008). One of the ways to reach reliable results when having uncertain, incomplete and conflicting information is to fuse information (Yager & Liu, 2008). Fuzzy set theory is usually used in MCDM in order to model the uncertainty in human knowledge (human evaluations) (Kahraman, 2008). Generally, in multi-criteria decision-making, fuzzy theory is combined with methods and deals with the fuzzification of problem inputs and its calculations. But maybe combining the results of different methods instead of fuzzifying a particular method will lead to more accurate and reliable results. In other words, instead of using one source for decision making, different sources should be integrated. The DST is a very powerful tool for information fusion and uncertainty modeling (Yager & Liu, 2008). The DST fuses information received from two or more sources and this fusion improves reliability and reduces uncertainty in decision making.

The approach that determines how to evaluate candidate alternatives is called a decision rule (Jelokhani-Niaraki & Malczewski, 2015). In this study, the QOWA was used as a decision rule-based method because decision makers will be able to determine the decision risk level according to the decision situation (Jelokhani-Niaraki & Malczewski, 2015) and provide high-low risk solutions to solve the hospital location problem. In fact, method QOWA allows decision makers to choose the strategy they need from a continuous range of pessimistic to optimistic strategies. Thus, the selected candidate sites were ranked using the QOWA MCDM method. Finally, the result of the QOWA method was compared with the results of other popular and well-known MCDM methods including EDAS (Keshavarz Ghorabaee et al., 2015), CODAS (Keshavarz Ghorabaee et al., 2016), TOPSIS (Hwang & Yoon, 1981) and VIKOR (Opricovic, 1998).

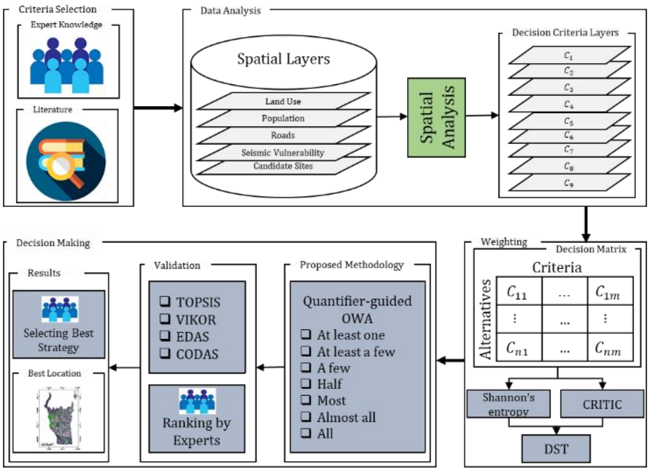

Figure 5. The proposed methodology

4.1. CRITIC objective weighting method

Criteria weights play an essential role in MCDM problems (Adalı & Tuş, 2019). The Criteria Importance Through Inter-criteria Correlation (CRITIC) is an objective weighting method developed by Diakoulaki et al. (Diakoulaki et al., 1995) in 1995. This method is based on two fundamental concepts in MCDM. These concepts are the contrast intensity and the criteria's conflicting character (Asgharizadeh & balani; Diakoulaki et al., 1995). The CRITIC uses correlation among criteria for determining the weights of criteria in MCDM problems (Zhao et al., 2011). Being a criterion more important indicates that the standard deviation in that criterion is larger, and its correlation with other criteria is less. In order to determine the weights of criteria by CRITIC, the following steps are performed (Adalı & Işık, 2017; Adalı & Tuş, 2019; Asgharizadeh & balani; Diakoulaki et al., 1995; Madic & Radovanović, 2015):

Step 1: The decision matrix is formed as Eq. (1) as follows:

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

In which n is the number of candidate sites, and m is the number of the criteria. The performance measure of the i^{th} site on the j^{th} criterion is showed by x_{ij}.

Step 2: The decision matrix is normalized using Eq. (2) for the criteria that are benefit and Eq. (3) for the criteria with cost on decision-making.

$$x^*_{ij} = \frac{x_{ij} - min(x_{ij})}{max(x_{ij}) - min(x_{ij})} \quad (2)$$

$$x^*_{ij} = \frac{max(x_{ij}) - x_{ij}}{max(x_{ij}) - min(x_{ij})} \quad (3)$$

Step 3: Each criterion's weight is calculated by using the following equations, taking into account its standard deviation and Spearman's Correlation with the other criteria.

$$C_j = \sigma_j \times \sum_{i=1}^{m} 1 - r_{ji} \quad (4)$$

$$W_j = \frac{C_j}{\sum_{j=1}^{m} C_j} \quad (5)$$

The above equations, σ_j is the standard deviation of the j^{th} criterion and r_{ji} is the Spearman's Correlation coefficient between the j^{th} and the i^{th} criterion, respectively.

4.2. Shannon's entropy

Shannon's entropy method was proposed by Shannon (1948). Entropy is a tool for measuring the abnormally, changeability, unstable behaviour, degree of disorder and uncertainty of the information and system (Wu et al., 2011). The Shannon's entropy method is a function of probability and parameter distribution for measuring uncertainty in a criterion (Farzin et al., 2021). The weights of the criteria in this method are determined based on the degree of dispersion and turbulence in each criterion of the decision matrix. In order to determine the weights of decision criteria by the Shannon's entropy, the following steps are performed (Shannon, 1948; Wu et al., 2011).

Step 1: The decision matrix is formed as Eq. (1).

Step 2: The decision matrix is normalized using Eq. (6).

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad (6)$$

Step 3: The degree of convergence of the values of each criterion (E_j) is determined using Eq. (7).

$$E_j = -k(\sum_{i=1}^{m} r_{ij}.ln(r_{ij})) \quad (7)$$

If the number of candidate sites is n, the constant value of k is calculated using Eq. (8).

$$k = \frac{1}{ln(n)} \quad (8)$$

Step 4: Using Eq. (9), the divergence value of each criterion is calculated.

$$D_j = 1 - E_j \quad (9)$$

Step 5: Finally, the criteria weights are calculated using Eq. (10).

$$w_j = \frac{D_j}{\sum_{j=1}^{m} D_j} \quad (10)$$

4.3. Dempster-Shafer theory

Dempster-Shafer Theory (DST) (Dempster, 1968; Shafer, 1992) is one of the most powerful methods in data fusion at the decision level. DST was first proposed by Dempster (1968), then focused on modeling uncertainty, supporting incomplete data, and evidence fusion from different sources (Shafer, 1992; Pahlavani et al., 2017). This theory can be used to fuse weights obtained by different weighting methods. In fact, the results of the different weighting methods are sources of evidence in DST. The main equations of this theory are based on three functions include: basic probability mass function (m), Belief function (Bel), and Plausibility function (Pl) (Sentz & Ferson, 2002).

The most important function in this theory is m function, which shows the mapping of all evidence for the existence of a state such as A by a number between 0 and 1 (Martin et al., 2010). The m function and its conditions are shown in Eq. (11).

$$\begin{cases} m: P(x) \rightarrow [0,1] \\ m(\phi) = 0 \\ \sum_{A\in P} m(A) = 1 \end{cases} \quad (11)$$

where P(x) is the power set, ϕ is null set and A is a subset of the power set.

Considering the m function and using Eq. (12), the bel function is calculated. In fact, the belief function represents the lower bound of the probability of a case such as A occurring. The bel function is equal to the sum of the m functions for a set such as B that are subsets of A.

$$bel(A) = \sum_{B|B\subseteq A} m(B) \quad (12)$$

The PI function is calculated by considering the m function and using Eq. (13). In fact, the PI function represents the upper bound of the probability of a case such as A occurring. The PI function is equal to the sum of the m functions for a set such as B whose intersection with case A is not null.

$$PI(A) = \sum_{B|B \cap A \neq \varnothing} m(B) \tag{13}$$

Eq. (14) is used to fuse several evidences using the DST.

$$m_1(A) \oplus m_2(A) \oplus \cdots \oplus m_n(A) = \frac{\sum_{\cap A_i = A} m_i(A)}{1-K} \tag{14}$$

The value of K in Eq. (14) is calculated as follows:

$$K = \sum_{\cap A_i = \varnothing} m_i(A) \tag{15}$$

4.4. QOWA

Yager in 1998 proposed the Ordered Weighted Averaging (OWA) operator for information fusion in MCDM problems and this method was developed in fuzzy context (Xu, 2005; Yager, 1988). It has been used in recent years for various applications in many research (Xu, 2005). This method is one of the best MCDM methods and is widely used in GIS. The following steps are performed to implement the OWA (Malczewski, 2006; Malczewski et al., 2003; Yager, 1988). Each alternative (i = 1, 2, 3, …, n) is explained by a set of criteria values: $a_{ij} \in [0, 1]$ t□at $j = 1, 2, 3, \ldots, m$. A MCDM problem includes a weight vector: $w_j \in [0, 1]$ t□at $j = 1, 2, 3, \ldots, m$ and $\sum_{j=1}^{m} w_j = 1$. The OWA operator for the ith alternative is defined by considering the input data (a set of criteria values, criteria weights and order weights: $v = v_1, v_2, v_3, \ldots, v_m$ $v_j \in [0, 1]$ t□at $j = 1, 2, 3, \ldots, m$ and $\sum_{j=1}^{m} v_j = 1$.) as follows:

$$OWA_i = \sum_{j=1}^{m} \left(\frac{u_j v_j}{\sum_{j=1}^{m} u_j v_j} \right) Z_{ij} \tag{16}$$

In the Eq. (6), $Z_{i1} \geq Z_{i2} \geq \cdots \geq Z_{im}$ are obtained by reordering the criteria values $a_{i1}, a_{i2}, \ldots, a_{im}$, and u_j is obtained by reordering the criteria weights according to the criteria values (Z_{ij}). One of the important points in this method is determining the order weights vector. For determining this vector, Yager suggested an approach as follows (Yager, 1996):

$$v_j = \left(\frac{\sum_{k=1}^{j} u_k}{\sum_{k=1}^{n} u_k} \right)^{\alpha} - \left(\frac{\sum_{k=1}^{j-1} u_k}{\sum_{k=1}^{n} u_k} \right)^{\alpha} \tag{17}$$

Given the Eq. (7), the OWA method combines linguistic terms with α parameters to provide a way to develop different scenarios of decision strategy (Meng, Malczewski, & Boroushaki, 2011). In Eq. (7), by changing the α parameter, different decision strategies can be created. For example, being α equal to 1 is in accordance with the "half" quantifier. Being α equal to 0 corresponds to an "at least one" quantifier. If the α parameter tends to infinity, it corresponds to an "all" quantifier. Table 2 shows the different α values and their equivalent linguistic variables. Increasing the value of α means increasing pessimism and reducing decision-maker optimism (Tale Jenekanlou, Karimi, & Taleai, 2015). This means that high-value weights are assigned to low-value criteria and, low-value weights are assigned to high-value criteria (Meng et al., 2011).

Table 2. The α parameter values and equal linguistic variables (Boroushaki & Malczewski, 2010; Malczewski, 2006)

linguistic quantifier	At least one	At least a few	A few	Half	Most	Almost all	All
α	$\alpha \to 0$	0.1	0.5	1	2	10	$\alpha \to \infty$
Decision strategy	Extremely optimistic	Very optimistic	Optimistic	Neutra l	Pessimistic	Very pessimistic	Extremely pessimistic

Since the sum of the weights is usually equal to 1, $\sum_{i=1}^{n} u_j = 1$ and Eq. (17) is simplified as follows:

$$v_j = \left(\sum_{k=1}^{j} u_k \right)^{\alpha} - \left(\sum_{k=1}^{j-1} u_k \right)^{\alpha} \tag{18}$$

Finally, the QOWA is introduced as follows:

$$OWA_i = \sum_{j=1}^{n} \left(\left(\sum_{k=1}^{j} u_k \right)^{\alpha} - \left(\sum_{k=1}^{j-1} u_k \right)^{\alpha} \right) Z_{ij} \tag{19}$$

In above Eq. α is related to ORness (reflecting risk taking) as follow: ORness = 1/ (1+ α), α ≥ 0 (Yager, 1996).

5. Experiments

In this section, the results of the study are presented. In the first part, the criteria weighting results by the CRITIC and Shannon's entropy methods, the correlations between the criteria, and the final weights of the criteria by the fusion of the weights obtained by the CRITIC and Shannon's entropy using DST were presented. In the second part, the ranking results of the QOWA were presented with different decision strategies. In the third part, the evaluation of the proposed methodology results was presented and compared with the results of several popular

MCDM methods. Finally, a comparison was also performed between the results of the proposed methodology and experts' opinions by considering different decision strategies.

5.1. CRITIC results

In this section, the criteria weights were calculated by considering the ten candidate sites by the CRITIC method. At first, the decision matrix was formed by Eq. (1). In the second step, the decision matrix was normalized using Eq. (2) for the benefit criterion and Eq. (3) for the cost criterion. Standard deviations and means for all criteria were then calculated. In the next step, the Spearman's Correlation coefficients were obtained and shown in Table 3. Table 3 shows the correlations between decision criteria. The Spearman's correlation values show that the criteria are highly correlated. Among these, the dependence between criteria C_2 and C_7, C_3 and C_4, C_3 and C_5, C_1 and C_7 was more than the others and very high. At the end, by using Eq. (4) and Eq. (5), the weights of criteria were calculated and shown in Table 4. Table 4 shows that the criteria of seismic vulnerability, distance from the major roads and population density were the most important criteria for selecting the optimal hospital location, respectively. The distance from existing hospitals criterion also has the lowest weight.

5.2. Shannon's entropy results

In this section, the criteria weights were calculated by considering the ten candidate sites by the Shannon's entropy method. At first, the decision matrix was formed by Eq. (1). In the second step, the decision matrix was normalized using Eq. (6). In the next step, using Eq. (7) the degree of convergence of each criterion were obtained and shown in the second row of the Table 5. In the next step, using Eq. (9) the divergence value of each criterion was obtained and shown in the third row of the Table 5. Finally, by Eq. (10), the weights of criteria were calculated and shown in the last row of the Table 5. Table 5 shows that the criteria of distance from green spaces, distance from the major roads and distance from existing hospitals were the most important criteria for selecting the optimal hospital location, respectively. The seismic vulnerability criterion also has the lowest weight.

5.3. DST Results

In order to calculate the final weights of the decision criteria using DST, the weights obtained by the CRITIC and Shannon's entropy were considered as basic probability mass function (m). At first, the value of the K parameter was calculated using Eq. (15), and then the results of the two weighting methods were fused using Eq. (14), and the final weights of the criteria were calculated as in Table 6. Table 6 shows that the criteria of distance from green spaces, distance from the major roads and population density were the most important criteria for selecting the optimal hospital location, respectively. The seismic vulnerability criterion also has the lowest weight.

Table 3. The Spearman's correlation values between decision criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1.0000	0.1218	-0.3394	0.3133	-0.1591	0.2934	-0.5467	-0.0146	0.0351
C_2	0.1218	1.0000	0.3532	-0.0861	0.4483	-0.0432	-0.6914	0.1096	-0.2346
C_3	-0.3394	0.3532	1.0000	-0.6514	0.5909	-0.0459	-0.1301	0.2080	-0.3829
C_4	0.31327	-0.0861	-0.6514	1.0000	-0.0025	0.4120	-0.1890	-0.1248	-0.0329
C_5	-0.1591	0.4483	0.5909	-0.0025	1.0000	0.4160	-0.2330	-0.1593	-0.0542
C_6	0.2934	-0.0432	-0.0459	0.4120	0.4160	1.0000	-0.1344	-0.3587	0.1970
C_7	-0.5467	-0.6914	-0.1301	-0.1890	-0.2330	-0.1344	1.0000	-0.3072	0.2593
C_8	-0.0146	0.1096	0.2080	-0.1248	-0.1593	-0.3587	-0.3072	1.0000	-0.0429
C_9	0.0351	-0.2346	-0.3829	-0.0329	-0.0542	0.1970	0.2593	-0.0429	1.0000

Table 4. The criteria weights by the CRITIC method.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_j	2.539	2.113	3.585	2.785	2.804	1.928	2.571	2.858	3.008
W_j	0.1050	0.0874	0.1482	0.1151	0.1159	0.0797	0.1063	0.1181	0.1243

Table 5. The criteria weights by the Shannon's entropy method

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
E_j	0.9417	0.9288	0.9714	0.8690	0.9502	0.9139	0.9588	0.9394	0.9065
D_j	0.0583	0.0712	0.0286	0.1310	0.0498	0.0861	0.0412	0.0606	0.0935
W_j	0.0939	0.1148	0.0461	0.2112	0.0803	0.1388	0.0664	0.0976	0.1507

Table 6. The final fused criteria weights by the DST

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
W_j	0.0905	0.0921	0.0627	0.2232	0.0854	0.1016	0.0648	0.1058	0.1720

5.4. QOWA results

At first, the decision matrix was formed by Eq. (1). The decision matrix was then normalized using Eq. (2) for the benefit criterion and Eq. (3) for the cost criterion. In the decision-making process, the value of a criterion is high if it is the 'benefit' criterion. In this study C_6, C_7 and C_8 are the criteria of benefit and there is a need to find a site where the values of these criteria are high. Moreover, the value of a criterion is low if it is the 'cost' criterion. In this study, C_1 – C_5 and C_9 are the criteria of cost and accordingly, it is necessary to find a site where the values of these criteria are low. In the next step, the value of each alternative's criteria was reordered from large to small (to determine Z_{ij}), and according to Z, the weights vector (obtained by the DST) was also reordered (to determine u_j). Afterwards, by using Eq. (8), the order weights were calculated (in this research, the values were considered same as the first row of Table 7). Finally, using Eq. (9), the QOWA operator values were determined for all alternatives. Table 7 shows the ranking of the QOWA method results. According to Table 7, the candidate sites' ranking results for the construction of a new hospital were almost the same, and by the six decision strategies, including Extremely optimistic, Very optimistic, Optimistic, Neutral, Pessimistic, and Very pessimistic, sites 5, 7 and 9 have been identified as the best options. In the Extremely pessimistic decision strategy, the scores of 7 sites have been calculated equal to zero, including sites 1-4, 6, 7, and 9. This means that in this strategy, 7 sites did not fulfill the minimum score for the hospital construction and failed to enter the ranking process. The ranking results of different decision strategies were shown in Figure 6.

Table 7. QOWA ranking results

Site	α: 0.0001		0.1		0.5		1		2		10		10000	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
A_1	0.80819	10	0.74178	10	0.53515	10	0.36754	10	0.18796	9	0.00422	9	0	-
A_2	0.99992	4	0.92886	4	0.70806	4	0.52360	5	0.30521	5	0.00723	7	0	-
A_3	0.99990	5	0.90186	6	0.61491	6	0.40440	6	0.20321	8	0.01027	6	0	-
A_4	0.99989	6	0.89811	7	0.60818	7	0.40287	7	0.20835	6	0.00621	8	0	-
A_5	0.99994	2	0.93613	3	0.74671	2	0.60309	2	0.45368	2	0.19784	1	0.13505	1
A_6	0.97846	9	0.90892	5	0.70292	5	0.54471	4	0.37579	4	0.10306	4	0	-
A_7	0.99995	1	0.95186	1	0.79039	1	0.64237	1	0.45708	1	0.11752	3	0	-
A_8	0.99987	8	0.89162	9	0.58500	9	0.37747	9	0.20611	7	0.04561	5	0.00508	3
A_9	0.99993	3	0.93622	2	0.74013	3	0.58214	3	0.40721	3	0.12792	2	0.05519	2
A_{10}	0.99988	7	0.89614	8	0.59716	8	0.38151	8	0.17728	10	0.00345	10	0	-

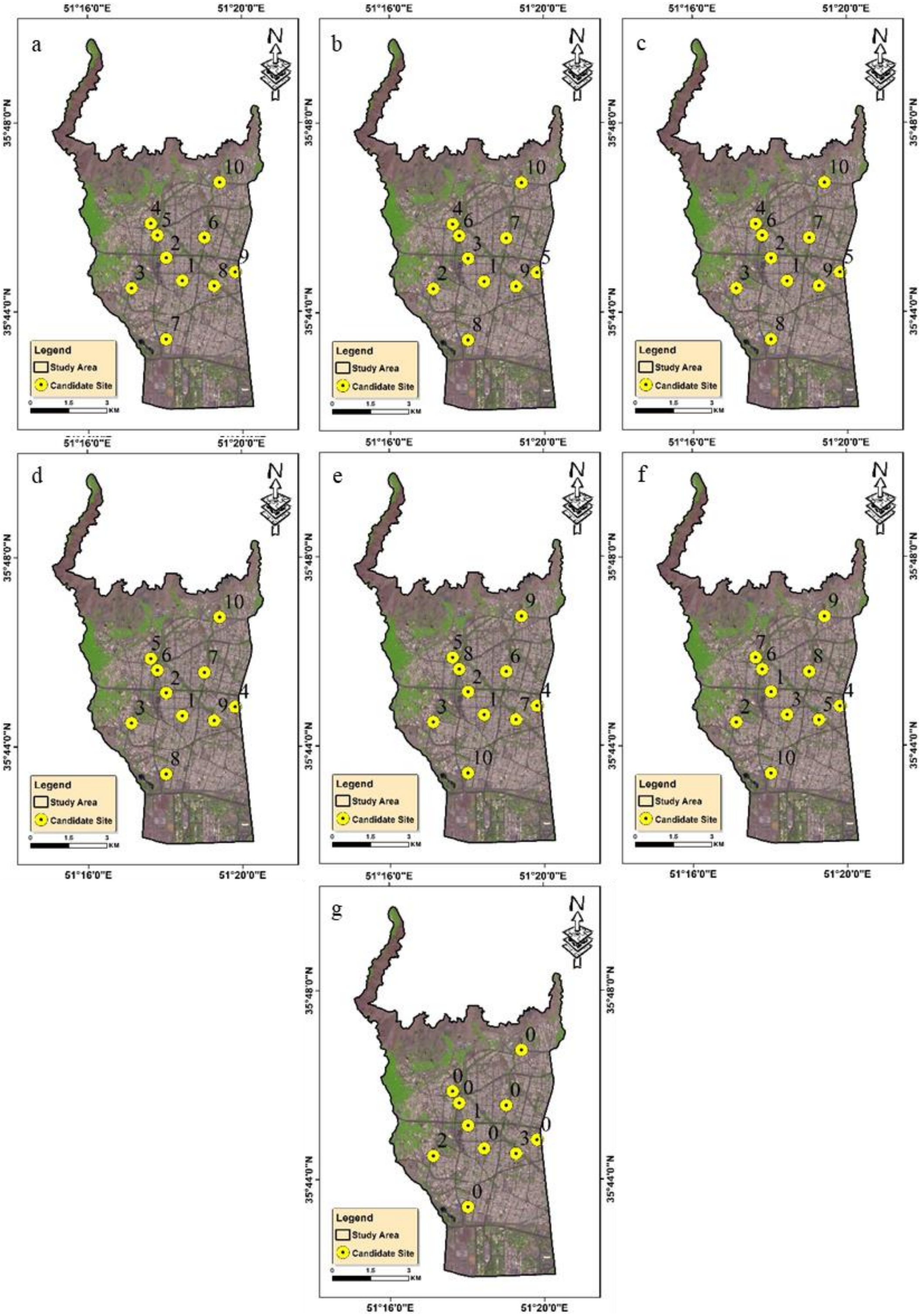

Figure 6. The different decision strategy maps: a) Extremely optimistic, b) Very optimistic, c) Optimistic, d) Neutral, e) Pessimistic, f) Very pessimistic, g) Extremely pessimistic

5.5. Validation

In this section, to evaluate the performance of the proposed methodology, the candidate sites were ranked by the experts, and also the results were compared to the results of several well-known MCDM methods. The results of the used models for evaluating the proposed methodology results are shown in Table 8. According to the literature review, EDAS, CODAS, TOPSIS and VIKOR have been used to select an optimal hospital location. The input weights vector for all the mentioned methods was obtained by the DST (Section 5.3.).

Also, in order to evaluate the results of the proposed methodology to use in real and practical applications, the selected candidate sites have been ranked by 15 experts *from the specialties in Urban Planning, Land use Planning (Spatial Planning) and Geospatial Information System (GIS). The selected experts have at least 5 years of practical experiments in the field of urban development and land use planning/ allocation. In order to aggregate the rankings made by the experts, the majority voting method has been used. For this purpose, the rank of each site has been the most repeated rank assigned by experts.*

As shown in Table 8, the results of expert rankings were significantly similar to the two methods of VIKOR and CODAS but not significantly similar to the results of TOPSIS and EDAS. Furthermore, by comparing these results with Table 7, the remarkable accuracy of all decision strategies considered in the presented methodology was observed.

The site ranking results are evaluated based on different decision strategies by the experts, and the best strategy was selected by them. The majority of experts consider a Neutral strategy to be more appropriate than the other decision strategies for ranking hospital locations. According to experts, the winner strategy (Neutral strategy) has a higher performance than other strategies in practical activities. Of course, they did not consider other strategies unusable or inappropriate, but according to their experiences, they saw the Neutral strategy as appropriate in most decision-making situations, while other strategies were more needed in certain situations. Figure 7 shows the results of experts' opinions. As shown in Figure 7, 23 experts (46%) voted for the Neutral decision strategy and considered it more appropriate than other strategies for choosing an optimal hospital location.

It is necessary to produce a wide range of results based on different decision strategies and in accordance with different decision-making situations in decisions related to urban development and planning. Because in the process of spatial planning and urban development, designing different decision-making scenarios and measuring the performance of the proposed scenario is very important and improves the knowledge about results of different decision-making scenarios. Therefore, even though the results of two methods of VIKOR and CODAS are close to the opinions of experts, but compared to the proposed methodology, it has received less attention from experts. Because the aforementioned methods are only able to model a decision strategy and cannot be useful in the case of different and possibly critical decision situations.

Table 8. The results of the other methods and expert's opinions

Site	Method				
	EDAS	CODAS	TOPSIS	VIKOR	Expert
A_1	8	10	8	10	10
A_2	2	5	1	5	6
A_3	6	4	6	8	4
A_4	9	6	9	6	5
A_5	5	2	5	2	2
A_6	4	7	3	4	8
A_7	3	1	4	1	1
A_8	10	8	10	7	4
A_9	1	3	2	3	3
A_{10}	7	9	7	9	9

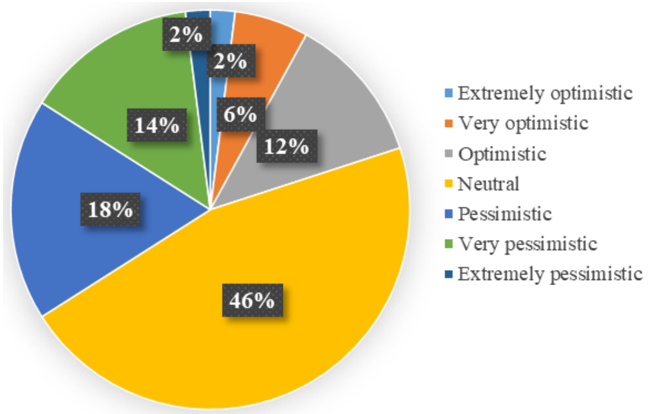

Figure 7. Experts' opinions

6. Discussion

In the previous researches, weighting methods based on experts' opinions have been used to choose an optimal location for the hospitals. Moreover, the correlations between the criteria and their uncertainty were often ignored in these researches. In the present study, the CRITIC and Shannon's entropy were used as the objective weighting methods to calculate the criteria weights and to consider the correlations between them and the existed uncertainty. Finally, in order to deal with the uncertainty in the weighting process, the results of both methods were fused by DST in the decision level. Table 3 shows a significant correlation between some of decision criteria. If this correlation is not considered, the results of the decision will be affected. It can be seen in Tables 4 and 5, the results of the two weighting methods are not only not similar but also contradictory. For example, CRITIC has identified seismic vulnerability as the most important criterion in decision making, while Shannon's entropy has considered this criterion as the least important criterion in decision making. Also, CRITIC has considered the distance from existing hospitals criterion as the least important ones, while Shannon's entropy has recognized it as one of the three important criteria. Therefore, in addition to modeling the uncertainty of the weighting process in decision making, *in order to deal with the contradiction of the two weighting methods, their results were fused by the DST in the decision level.*

The results of the DST were a combination of the results of two weighting methods. The results of the DST showed that three criteria included distance from green spaces (same as Shannon's entropy), distance from the major roads (same as the CRITIC and Shannon's entropy), and population density (same as CRITIC) were the most important criteria in decision-making. Same as Shannon's entropy, but not same as the CRITIC, the results of this method also showed that the seismic vulnerability criterion is the least important in decision making. The results of the DST showed that the distance from existing hospitals was the fourth most important criterion in the decision-making process, and this is in contrast to the results of the CRITIC, which recognized this criterion as the least important criterion in the decision-making. As can be seen, different weighting methods have led to different results, and in order to have the advantage of all methods, their results can be fused. In the present study, in order to have the advantage of "considering the correlation between the criteria" (by CRITIC), "dealing with the uncertainty in the criteria values" (by Shannon's entropy), and of course modeling the uncertainty in the weighting process, the DST fusion model has been used in decision-level.

There are usually different strategies in the actual decision-making process and like different weighting methods, different decision strategies have advantages. MCDM methods are mainly unable to provide different decision strategies. Hence, the Quantifier-guided OWA method was used to select an optimal hospital location was used in order to model the different decision strategies. In this method, changing the alpha parameter results in creating different decision strategies. In this research, the candidate sites' ranking process was carried out by considering seven famous decision strategies, including Extremely optimistic, Very optimistic, Optimistic, Neutral, Pessimistic, Very pessimistic, and Extremely pessimistic. As shown in Table 7, the ranking of the candidate sites was almost the same in all the different decision strategies. However, the scores of the candidate sites in each strategy were significant. Two sample decision strategies were explained in the following. In an Extremely optimistic decision strategy (alpha equals 0.0001), all sites' scores were almost equal and high (close to number 1), which means that all these candidate sites were optimal locations. In the highly pessimistic decision strategy (alpha equals 10,000), the scores of seven sites were almost zero that means they were not suitable for the hospital at all. Also, the scores of the three sites with nonzero scores were very low, and the values of these scores were far apart from each other. Based on the results, by moving from optimistic strategies to pessimistic strategies, the degree of suitability of candidate sites decreases. This means that the optimistic strategists identify all or most of the candidate sites suitable for the construction of the hospital and give them a high score in a way in the Extremely optimistic strategy these values were close to the ideal value. While pessimistic strategies do not consider the most sites suitable for hospital construction and give them a very low score or even the worst value.

To evaluate the results of the proposed methodology, the ranking results of the proposed methodology were compared with that of four MCDM methods, including EDAS, CODAS, TOPSIS, and VIKOR, as well as rankings performed by the experts (Table 7 and Table 8). This comparison indicates that the proposed methodology results were closer to the rankings performed by the experts compared to that of the other studied MCDM methods. The results of CODAS and VIKOR methods were close to the ranking performed by the experts and also to the results of the proposed methodology. A noteworthy point in the recent comparison was the inability of CODAS and VIKOR methods to model different decision strategies and the uncertainty in the decision-making process. Of course, combining these methods with fuzzy logic (Zadeh, 1975) adds to their ability to model uncertainty, but they are still not able to model different decision strategies. The results of the TOPSIS and EDAS methods were not similar to the rankings performed by the experts and the results of the proposed methodology.

Based on the research results by Adalı and Tuş (2019), the results of TOPSIS, EDAS, and CODAS methods might have the same or significant similarities, but in the present study, significant similarities were not observed. This difference can be due to the following reasons. In the present study, the search space (the number of candidate sites) has been increased, while in Adalı and Tuş (2019), the number of candidate sites was only 4. Also, in Adalı and Tuş (2019), only the CRITIC weighting method was used, but in the present study, the combination of the CRITIC and Shannon's entropy weighting methods were used.

Different decision strategies can be used in different decision situations. According to experts, a Neutral decision strategy (chosen by 44% of the experts) has been the best decision strategy to choose an optimal location for the hospital. Of course, different decision-making strategies may be suitable in different situations. Depending on the decision-making situation, the decision-makers' points of view and the available possibilities of each decision-making strategy are important. In general, the proposed methodology results were closer to the results of the rankings performed by the experts. It is also possible to rank the sites with different decision strategies in the QOWA method.

7. Conclusion

In the present study, a hybrid methodology has been proposed, including the CRITIC and Shannon's entropy objective weighting methods, DST, and the QOWA MCDM method, to determine an optimal hospital location. Accordingly, the GIS has been used to consider spatial criteria and perform related spatial analysis and geo-processing. In order to consider the correlations between the criteria, the CRITIC method has been used. Shannon's entropy to consider the uncertainty in criteria values. In order to fuse the results of the two weighting methods and to deal with the uncertainty and contradiction, the DST has been used. Results showed that the criteria of distance from green spaces, distance from the major roads and population density were the most important criteria for selecting the optimal hospital location, respectively. The seismic vulnerability criterion also has the lowest weight. Finally, for modeling the existing uncertainty in ranking and considering the different decision strategies in decision making, the Quantifier-guided OWA MCDM method has been used. Unlike the most MCDM methods with only one ranking result, the proposed methodology can provide rankings in different situations. By comparing the results of the proposed methodology with the results of four well-known MCDM methods, including EDAS, CODAS, TOPSIS, and VIKOR, it was found that the proposed methodology has higher accuracy and performance. The results of the CODAS and VIKOR methods were significantly similar to the rankings performed by the experts and the Neutral decision strategy of the proposed methodology. However, these two methods can model only one strategy and cannot model the other decision strategies. According to experts, a Neutral decision strategy (chosen by 46% of the experts) has been the best decision strategy to choose an optimal location for the hospital and then Pessimistic (chosen by 18% of the experts), Very pessimistic (chosen by 14% of experts), Optimistic (chosen by 12% of the experts), Very optimistic (chosen by 6% of the experts), Extremely optimistic (chosen by 2% of the experts), and the Extremely pessimistic (chosen by 2% of the experts). The use of objective weighting methods and fuse their results can be suitable for site selection applications and can be replaced by weighting methods based on experts' opinions. In the present study, due to the unavailability of the totally different transportation types of standard road network, for preparing some of the decision criteria maps the Euclidean distance was used. Considering that preparing the map of decision criteria using network analysis is closer to reality, it is recommended to use the distance on the road network instead of the Euclidean distance. A combination of subjective (such as Best-Worst Method) and objective weighting methods is suggested for a future work to fuse the weights.

References

Abdullahi, S., Mahmud, A. R. b., & Pradhan, B. (2014). Spatial modelling of site suitability assessment for hospitals using geographical information system-based multicriteria approach at Qazvin city, Iran. Geocarto International, 29(2), 164-184.

Adalı, E. A., & Işık, A. T. (2017). CRITIC and MAUT methods for the contract manufacturer selection problem. European Journal of Multidisciplinary Studies, 2(5), 93-101.

Adalı, E. A., & Tuş, A. (2019). Hospital site selection with distance-based multi-criteria decision making methods. International Journal of Healthcare Management, 1-11.

Aalianvari, A., Katibeh, H., & Sharifzadeh, M. (2012). Application of fuzzy Delphi AHP method for the estimation and classification of Ghomrud tunnel from groundwater flow hazard. Arabian journal of geosciences, 5(2), 275-284.

Ahadnejad, M., Ghaderi, H., Hadian, M., Haghighatfard, P., Darvishi, B., Haghighatfard, E., Zegordi, B. & Bordbar, A. (2015). Location allocation of health care centers using geographical information system: region 11 of Tehran. Journal of Fasa University of Medical Sciences, 4(4), 463-474. (In Persian)

Ahmed, A. H., Mahmoud, H., & Aly, A. M. M. (2016). Site suitability evaluation for sustainable distribution of hospital using spatial information technologies and AHP: A case study of Upper Egypt, Aswan City. Journal of Geographic Information System, 8(05), 578.

Alavi, S. A., Ahmadabadi, A., Molaei Qelichi, M., Pato, V., & Borhani, K. (2013). Proper site selection of urban hospital using combined techniques of MCDM and Spatial analysis of GIS (Case study: region 7 in Tehran city). Hospital, 12(2), 9-18. (In Persian)

Alinia, H. S., & Delavar, M. (2011). Tehran's seismic vulnerability classification using granular computing approach. Applied Geomatics, 3(4), 229-240.

Asgharizadeh, E., & balani, A. M. Multiple attribute decision making techniques. Tehran, Iran: Uneversity of Tehran, Press. (In Persian).

Boroushaki, S., & Malczewski, J. (2010). Using the fuzzy majority approach for GIS-based multicriteria group decision making . Computers & Geosciences, 36(3), 302-312.

Brail, R. K., & Klosterman, R. E. (2001). Planning support systems: Integrating geographic information systems, models, and visualization tools: ESRI, Inc.

Chatterjee, D., & Mukherjee, B. (2013). Potential hospital location selection using AHP: a study in rural India. International journal of computer applications, 71(17).

Cheniki, K., Baziz, A., & Boudiaf, B. (2019). Evaluating Relationship between Mixed-land Use and Land-use Compatibility in Algiers Bay. International Journal of Environmental and Science Education-IJESE, 14(7), 389-404.

Collins, M. G., Steiner, F. R., & Rushman, M. J. (2001). Land-use suitability analysis in the United States: historical development and promising technological achievements. Environmental management, 28(5), 611-621.

Daskin, M. S., & Dean, L. K. (2005). Location of health care facilities. In Operations research and health care (pp. 43-76): Springer.

Davtalab, M., & Alesheikh, A. A. (2018). Spatial optimization of biomass power plant site using fuzzy analytic network process. Clean Technologies and Environmental Policy, 20(5), 1033-1046.

Dempster AP. (1968). A generalization of Bayesian inference. Journal of the Royal Statistical Society: Series B. 205-247.

Diakoulaki, D., Mavrotas, G., & Papayannakis, L. (1995). Determining objective weights in multiple criteria problems: The critic method. Computers & Operations Research, 22(7), 763-770.

Farzin, M., Avand, M., Ahmadzadeh, H., Zelenakova, M., & Tiefenbacher, J. P. (2021). Assessment of Ensemble Models for Groundwater Potential Modeling and Prediction in a Karst Watershed. Water, 13(18), 2540.

Feizizadeh, B., & Blaschke, T. (2013). GIS-multicriteria decision analysis for landslide susceptibility mapping: comparing three methods for the Urmia lake basin, Iran. Natural hazards, 65(3), 2105-2128.

Gaetan, C., & Guyon, X. (2010). Spatial statistics and modeling (Vol. 90). New York: Springer.

Guler, D., & Yomralioglu, T. (2020). Suitable location selection for the electric vehicle fast charging station with AHP and fuzzy AHP methods using GIS. Annals of GIS, 26(2), 169-189.

Halder, B., Bandyopadhyay, J., & Banik, P. (2020). Assessment of hospital sites' suitability by spatial information technologies using AHP and GIS-based multi-criteria approach of Rajpur–Sonarpur Municipality. Modeling Earth Systems and Environment, 6(4), 2581-2596.

Hashemkhani Zolfani, S., Yazdani, M., Ebadi Torkayesh, A., & Derakhti, A. (2020). Application of a Gray-Based Decision Support Framework for Location Selection of a Temporary Hospital during COVID-19 Pandemic. Symmetry, 12(6), 886.

Hwang, C.-L., & Yoon, K. (1981). Methods for multiple attribute decision making. In Multiple attribute decision making (pp. 58-191): Springer.

ICTOTM: Information and Communication Technology Organizatin of Tehran Municipality. (2019). Statistics of Tehran Municipality 2018 (Statistical Yearbook of Tehran Municipality) (In Persian).

Jahan, A., Mustapha, F., Sapuan, S. M., Ismail, M. Y., & Bahraminasab, M. (2012). A framework for weighting of criteria in ranking stage of material selection process. The International Journal of Advanced Manufacturing Technology, 58(1), 411-420.

Jelokhani-Niaraki, M., & Malczewski, J. (2015). A group multicriteria spatial decision support system for parking site selection problem: A case study. Land Use Policy, 42, 492-508.

Kahraman, C. (Ed.). (2008). Fuzzy multi-criteria decision making: theory and applications with recent developments (Vol. 16). Springer Science & Business Media.

Karakuş, C. B., Demiroğlu, D., Çoban, A., & Ulutaş, A. (2020). Evaluation of GIS-based multi-criteria decision making methods for sanitary landfill site selection: the case of Sivas city, Turkey. Journal of Material Cycles and Waste Management, 22(1), 254-272.

Karimi, H., Amiri, S., Huang, J., & Karimi, A. (2019). Integrating GIS and multi-criteria decision analysis for landfill site selection, case study: Javanrood County in Iran. International journal of environmental science and technology, 16(11), 7305-7318.

Keshavarz Ghorabaee, M., Zavadskas, E. K., Olfat, L., & Turskis, Z. (2015). Multi-criteria inventory classification using a new method of evaluation based on distance from average solution (EDAS). Informatica, 26(3), 435-451.

Keshavarz Ghorabaee, M., Zavadskas, E. K., Turskis, Z., & Antucheviciene, J. (2016). A NEW COMBINATIVE DISTANCE-BASED ASSESSMENT (CODAS) METHOD FOR MULTI-CRITERIA DECISION MAKING . Economic Computation & Economic Cybernetics Studies & Research, 50(3).

Khamespanah, F., Delavar, M. R., Alinia, H. S., & Zare, M. (2013). Granular computing and Dempster–Shafer integration in seismic vulnerability assessment. In Intelligent systems for crisis management (pp. 147-158): Springer.

Kim, J. I., Senaratna, D. M., Ruza, J., Kam, C., & Ng, S. (2015). Feasibility study on an evidence-based decision-support system for hospital site selection for an aging population. Sustainability, 7(3), 2730-2744.

Kumar, P., Singh, R. K., & Sinha, P. (2016). Optimal site selection for a hospital using a fuzzy extended ELECTRE approach. Journal of Management Analytics, 3(2), 115-135.

Lin, C.-T., & Tsai, M.-C. (2010). Location choice for direct foreign investment in new hospitals in China by using ANP and TOPSIS. Quality & Quantity, 44(2), 375-390.

Madic, M., & Radovanović, M. (2015). Ranking of some most commonly used nontraditional machining processes using ROV and CRITIC methods. UPB Sci. Bull., Series D, 77(2), 193-204.

Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview. Progress in planning, 62(1), 3-65.

Malczewski, J. (2006). Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis. International Journal of Applied Earth Observation and Geoinformation, 8(4), 270-277.

Malczewski, J., Chapman, T., Flegel, C., Walters, D., Shrubsole, D., & Healy, M. A. (2003). GIS–multicriteria evaluation with ordered weighted averaging (OWA): case study of developing watershed management strategies. Environment and Planning A, 35(10), 1769-1784.

Martin, R., Zhang, J. & Liu, C. (2010) Dempster–Shafer theory and statistical inference with weak beliefs. Statistical Science 25(1):72–87.

Meng, Y., Malczewski, J., & Boroushaki, S. (2011). A GIS-based multicriteria decision analysis approach for mapping accessibility patterns of housing development sites: a case study in Canmore, Alberta. Journal of Geographic Information System, 3(01), 50.

Mohammadi, K., Alesheikh, A. A., & Taleai, M. (2019). Locating Hospital Centers By an Integration of BWM ،DANP ،VIKOR and COPRAS Methods (Case Study: Region 1, City of Tehran). Engineering Journal of Geospatial Information Technology, 7(3), 11-20. (In Persian).

Moradi, M., Delavar, M. R., & Moshiri, B. (2015). A GIS-based multi-criteria decision making approach for seismic vulnerability assessment using quantifier-guided OWA operator: a case study of Tehran, Iran. Annals of GIS, 21(3), 209-222.

Moradian, M. J., Ardalan, A., Nejati, A., Boloorani, A. D., Akbarisari, A., & Rastegarfar, B. (2017). Risk criteria in hospital site selection: a systematic review. PLoS currents, 9.

Noorollahi, E., Fadai, D., Akbarpour Shirazi, M., & Ghodsipour, S. H. (2016). Land suitability analysis for solar farms exploitation using GIS and fuzzy analytic hierarchy process (FAHP)—a case study of Iran. Energies, 9(8), 643.

Opricovic, S. (1998). Multicriteria optimization of civil engineering systems. Faculty of Civil Engineering, Belgrade, 2(1), 5-21.

Pahlavani, P., Sheikhian, H., & Bigdeli, B. (2017). Assessment of an air pollution monitoring network to generate urban air pollution maps using Shannon information index, fuzzy overlay, and Dempster-Shafer theory, A case study: Tehran, Iran. Atmospheric Environment, 167, 254-269.

Parsa Moghadam, M., Yazdani, M., Seyyedin, A., & Pashazadeh, M. (2017). Optimal site selection of urban hospitals using GIS software in Ardabil City. Journal of Ardabil University of Medical Sciences, 16(4), 374-388. (In Persian).

Şahin, T., Ocak, S., & Top, M. (2019). Analytic hierarchy process for hospital site selection. Health Policy and Technology, 8(1), 42-50.

Sentz, K., & Ferson, S. (2002). Combination of evidence in Dempster-Shafer theory, vol. 4015. Albuquerque: Sandia National Laboratories.

Senvar, O., Otay, I., & Bolturk, E. (2016). Hospital site selection via hesitant fuzzy TOPSIS. IFAC-PapersOnLine, 49(12), 1140-1145.

Shafer G. (1992). The Dempster-Shafer theory. Encyclopedia of artificial intelligence.330-331.

Shannon, C. E. (1948). "A mathematical theory of communication", The Bell system technical journal, 27(3), pp. 379-423.

Sharmin, N., & Neema, M. (2013). A GIS-based multi-criteria analysis to site appropriate locations of hospitals in Dhaka City. Hospital, 8, 0-37.

Sheikhian, H., Delavar, M. R., & Stein, A. (2017). A GIS‐based multi‐criteria seismic vulnerability assessment using the integration of granular computing rule extraction and artificial neural networks. Transactions in GIS, 21(6), 1237-1259.

Silavi, T., Malek, M. R., & Delavar, M. R. (2006). Multicriteria map overlay in geospatial information system via intuitionistic fuzzy AHP method. In Applied Artificial Intelligence (pp. 401-408): World Scientific.

Soltani, A., Inaloo, R. B., Rezaei, M., Shaer, F., & Riyabi, M. A. (2019). Spatial analysis and urban land use planning emphasising hospital site selection: a case study of Isfahan city. Bulletin of Geography. Socio-economic Series, 43(43), 71-89.

Soltani, A., & Marandi, E. Z. (2011). Hospital site selection using two-stage fuzzy multi-criteria decision making process. Journal of Urban and environmental engineering, 5(1), 32-43.

Taleai, M., Sharifi, A., Sliuzas, R., & Mesgari, M. (2007). Evaluating the compatibility of multi-functional and intensive urban land uses. International Journal of Applied Earth Observation and Geoinformation, 9(4), 375-391.

Tale Jenekanlou, A., Karimi, M., & Taleai, M. (2015). Residential Land Suitability Assessment Using Fuzzy Group TOPSIS-OWA. Journal of Geomatics Science and Technology, 4(4), 29-46. (In Persian).Tayyebi, A., Delavar, M., Tayyebi, A., & Golobi, M. (2010). Combining multi criteria decision making and Dempster Shafer theory for landfill site selection. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci, 38(8), 1073-1078.

Teniwut, W., Marimin, M., & Djatna, T. (2019). GIS-Based multi-criteria decision making model for site selection of seaweed farming information centre: A lesson from small islands, Indonesia. Decision Science Letters, 8(2), 137-150.

Tripathi, A. K., Agrawal, S., & Gupta, R. D. (2021). Comparison of GIS-based AHP and fuzzy AHP methods for hospital site selection: a case study for Prayagraj City, India. GeoJournal, 1-22.

Vahidnia, M. H., Alesheikh, A. A., & Alimohammadi, A. (2009). Hospital site selection using fuzzy AHP and its derivatives. Journal of environmental management, 90(10), 3048-3056.

Wang, C.-N., Huang, Y.-F., Chai, Y.-C., & Nguyen, V. T. (2018). A multi-criteria decision making (MCDM) for renewable energy plants location selection in Vietnam under a fuzzy environment. Applied Sciences, 8(11), 2069.

Wang, C.-N., Nguyen, V. T., Duong, D. H., & Thai, H. T. N. (2018). A hybrid fuzzy analysis network process (FANP) and the technique for order of preference by similarity to ideal solution (TOPSIS) approaches for solid waste to energy plant location selection in Vietnam. Applied Sciences, 8(7), 1100.

Wang, C.-N., Tsai, T.-T., & Huang, Y.-F. (2019). A model for optimizing location selection for biomass energy power plants. Processes, 7(6), 353.

Wang, W. (2019). Site Selection of Fire Stations in Cities Based on Geographic Information System and Fuzzy Analytic Hierarchy Process. Ingénierie des Systèmes d'Information, 24(6).

Wissem, E., Ahmed, F., & Mounir, B. (2011). Multicriteria method for a site selection of a new hospital in Sfax. Paper presented at the 2011 4th International Conference on Logistics.

Witlox, F., Antrop, M., Bogaert, P., De Maeyer, P., Derudder, B., Neutens, T., . . . Van de Weghe, N. (2009). Introducing functional classification theory to land use planning by means of decision tables. Decision Support Systems, 46(4), 875-881.

Wu, C.-R., Lin, C.-T., & Chen, H.-C. (2007). Optimal selection of location for Taiwanese hospitals to ensure a competitive advantage by using the analytic hierarchy process and sensitivity analysis. Building and environment, 42(3), 1431-1444.

Wu, J., Sun, J., Liang, L., & Zha, Y. (2011). Determination of weights for ultimate cross efficiency using Shannon entropy. Expert Systems with Applications, 38(5), 5162-5165.

Xu, Z. (2005). An overview of methods for determining OWA weights. International journal of intelligent systems, 20(8), 843-865.

Yager, R. R. (1988). On ordered weighted averaging aggregation operators in multicriteria decisionmaking. IEEE Transactions on systems, Man, and Cybernetics, 18(1), 183-190.

Yager, R. R. (1996). Quantifier guided aggregation using OWA operators. International journal of intelligent systems, 11(1), 49-73.

Yager, R. R., & Liu, L. (Eds.). (2008). Classic works of the Dempster-Shafer theory of belief functions (Vol. 219). Springer.

Zadeh, L. A. (1975). Fuzzy logic and approximate reasoning. Synthese, 30(3), 407-428.

Zandi, I., & Delevar, M. R. (2021). Integration of GIS, Shannon Entropy and Multi-Criteria Decision Making for Hospital Site Selection. In 29th Annual GIS Research UK Conference (GISRUK), Cardiff, Wales, UK.

Zandi, I., Pahlavani, P., & Bigdeli, B. (2021). Combining CRITIC Objective Weighting Method with CODAS and VIKOR Methods for Selecting Prospect Hospital Sites (Case Study: The Fifth District of Tehran). Geography and Urban Space Development, 7(2), 41-63. (In Persian).

Zardari, N. H., Ahmed, K., Shirazi, S. M., & Yusop, Z. B. (2015). Weighting methods and their effects on multi-criteria decision making model outcomes in water resources management. Springer.

Zhao, Q.-H., Zhou, X., Xie, R.-F., & Li, Z.-C. (2011). Comparison of three weighing methods for evaluation of the HPLC fingerprints of cortex fraxini. Journal of liquid chromatography & related technologies, 34(17), 2008-2019.