Research Paper

Ranking of Suitable Areas for Establishing Industries in Kashan City Using VIKOR and TOPSIS Methods in Fuzzy Environment

Katayoun Omidi[1], Afsaneh Afzali[1*], Hossein Vahidi[2], Sheida Mahnam[3]

1. Department of Environment, Faculty of Natural Resources and Earth Sciences, University of Kashan, Kashan, Iran.
2. Department of Environment, Institute of Science and High Technology and Environmental Sciences, Graduate University of Advanced Technology, Kerman, Iran.
3. International Relations, Iranology Foundation, Tehran, Iran.

Use your device to scan and read the article online

Citation Omidi K, Afzali A, Vahidi H, Mahnam S. Ranking of Suitable Areas for Establishing Industries in Kashan City Using VIKOR and TOPSIS Methods in Fuzzy Environment. Journal of Advances in Environmental Health Research. 2022; 10(2):133-148. http://dx.doi.org/10.32598/JAEHR.10.2.1241

http://dx.doi.org/10.32598/JAEHR.10.2.1241

Article info:
Received: 21 Sep 2021
Accepted: 15 Dec 2021
Publish: 01 Apr 2022

Keywords:
Industrial site selection, Fuzzy VIKOR, Fuzzy TOPSIS, Kashan City

ABSTRACT

Background: In this research, among the Multi Criteria Decision Making (MCDM) methods, a combination of VIKOR and TOPSIS methods with fuzzy set theory was used to overcome the uncertainty in the ranking of alternatives. The purpose of this paper was to locate the industries of Kashan City and rank the appropriate alternatives using analytic hierarchical process (AHP) and the prioritization methods of fuzzy VIKOR and fuzzy TOPSIS.

Methods: In this study, first, the effective criteria in GIS (Geographic Information System) were examined and standardized according to fuzzy logic. Then, by presenting expert opinion through AHP, the criteria were weighted, and in order to determine suitable places for establishing industries, according to the required minimum area, six alternatives were extracted from the weighted linear combination method. Subsequently, the alternatives were ranked using fuzzy VIKOR and fuzzy TOPSIS methods. The sensitivity analysis was performed in the fuzzy TOPSIS method by shifting the criteria weights and producing different weighting scenarios. The fuzzy VIKOR method was analyzed for different values of the υ variable.

Results: Weighting of criteria by AHP showed that the distance from surface water with a weight coefficient of 0.200 was the most important one. according to the required minimum area, six alternatives were extracted from the weighted linear combination method.

Conclusion: The sensitivity analysis of both methods showed that 405 hectares in the Southeast of Kashan are the best ones to establish industries.

*** Corresponding Author:**
Afsaneh Afzali, Assistant Professor.
***Address:** Department of Environment, Institute of Science and High Technology and Environmental Sciences, Graduate University of Advanced Technology, Kerman, Iran.*
***Phone:** +98 (913) 3977793*
***E-mail:** a.afzali@kashanu.ac.ir, afzali_afsaneh@yahoo.com*

1. Introduction

Decisions about the site selection of a particular industrial activity may be driven by many geographical, social, political, economic, and historical factors [1]. One of the new issues that researchers and governments have considered in recent years is site selection for establishing industries and the prevention of environmental crises, and the sustainable use of all land resources [2]. So far, different site selection methods of industrial units have been used by researchers in which different factors have been identified [3] such as raw materials, energy, transportation, labor, water, market [1], even the type of production and the amount of employment in the neighboring country in the same industry [4], climate, workers, merchants, craftsmen [5] as well as regional demand, regional production costs, regional policies, economic density, labor market potential and wage levels of the manufacturing sector [6].

However, with scientific and technological advances (such as remote energy transfer and replacement of various available raw materials), geographical factors have been limited, and their effects have diminished, and newer factors have become more prominent [1]. Meanwhile, government policies are increasingly seeking to address environmental degradation and reduce industrial density [1]. In other words, the climatic and environmental characteristics of the region and the density of a particular industry have become more important for location selection [6].

Site selection depends on considering several factors, and therefore, it is a Multi-Criteria Decision-Making (MCDM) process [7]. One of the MCDM methods used in ranking alternatives is the VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) method in a fuzzy environment. The degree of proximity to the ideal solution in VIKOR method is considered for ranking [8]. VIKOR method is applied to solve discrete decision problems disproportionate to different and conflicting criteria (different units of measure) [9]. The decision matrix and the weight of the indicators are the system's input [10], and the solutions close to the ideal solution are justified [11]. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is another method of MCDM based on proximity to the ideal answer. In the TOPSIS method, the superior option must have the shortest distance from the ideal answer and the maximum distance from the anti-ideal answer. The TOPSIS method introduces two points of ideal and anti-ideal without considering the relative importance of distances from these two points [12]. In the decision-making process, decision-makers often face doubts and uncertainties. In fact, natural language for expressing judgment is always subjective or ambiguous. The theory of fuzzy sets introduced by Zadeh expresses verbal words in the decision-making process to remove the ambiguity and subjectivity of decision-making judgment [13, 14]. Some researches have been done using the two methods of Fuzzy TOPSIS and Fuzzy VIKOR.

Oveisi and Afzali, studied landfill site selection of municipal solid waste in Kashan City Using OWA (ordered weighted average) and TOPSIS Fuzzy methods. They concluded that the most suitable area for landfilling is located in the southeast of the area [15]. Chalik, in the research of evaluating social media platforms in a travel agency used the best / worst method to weigh the criteria and the fuzzy VIKOR method to rank the results. The results showed that the proposed method was valid and can play a role in improving the decision-making process of companies and organizations [16]. Sadeghi et al., in the study of investigating renewable power plants using AHP (Analytical Hierarchy Process), TOPSIS and VIKOR methods concluded that all three methods well-prioritized the power plants while their results were almost the same [17]. Ariafar et al., in the study of selecting electroshock device supplier using TOPSIS, VIKOR, and SAW (Simple Additive Weightin) methods in hospital Afzalipour Hospital, Kerman showed that the results obtained from all three models were similar and confirmed each other. They presented that the use of several decision-making methods with different criteria and the similarity of the results also increases the validity of the results [18]. Chezgi and Soheili, in the research of site selection of flood spreading projects in an arid and semi-arid region ranked the suitable areas for flood spreading using TOPSIS and VIKOR methods. Their results indicated that, according to the TOPSIS model, the central part and according to the VIKOR model, the southern part of the city were the best places for spreading floods [19].

Rahmani and Omidvari, in the study of safety risk assessment in electricity distribution using the improved ET&BA method and its ranking with VIKOR and TOPSIS models in a fuzzy environment, concluded that the two methods have an excellent sufficiency for risks ranking [20]. In a comparative study, Khajavi and Fattahi Nafchi combined algorithms to evaluate financial performance in Tehran stock exchange companies used AHP Fuzzy for weighting the criteria and Fuzzy

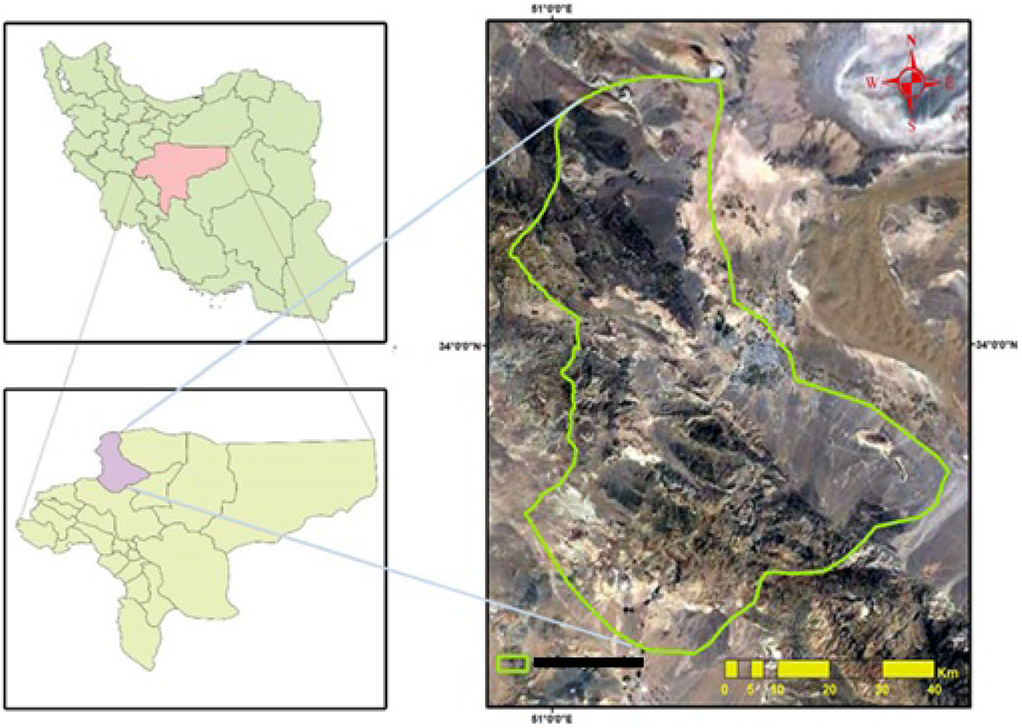

Figure 1. The location of the study are

TOPSIS and Fuzzy VIKOR for ranking the studied companies [21]. Mohtashami and Miri-Asl presented a combined model of MCDM with a fuzzy approach to select maintenance strategies, first calculated the weight of the factors and then prioritized the strategies through Fuzzy TOPSIS and Fuzzy VIKOR [22].

Tarokh et al., in the study of credit risk management under uncertainty using a Fuzzy VIKOR method, solved a numerical example on the credit rating of bank customers and thus defined the best available alternative for determining the grant facilities in uncertain circumstances [23]. Radmehr and Araghinejad applied a fuzzy multi-criteria spatial decision-making method to determine flood vulnerable areas in the Tehran watershed, using the AHP method to weight the criteria and the Fuzzy TOPSIS method for the final ranking of sub-basin. To do the Fuzzy TOPSIS method's sensitivity, they changed the weights of the criteria and generated weighting scenarios [24]. Shafaei et al. developed a Fuzzy TOPSIS development based on the principles of sustainability in Mashhad Steel Plant by determining 20 criteria and their weighting, ranked the alternatives by fuzzy TOPSIS method, and their results showed Toos Industrial Town is a suitable place for the construction of a steel plant in Mashhad [25].

The industrial development of Kashan City and its social, economic and cultural potential opens up a very promising outlook for the region's social growth and economic prosperity, and increasing employment capacity for planners. It is therefore necessary to plan and identify suitable locations for the establishment of industries that, in addition to providing suitable economic conditions for industries, creating employment, raising income levels and improving macroeconomic indicators has the least negative effects on the natural and human environment of the study area. Accordingly, the present study was conducted to identify and rank suitable areas for establishing industries in Kashan City using the AHP weighting method and VIKOR and TOPSIS prioritization methods in fuzzy environments.

2. Materials and Methods

Study area

Kashan City, located in the 51◦ 27′ longitude and 33◦ 59′ latitude, has 323,371 people, 4392 km^2 (Figure 1). The city has four central sections, Qamsar, Niasar, Barzok, and the city's center as Kashan with a height of 945 meters. Kashan City with the superiorities such as being in a special geographical position, access to the Tehran-Isfahan freeway, being located in the north-south transit route, is located in the north-south railway route, security of investment in the region, and approval and launching of the special economic zone have a suitable spatial capacity for the establishment of industries and industrial towns.

Data

In this research, previous studies and the standards of the Department of Environment and reviewing the available data were used to assess the area. The data are criteria such as slope, land use, distance from residential areas, distance from surface water, distance from wells and springs, distance from roads, distance from faults, distance from industrial areas, distance from power lines, and underground water depths.

Methodology

In this study, the criteria have different scales, and also some criteria have a positive aspect and some have a negative aspect. Therefore, in order to compare different measurement scales, non-scaling should be used. The values of different criteria are dimensionless and cumulative and are classified to be compared with each other [26]. For this purpose, Fuzzy logic was used to standardize the criteria. After their weighting by AHP, the criteria were superimposed using the weighted linear combination (WLC) method to prepare the final map. The suitable locations for WLC industrial sites in the final map were selected with a pixel value of more than 200 and the minimum area required for planning. Subsequently, the selected sites and their prioritization were evaluated using Fuzzy VIKOR and Fuzzy TOPSIS methods.

The fuzzy VIKOR method

Opricovic first proposed the VIKOR method in 1998. The method was developed by Opricovic and Tzeng based on Lp-metric [27]. Subsequently, the multi-criteria optimization of complex systems was considered in the VIKOR method [28] based on the categorization and choosing from a set of alternatives to determine compromise solutions for a problem with conflicting criteria and help decision-makers for reaching a final decision.

The closest justified answer to each index's ideal answer is considered for the compromise answer as a mutual agreement [28, 29]. The steps of the fuzzy VIKOR method presented in this research are as follows [30]:

Step 1: The decision matrix is formed based on the data collected (in this study with nine criteria and six alternatives). Suppose the numbers in the table are triangular fuzzy numbers (Equation 1).

$$D=\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array}\begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_k \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mk} \end{bmatrix} \end{array}$$

1. $i=1, 2, ..., m; j = 1, 2, ..., k$

Triangular fuzzy numbers based on Table 1 were used to convert expressive expressions.

Step 2: Positive and negative ideal alternatives are determined based on Equations 2 and 3, where:

$i=1,..., n$ and $j=1,..., m$. if $\tilde{f}_j^*=(l_{ij}^*,m^{ij*},r_{ij}^*)$ and $\tilde{f}_j^-=(l_{ij}^-,m_{ij}^-,r_{ij}^-)$

For positive indicators (profit), the ideal and anti-ideal values are as presented in Equation 2:

2. $\tilde{f}_j^*=max_I(\tilde{x}_{ij})\ \tilde{f}_j^-=min_I(\tilde{x}_{ij})$

For negative indicators (cost), the ideal and anti-ideal values are as presented in Equation 3:

3. $\tilde{f}_j^*=min_I(\tilde{x}_{ij})\ \tilde{f}_j^-=max_I(\tilde{x}_{ij})$

Step 3: The utility measure and regret measure of the alternatives are calculated in which i = 1,…, n and j = 1,…, n and j = 1,…, m. If $S_{\tilde{j}}=(s_j^l,s_j^m,s_j^r)$, $R_{\tilde{j}}=(R_j^l,R_j^m,R_j^r)$ and $w_{\tilde{j}}=(w_j^l,w_j^m,w_j^r)$, according to Equations 4 and 5, where:

4. $\tilde{S}_j=\sum_{j=1}^{n} \tilde{w}_j\otimes(\frac{\tilde{f}_j^*\ominus\tilde{x}_{ij}}{\tilde{f}_j^*\ominus\tilde{f}_j^-})$

5. $\tilde{R}_j=max_j\ [\tilde{w}_j\otimes(\frac{\tilde{f}_j^*\ominus\tilde{x}_{ij}}{\tilde{f}_j^*\ominus\tilde{f}_j^-})]$

, where $\tilde{S}j$ and $\tilde{R}j$ are respectively the utility measure and regret measure of each of the alternatives. In the utility measure, these distances are averaged. However, in regret measure, only the maximum value of the distance from the ideal state of criteria is calculated for each alternative, and $\tilde{w}$ is the weight of each of the criteria., the distance between the fuzzy numbers of Equations 4 and 5 is calculated as shown in Equations 6 and 7 using the vertex method [31].

6. $S'_j=\sum_{j=1}^{m}\frac{(\tilde{f}_i d_{v1}(\tilde{f}_i+\tilde{a}_{ij})}{d_{v1}(\tilde{f}_i+\tilde{f}_i^-)}$

Table 1. Converting the ratios of options to triangular fuzzy numbers [31]

Expressive Phrases	Triangular Fuzzy Numbers (Options Preferred)
Very Low (VL)	(0, 0, 1)
Low (L)	(0, 1, 3)
Moderately Low (ML)	(1, 3, 5)
Medium (M)	(3, 5, 7)
Modertely High (MH)	(5, 7, 9)
High (H)	(7, 9, 10)
Very High (VH)	(9, 10, 10)

$$\sum_{j=1}^{m} \frac{w_i^* \sqrt{1/3[(f_i^{+L}-a_{ij}^{L})^2+(f_i^{+m}-a_{ij}^{m})^2+(f_i^{+R}-a_{ij}^{R})^2]}}{w_i^* \sqrt{1/3[(f_i^{+L}-f_i^{-L})^2+(f_i^{+m}-f_i^{-m})^2+(f_i^{+R}-f_i^{-R})^2]}}$$

7. $$R'_j=\max_i \left\{ \frac{w_i^* d_{v1}(\tilde{f}_i+\tilde{a}_{ij})}{d_{v1}(\tilde{f}_i+\tilde{f}_i^-)} \right\}$$

$$\max_i \left\{ \sum_{j=1}^{m} \frac{w_i^* \sqrt{1/3[(f_i^{+L}-a_{ij}^{L})^2+(f_i^{+m}-a_{ij}^{m})^2+(f_i^{+R}-a_{ij}^{R})^2]}}{w_i^* \sqrt{1/3[(f_i^{+L}-f_i^{-L})^2+(f_i^{+m}-f_i^{-m})^2+(f_i^{+R}-f_i^{-R})^2]}} \right.$$

Step 4: Q as the VIKOR index with the assumption υ=0.5 (parameter υ is a weight for the maximum group utility whose value is between 0 and 1 and is usually considered 0.5 [29]) is calculated based on Equations 8-10.

8. $$Q_j=v\frac{\tilde{S}_j^*-\tilde{S}^*}{\tilde{S}_j^--\tilde{S}^*}+(1-v)\frac{\tilde{R}_j^*-\tilde{R}^*}{\tilde{R}_j^--\tilde{R}^*}$$

9. $$\tilde{R}^-=Max_i\tilde{R}_i \quad \tilde{R}^*=Min_i\tilde{R}_i$$

10. $$\tilde{S}^*=Min_i\tilde{S}_i \quad \tilde{S}^-=Max_i\tilde{S}_i$$

Step 5: Ranking the alternatives based on the VIKOR index is done. Finally, the alternatives are sorted into three groups based on Q, S, and R values, from small to large. The best option is the one that has the smallest Q, provided that the following conditions are met [32]:

First condition: acceptable advantage. If alternatives A1 and A2 rank first and second among the m alternatives, Equation 11 must be satisfied:

11. $$Q(A'_2)-Q(A'_1)\geq\frac{1}{m-1}$$

In terms of ranking according to the Q criterion, A2 is the second alternative, and A1 is the best alternative with the lowest value for Q, and m is the number of available alternatives.

Second condition: acceptable stability. Alternative A1 must be recognized as the top rank in at least one of the S and R groups.

The following situations may be considered. The first condition: When the first condition is not met, a set of alternatives as presented in Equation 12 are selected as the best alternatives:

12. Alternatives = A1, A2,… .., Am

The maximum value of M is calculated according to Equation 13:

13. $Q(AM)-Q(A1) < 1/(m-1)$

The second condition: When only the second condition is not met, two alternatives of A1 and A2 are selected as the best alternatives.

Third condition: If both conditions are met, the ranking will be based on Q. The lower the Q, the better the alternative.

Sensitivity analysis in fuzzy VIKOR method

The Q index would be calculated for different values of υ between zero and one to perform the sensitivity analysis of the fuzzy VIKOR method.

The fuzzy TOPSIS method

Due to the characteristics of fuzzy decision-making methods, these methods provide results closer to reality than classical methods. One of these methods is the fuzzy TOPSIS method, in which the decision matrix is defined as fuzzy numbers. Chen and Hwang first developed this method in 1992, which, like the classical TOPSIS method, ranks options based on their distance from the positive and negative ideals [33]. The difference between the different models of this method is the type of fuzzy number used, the normalization method, and the ranking method.

The steps of the fuzzy TOPSIS method in this study are as follows:

Step 1: A fuzzy decision matrix is formed in which the columns of the matrix are the evaluation criteria, and the rows are the alternatives.

Triangular fuzzy numbers based on Table 1 were used to convert the expressive expressions (Equation 14):

$$D=\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array}\begin{array}{c} C_1\ C_2\ \ C_k \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mk} \end{bmatrix}\end{array}$$

14. $i = 1, 2, ..., m; j = 1, 2, ..., k$

Step 2: The fuzzy decision matrix is normalized, which its members are denoted by rij (Equations 15, 16). If the elements of the fuzzy decision matrix are xij = (aij, bij, cij), then:

15. $$\bar{r}_{ij}=\left(\frac{a_{ij}}{c_j^+},\frac{b_{ij}}{c_j^+},\frac{c_{ij}}{c_j^+}\right)\ j\in Bennefit\ ,\ c_j^+=\max_i c_{ij}$$

16. $$\bar{r}_{ij}=\left(\frac{a_j^-}{c_{ji}},\frac{a_j^-}{b_{ji}},\frac{a_j^-}{c_{ji}}\right)\ j\in cost\ ,\ a_j^+=\max_i a_{ij}$$

Step 3: By multiplying the weights of different criteria in the normalized decision matrix, this matrix is weighted. The values of the weighted matrix (V) are denoted by vij (Equation 17):

17. $\tilde{V}_j=[\tilde{v}_j]\ ,\ \tilde{v}_{ij}=\tilde{r}_{ij}(.)\ \tilde{w}_j$

Step 4: The distance of each alternative from the positive ideal and the negative ideal solution is calculated (Equations 18-21):

18. $A^+=(\tilde{v}_1^+,\tilde{v}_2^+,...\tilde{v}_n)\ ,\ \tilde{v}_j^+=(1,1,1)$

19. $A^-=(\tilde{v}_1^-,\tilde{v}_2^-,...\tilde{v}_n)\ ,\ \tilde{v}_j^+=(0,0,0)$

20. $d_i^+=\sum_{j=1}^{n} d\,(\tilde{v}_{ij},\tilde{v}_{ij}^+)\ i=1,2,...,m$

21. $d_i^-=\sum_{j=1}^{n} d\,(\tilde{v}_{ij},\tilde{v}_{ij}^-)\ i=1,2,...,m$

d represents the Euclidean distance obtained from Equation 22 for two triangular fuzzy numbers n˜=(a1, b2, c3), and m˜=(a1, b2, c3).

22. $D(m,n=2\sqrt{1/3\ [(m_1-n_1)^2+(m_2-n_2)^2+(m_3-n_3)^2]}\ )$

Step 5: In this step, according to the obtained positive (d+) and negative (d-) ideal points, the coefficient of the proximity of each of the options is obtained from Equation 23. The alternative which has a higher proximity coefficient is ranked higher [34].

23. $CC_i=\frac{d_i^-}{d_i^++d_i^-}$

3. Results and Discussion

In this study, Analytical Hierarchy Process (AHP) was used to determine the weight of the criteria (Table 2). According to the results of weighting by AHP, the distance from surface water with a weight coefficient of 0.200 had the highest weight value, which indicates its highest importance, and the distance from industrial areas with a weight coefficient of 0.043 is the least important criterion in industrial site selection in the area and considering that the overall inconsistency in this method was 0.01, the results were acceptable.

Then, the final map was obtained using the Weighted Linear Combination method by standardizing the layers based on fuzzy logic. The results showed six suitable areas for establishing industries in the east and south-east of Kashan City (Figure 2).

Ranking of alternatives using Fuzzy VIKOR method

In order to rank the alternative areas using the Fuzzy VIKOR method, the fuzzy decision matrix was formed with nine criteria and six alternatives (Table 3). The numbers of this matrix were extracted from standardized maps by the fuzzy method, and according to Table 1, the alternatives numbers were converted to triangular fuzzy numbers. Positive and negative ideal points were calculated to Equation 2, and the utility measure and regret measure of each alternative were also calculated using Equations 6 and 7 (Table 4), and using Equation 8, the VIKOR index was determined (Table 5).

According to the fuzzy VIKOR method, selecting the final alternative is done by controlling two conditions. The following conditions are checked:

If the alternatives A5, A2, A6, A1.A3, A4 represent the first, second, third, fourth, fourth, and fifth alter-

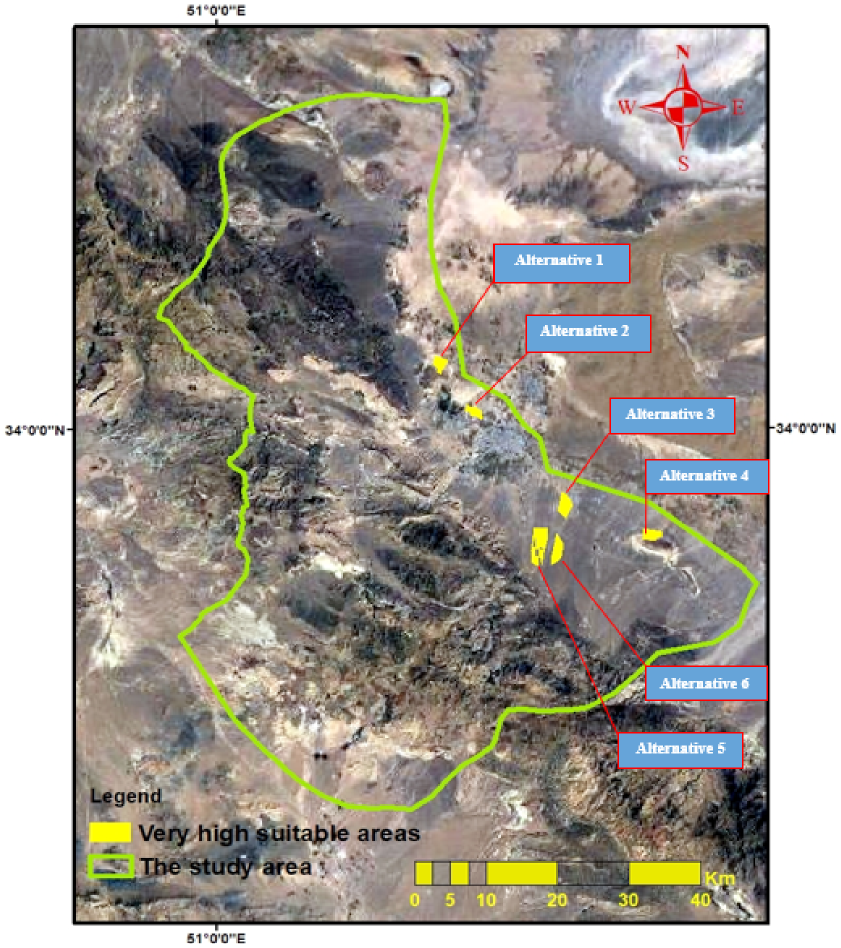

Figure 2. The location of suitable areas for the establishment of industries in Kashan City

native, respectively based on the value of Q and m, Indicates the number of alternatives:

First condition

$$Q(A_2) - Q(A_5) \geq 1.(m-1) \quad 0.627-0 \geq \frac{1}{6-1} \quad 0627 \geq 0.2$$

As can be seen, the first condition is met based on Equation 11, and in this step, alternative A5 is selected as the top rank.

Second condition

Alternative A5 was recognized as the top rank having the lowest values in both groups of R and S (0.107 and 0.326). As a result, the second condition is also met, and given that both conditions are met, the alternatives will be ranked based on Q. (The lower the Q number, the better the alternative). As a result, the alternatives were ranked as follows: A5> A2>A6>A1, A3>A4.

The results of sensitivity analysis of fuzzy VIKOR method

A sensitivity analysis was performed to evaluate the effect of parameter υ changes on alternatives ranking results. According to the results of Table 6, Alternative five is not sensitive to changes in parameter υ. However, the sensitivity is low for other alternatives, and

Table 2. Final weight of evaluation criteria site selection of industries

Criterion	Distance From Wells and Springs	Distance From Residential Areas	Underground Water Depths	Land Use	Distance From Power Lines	Distance From Surface Water	Distance From Roads	Distance From Industrial Areas	Slope
Weight	0.175	0.107	0.127	0.107	0.102	0.200	0.085	0.043	0.054

Table 3 . Decision matrix of the fuzzy VIKOR method and positive and negative ideal points

Alternative	Slope	Distance From Industrial Areas	Distance From Roads	Distance From Surface Water	Distance From Power Lines	Land Use	Underground Water Depths	Distance From Residential Areas	Distance From Wells and Springs
A1	9,10,10	5,7,9	7,9,10	1,3,5	9,10,10	1,3,5	9,10,10	0,0,1	1,3,5
A2	9,10,10	3,5,7	9,10,10	5,7,9	9,10,10	0,1,3	9,10,10	0,0,1	0,0,1
A3	9,10,10	5,7,9	7،9،10	1,3,5	9,10,10	0,1,3	9,10,10	0,1,3	1,3,5
A4	9,10,10	5,7,9	9,10,10	1,3,5	7,9,10	0,1,3	9,10,10	0,1,3	1,3,5
A5	9,10,10	5,7,9	7,9,10	3,5,7	9,10,10	0,1,3	7,9,10	0,1,3	3,5,7
A6	7,9,10	5,7,9	9,10,10	5,7,9	9,10,10	0,1,3	3,5,7	0,0,1	0,1,3
F^*	9,10,10	5,7,9	9,10,10	5,7,9	9,10,10	1,3,5	9,10,10	0,1,3	3,5,7
F^-	7,9,10	3,5,7	7,9,10	1,3,5	7,9,10	0,1,3	3,5,7	0,0,1	0,0,1

Table 4. The values of Ri & Si and maximum and minimum values of Si and Ri

Alternatives	SJ	S*	S^-	RJ	R*	R^-
A1	0.464	0.326	0.529	0.200	0.107	0.200
A2	0.432			0.175		
A3	0.464			0.200		
A4	0.481			0.200		
A5	0.326			0.107		
A6	0.529			0.134		

alternative 5 with the lowest value of the VIKOR index was recognized as the best alternative.

Ranking of alternatives by using Fuzzy TOPSIS method

In order to rank the alternatives by using the Fuzzy TOPSIS method, the decision matrix was formed according to nine criteria and six alternatives (Table 7). The numbers of this matrix were first extracted from the standardized maps by the weighted linear combination method, and triangular fuzzy numbers based on Table 1 were used to convert the expressions.

In the next step, the maximum data of each member of the matrix was determined in the third column of Table 7 for normalization, and by dividing each of the members of each member by the maximum of this

Table 5. Final ranking and selection of the best alternative using the fuzzy VIKOR method

Alternatives	SJ (Utility)	Alternatives	RJ (Regret)	Alternatives	Q (VIKOR Index)
5	0.326	5	0.107	5	0
2	0.432	6	0.133	2	0.627
3	0.464	2	0.175	6	0.645
1	0.464	1	0.2	1	0.841
4	0.481	3	0.2	3	0.841
6	0.529	4	0.2	4	0.833

Table 6. Results of sensitivity analysis by using Fuzzy VIKOR method

Alternatives	υ=0	υ=0.1	υ=0.2	υ=0.3	υ=0.4	υ=0.5	υ=0.6	υ=0.7	υ=0.8	υ=0.9	υ=1
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
A1	1	0.968	0.936	0.905	0.873	0.841	0.809	0.778	0.746	0.714	0.682
A2	0.731	0.71	0.689	0.669	0.648	0.627	0.606	0.585	0.564	0.543	0.522
A3	1	0.968	0.936	0.905	0.873	0.841	0.809	0.778	0.746	0.714	0.682
A4	1	0.977	0.953	0.93	0.906	0.883	0.86	0.836	0.813	0.79	0.766
A5	0	0	0	0	0	0	0	0	0	0	0
A6	0.29	0.361	0.432	0.503	0.574	0.645	0.716	0.787	0.858	0.929	1

Table 7. Decision matrix in fuzzy TOPSIS method

Alternative	Distance from in-Dustrial Areas	Slope	Distance from Roads	Distance from Pow-er Lines	Distance from Residential Areas	Land Use	Underground Water Depths	Distance from Wells and Springs	Distance from Surface Water
A1	5,7,9	9,10,10	7,9,10	9,10,10	0,0,1	1,3,5	9,10,10	1,3,5	1,3,5
A2	3,5,7	9,10,10	9,10,10	9,10,10	0,0,1	0,1,3	9,10,10	0,0,1	5,7,9
A3	5,7,9	9,10,10	7,9,10	9,10,10	0,1,3	0,1,3	9,10,10	1,3,5	1,3,5
A4	5,7,9	9,10,10	9,10,10	7,9,10	0,1,3	0,1,3	9,10,10	1,3,5	1,3,5
A5	5,7,9	9,10,10	7,9,10	9,10,10	0,1,3	0,1,3	7,9,10	3,5,7	3,5,7
A6	5,7,9	7,9,10	9,10,10	9,10,10	0,0,1	0,1,3	3,5,7	0,1,3	5,7,9
Maximum	9	10	10	10	3	5	10	7	9

Table 8. Fuzzy TOPSIS normalized decision matrix

Alterna-tive	Distance From inDus-trial Areas	Slope	Distance From Roads	Distance From Power Lines	Distance From Residen-tial Areas	Land Use	Under-ground Water Depths	Distance From Wells and Springs	Distance From Surface Water
Alterna-tive 1	0.56,0.78,1	0.9,1,1	0.7,0.9,1	0.9,1,1	0,0,0.33	0.2,0.6,1	0.9,1,1	0.14,0.43,0.71	0.11,0.33,0.56
Alterna-tive 2	0.33,0.56,0.78	0.9,1,1	0.9,1,1	0.9,1,1	0,0,0.33	0,0.2,0.6	0.9,1,1	0,0,0.14	0.56,0.78,1
Alterna-tive 3	0.56,0.78,1	0.9,1,1	0.7,0.9,1	0.9,1,1	0,0.33,1	0,0.2,0.6	0.9,1,1	0.14,0.43,0.71	0.11,0.33,0.56
Alterna-tive 4	0.56,0.78,1	0.9,1,1	0.9,1,1	0.7,0.9,1	0,0.33,1	0,0.2,0.6	0.9,1,1	0.14,0.43,0.71	0.11,0.33,0.56
Alterna-tive 5	0.56,0.78,1	0.9,1,1	0.7,0.9,1	0.9,1,1	0,0.33,1	0,0.2,0.6	0.7,0.9,1	0.43,0.71,1	0.33,0.56,0.78
Alterna-tive 6	0.56,0.78,1	0.7,0.9,1	0.9,1,1	0.9,1,1	0,0,0.33	0,0.2,0.6	0.3,0.5,0.7	0,0.14,0.43	0.56,0.78,1
Criteria Weight	0.043	0.054	0.085	0.102	0.107	0.107	0.127	0.175	0.2

Table 9. Weighting of the normalized fuzzy TOPSIS matrix

Alternative	Distance From inDustrial Areas	Slope	Distance From Roads	Distance From Power Lines
1	0.02,0.03,0.04	0.05,0.05,0.05	0.06,0.08,0.09	0.09,0.10,0.10
2	0.01,0.02,0.03	0.05,0.05,0.05	0.08,0.09,0.09	0.09,0.10,0.10
3	0.02,0.03,0.04	0.05,0.05,0.05	0.06,0.08,0.09	0.09,0.10,0.10
4	0.02,0.03,0.04	0.05,0.05,0.05	0.08,0.09,0.09	0.07,0.09,0.10
5	0.02,0.03,0.04	0.05,0.05,0.05	0.06,0.08,0.09	0.09,0.10,0.10
6	0.02,0.03,0.04	0.04,0.05,0.05	0.08,0.09,0.09	0.09,0.10,0.10

Alternative	Distance from Residential Areas	Land Use	Underground Water Depths	Distance from Wells and Springs	Distance from Surface Water
1	0.00,0.00,0.04	0.02,0.06,0.11	0.11.0.13,0.13	0.03,0.08,0.13	0.02,0.07,0.11
2	0.00,0.00,0.04	0.00,0.02,0.06	0.11.0.13,0.13	0.00,0.00,0.03	0.11,0.16,0.20
3	0.00,0.04,0.11	0.00,0.02,0.06	0.11.0.13,0.13	0.03,0.08,0.13	0.02,0.07,0.11
4	0.00,0.04,0.11	0.00,0.02,0.06	0.11.0.13,0.13	0.03,0.08,0.13	0.02,0.07,0.11
5	0.00,0.04,0.11	0.00,0.02,0.06	0.09,0.11,0.13	0.08,0.13,0.18	0.07,0.11,0.16
6	0.00,0.00,0.04	0.00,0.02,0.06	0.04,0.06,0.09	0.00,0.03,0.08	0.11,0.16,0.20

member of the matrix, the normalized matrix of fuzzy decision making was formed (Table 8).

The decision weighting matrix was obtained by multiplying the weights of different criteria in the normalized decision matrix of fuzzy TOPSIS (Table 9).

Positive and negative ideal points were considered as fixed numbers (1,1,1 and 0,0,0).

To calculate the distance of each alternative from the positive and negative ideal points, first, the difference between the weighted matrix and the positive and negative ideal points was obtained based on Equations 20 and 21 (Tables 10 and 11). Then the distance from the positive and negative ideal points was calculated based on Equation 22 (Table 12).

Table 10. Difference matrix between the normalized matrix points of fuzzy TOPSIS decision making and the positive ideal solution

Alternative	Distance From in-Dustrial Areas	Slope	Distance From Roads	Distance from Power Lines	Distance from Residential Areas	Land Use	Underground Water Depths	Distance from Wells and Springs	Distance from Surface Water
A1	0.9661	0.9473	0.9259	0.901	0.9878	0.936	0.8768	0.9254	0.9336
A2	0.9757	0.9473	0.9174	0.901	0.9878	0.9713	0.8768	0.9912	0.8448
A3	0.9661	0.9473	0.9259	0.901	0.953	0.9713	0.8768	0.9254	0.9336
A4	0.9661	0.9473	0.9174	0.9112	0.953	0.9713	0.8768	0.9254	0.9336
A5	0.9661	0.9473	0.9259	0.901	0.953	0.9713	0.8896	0.8755	0.8892
A6	0.9661	0.9527	0.9174	0.901	0.9878	0.9713	0.9363	0.9667	0.8448

Table 11. Difference matrix between the normalized matrix points of fuzzy TOPSIS decision making and the negative ideal solution

Alternative	Distance from in Dustrial Areas	Slope	Distance from Roads	Distance from Power Lines	Distance from Residential Areas	Land Use	Under-ground Water Depths	Distance from Wells and Springs	Distance from Surface Water
1	0.0343	0.0522	0.0744	0.0987	0.0206	0.0731	0.1229	0.0853	0.0759
2	0.0251	0.0522	0.0822	0.0987	0.0206	0.0391	0.1229	0.0144	0.1597
3	0.0343	0.0522	0.0744	0.0987	0.0651	0.0391	0.1229	0.0853	0.0759
4	0.0343	0.0522	0.0822	0.0893	0.0651	0.0391	0.1229	0.0853	0.0759
5	0.0343	0.0522	0.0744	0.0987	0.0651	0.0391	0.1111	0.1314	0.1168
6	0.0343	0.0473	0.0822	0.0987	0.0206	0.0391	0.0668	0.0456	0.1597

Table 12. Distance of alternatives from positive and negative ideal points in fuzzy TOPSIS method

Alternatives	D+	D-
Alternative 1	8.3999	0.6373
Alternative 2	8.4133	0.6148
Alternative 3	8.4005	0.6478
Alternative 4	8.4022	0.6463
Alternative 5	8.3190	0.7232
Alternative 6	8.4441	0.5941

In the next step, the coefficient of the proximity of each alternative was calculated based on Equation 23 and considering that the value of this index (CCj) is between zero and one. Any alternative whose value is closer to one indicates the superiority of that alternative, the ranking of the alternatives was done in the fuzzy TOPSIS method (Table 13).

As shown in Table 13, alternative 5 had the highest priority because its proximity coefficient was higher than other alternatives and has the lowest distance from the positive ideal and the highest distance from the negative ideal. Alternatives 3, 4, 1, 2, and 6 stand in the following priority, respectively.

Table 13. Relative proximity of each alternative to the negative and positive ideal solution and prioritization of alternatives based on the Fuzzy TOPSIS method

Alternatives	Alternatives Ranking	CCj
1	4	0.0705
2	5	0.0681
3	2	0.0716
4	3	0.0714
5	1	0.0800
6	6	0.0657

Table 14. CCJ index values (proximity coefficient) in the sensitivity analysis of alternatives for different weighting scenarios in the fuzzy TOPSIS method

CCJ Index	Criterion Weight									CCJ					
	W1	W2	W3	W4	W5	W6	W7	W8	W9	A1	A2	A3	A4	A5	A6
Main mode	0.2	0.175	0.127	0.107	0.107	0.102	0.085	0.054	0.043	0.071	0.068	0.072	0.071	0.080	0.066
CC12=1	0.175	0.2	0.127	0.107	0.107	0.102	0.085	0.054	0.043	0.071	0.066	0.072	0.072	0.080	0.064
CC13=2	0.127	0.175	0.2	0.107	0.107	0.102	0.085	0.054	0.043	0.075	0.069	0.076	0.076	0.082	0.064
CC14=3	0.107	0.175	0.127	0.2	0.107	0.102	0.085	0.054	0.043	0.074	0.064	0.071	0.071	0.078	0.061
CC15=4	0.107	0.175	0.127	0.107	0.2	0.102	0.085	0.054	0.043	0.069	0.062	0.074	0.074	0.080	0.060
CC16=5	0.102	0.175	0.127	0.107	0.107	0.2	0.085	0.054	0.043	0.077	0.070	0.078	0.077	0.084	0.068
CC17=6	0.085	0.175	0.127	0.107	0.107	0.102	0.2	0.054	0.043	0.077	0.070	0.078	0.079	0.084	0.068
CC18=7	0.054	0.175	0.127	0.107	0.107	0.102	0.085	0.2	0.043	0.080	0.071	0.081	0.081	0.086	0.067
CC19=8	0.043	0.175	0.127	0.107	0.107	0.102	0.085	0.054	0.2	0.078	0.064	0.079	0.079	0.084	0.066
CC23=9	0.2	0.127	0.175	0.107	0.107	0.102	0.085	0.054	0.043	0.073	0.073	0.074	0.074	081/0	0.067
CC24=10	0.2	0.107	0.127	0.175	0.107	0.102	0.085	0.054	0.043	0.072	0.070	0.071	0.070	0.077	0.067
CC25=11	0.2	0.107	0.127	0.107	0.175	0.102	0.085	0.054	0.043	0.068	0.069	0.072	0.072	0.079	0.065
CC26=12	0.2	0.102	0.127	0.107	0.107	0.175	0.085	0.054	0.043	0.074	0.075	0.076	075/0	0.082	0.071
CC27=13	0.2	0.085	0.127	0.107	0.107	0.102	0.175	0.054	0.043	0.074	0.077	0.075	0.076	0.081	0.073
CC28=14	0.2	0.054	0.127	0.107	0.107	0.102	0.085	0.175	0.043	0.077	0.080	0.078	0.078	0.083	0.074
CC29=15	0.2	0.043	0.127	0.107	0.107	0.102	0.085	0.054	0.175	0.075	0.075	0.076	0.076	0.081	0.074
CC34=16	0.2	0.175	0.107	0.127	0.107	0.102	0.085	0.054	0.043	0.070	0.067	0.070	0.070	0.079	0.065
CC35=17	0.2	0.175	0.107	0.107	0.127	0.102	0.085	0.054	0.043	0.069	0.066	0.071	0.071	0.079	0.065
CC36=18	0.2	0.175	0.102	0.107	0.107	0.127	0.085	0.054	0.043	0.071	0.068	0.072	0.071	0.080	0.067
CC37=19	0.2	0.175	0.085	0.107	0.107	0.102	0.127	0.054	0.043	0.070	0.068	0.071	0.071	0.080	0.068
CC38=20	0.2	0.175	0.054	0.107	0.107	0.102	0.085	0.127	0.043	0.071	0.068	0.072	0.071	0.081	0.069
CC39=21	0.2	0.175	0.043	0.107	0.107	0.102	0.085	0.054	0.127	0.069	0.065	0.070	0.070	0.079	0.068
CC45=22	0.2	0.175	0.127	0.107	0.107	0.102	0.085	0.054	0.043	0.071	0.068	0.072	0.071	0.080	0.066
CC46=23	0.2	0.175	0.127	0.102	0.107	0.107	0.085	0.054	0.043	0.071	0.068	0.072	0.072	0.080	0.066
CC47=24	0.2	0.175	0.127	0.085	0.107	0.102	0.107	0.054	0.043	0.071	0.070	0.073	0.073	0.081	0.067
CC48=25	0.2	0.175	0.127	0.054	0.107	0.102	0.085	0.107	0.043	0.072	0.072	0.075	0.075	0.084	0.069
CC49=26	0.2	0.175	0.127	0.043	0.107	0.102	0.085	0.054	0.107	0.071	0.070	0.075	0.075	0.083	0.069
CC56=27	0.2	0.175	0.127	0.107	0.102	0.107	0.085	0.054	0.043	0.071	0.069	0.072	0.072	0.080	0.066
CC57=28	0.2	0.175	0.127	0.107	0.085	0.102	0.107	0.054	0.043	0.072	0.070	0.072	0.072	0.081	0.068
CC58=29	0.2	0.175	0.127	0.107	0.054	0.102	0.085	0.107	0.043	0.075	0.073	0.074	0.074	0.082	0.070

CCJ Index	Criterion Weight									CCJ					
	W1	W2	W3	W4	W5	W6	W7	W8	W9	A1	A2	A3	A4	A5	A6
Main mode	0.2	0.175	0.127	0.107	0.107	0.102	0.085	0.054	0.043	0.071	0.068	0.072	0.071	0.080	0.066
CC59=30	0.2	0.175	0.127	0.107	0.043	0.102	0.085	0.054	0.107	0.075	0.071	0.073	0.073	0.081	0.070
CC67=31	0.2	0.175	0.127	0.107	0.107	0,085	0.102	0.054	0.043	0.070	0.068	0.071	0.072	0.080	0.066
CC68=32	0.2	0.175	0.127	0.107	0.107	0.054	0.085	0.102	0.043	0.071	0.068	0.072	0.072	0.080	0.065
CC69=33	0.2	0.175	0.127	0.107	0.107	0.043	0.085	0.054	0.102	0.069	0.066	0.070	0.071	0.079	0.065
CC78=34	0.2	0.175	0.127	0.107	0.107	0.102	0.054	0.085	0.043	0.071	0.068	0.072	0.071	0.080	0.065
CC79=35	0.2	0.175	0.127	0.107	0.107	0.102	0.043	0.054	0.085	0.070	0.066	0.071	0.071	0.080	0.065
CC89=36	0.2	0.175	0.127	0.107	0.107	0.102	0.085	0.043	0.054	0.070	0.068	0.071	0.071	0.080	0.066
										0.072	0.0692	0.0734	0.0732	0.0808	0.0670

The results of sensitivity analysis of the fuzzy TOPSIS method

The sensitivity analysis results in the fuzzy TOPSIS method were performed by shifting the weights of the criteria, producing different weighting scenarios, and calculating the proximity index for each scenario (Table 14 and Figure 3). For example, CC34 represents a scenario in which criteria 3 and 4 are shifted. According to Table 14, it can be seen that in Scenario 7, the weights of criteria 1 and 8 have shifted, and the alternatives A1, A3, A4, A5 have the highest CCJ values of 0.08, 0.081, 0.081, and 0.086 compared to their initial values of 0.071, 0.072, 0.071, 0.080. In scenario 14, the weights of criteria 2 and 8 were shifted together. Alternative A2 has the highest CCJ value of 0.080 compared to its initial value of 0.068. In scenarios 13 and 14, where the weights of criteria 2, 7, 2, and 8 have been shifted, alternative A6 has the highest CCJ value of 0.074 compared to its initial value of 0.066. In contrast, alternative 5 in 36 scenarios is the first priority.

The obtained results in this study showed the suitable areas for establishing industries in the east and south-east of the city. The main reasons for this desirability of industrial area establishment are included as full access to the leading road network, the concentration of wells in the east of the city for industries to access water, the existence of a perfectly suitable slope, complete and easy access to the railway network, considering that the railway crossing route is between Kashan and Aranobidgol, access to power transmission lines and proximity to other industries to access infrastructure. In between both fuzzy VIKOR and fuzzy TOPSIS methods, Alternative 5 with an area of 405 hectares with a pixel value above 200, was introduced as the most suitable location and the ranking of the subsequent alternatives in these two methods

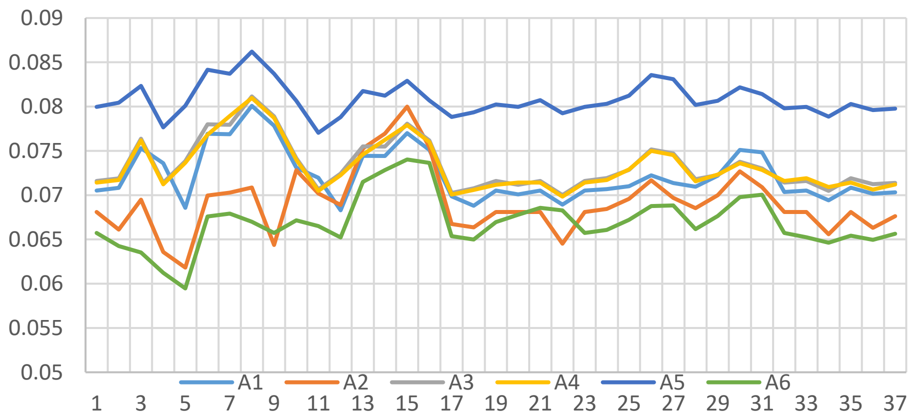

Figure 3. Sensitivity analysis diagram for different weighting scenarios in fuzzy TOPSIS

was a little different, the reason for some of these differences is as follows: both methods use a cumulative function that represents the distance from the ideals. TOPSIS does not consider the importance of distances from positive and negative ideals. For this reason, the best solution in TOPSIS is not always and necessarily the closest solution to the ideal positive state. VIKOR uses linear normalization, and therefore, the values normalized in the VIKOR method do not depend on the unit of measurement of the criteria; while TOPSIS uses vector normalization, and the normalized values may depend on the unit of measurement of the criteria. In the VIKOR method, the agreed solution is a possible solution that is the closest solution to the ideal solution (existence of υ).

Opricovic and Tzeng [27] pointed out the differences between the two methods and believe that both methods are part of MCDM methods that show the ideal solution through the cumulative function. They presented the VIKOR method ranks based on the method known as the compromise solution (the answer obtained by mutual agreement between the criteria). In contrast, the basis of the TOPSIS method is the selection of alternatives based on the minimum distance from the positive ideal solution and the maximum distance from the negative ideal solution. As a result, TOPSIS does not consider the relative importance of distances, which is its major weakness.

4. Conclusion

The present study was conducted with the aim of ranking the selected locations for the establishment of industries. For this purpose, different criteria should be considered, which may conflict with each other and cause ambiguity in the decision-making process. In this research, uncertainties in the decision-making process are expressed using verbal variables that can be converted to triangular fuzzy numbers in the form of fuzzy VIKOR and fuzzy TOPSIS methods. In the fuzzy TOPSIS method, the alternatives were ranked based on their distance from the positive and negative ideals. In the fuzzy VIKOR method, alternatives were prioritized based on proximity to the ideal answer. Implementing the evaluation process in a fuzzy environment is among the strength of fuzzy TOPSIS and fuzzy VIKOR methods to reduce uncertainty in real-world problems and ambiguity in factual data. Finally, the strength of the methods was performed for different values of υ in the fuzzy VIKOR method and by shifting the weight of criteria for the fuzzy TOPSIS method. The sensitivity analysis results showed that alternative 5 had priority in terms of the best location. It should be noted that the proposed methods can be used to solve MCDM problems under uncertain conditions. Finally, it can be said that due to the possibility of increasing and decreasing the information layers as well as changing the weight of each layer at any time and according to the conditions of each region, the capabilities of these models can be used as a model in locating industries across the country.

Ethical Considerations

Compliance with ethical guidelines

This study does not contain any ethical issues, such as with no human or animal sample.

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

Data collection, manuscript writing and data analysis: Katayoun Omidi, Afsaneh Afzali; Manuscript results evaluation: Hossein Vahidi, Sheida Mahnam; Reviewing and revising the manuscript: Afsaneh Afzali, Hossein Vahidi, Sheida Mahnam.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgments

The authors would like to acknowledge the anonymous reviewers of the Journal of Advances in Environmental health Research.

References

[1] Tiwari P. 7 general factors influencing location of industries in India. Sindhnur: Geographynotes; 2014. [Link]

[2] Jafari HR, Karimi S. [Site selection for the establishment of industrial sites in Qom province; using GIS (Persian)]. J Environ Stud. 2005; 31(37):45-52. [Link]

[3] Forghani A, Yazdanshenas N, Akhoundi AR. [A general framework for locating the industrial centers at the national level along with a case study (Persian)]. J Manag Knowl. 2007; 20(77):81-104.[Link]

[4] Holmes TJ. Localization of industry and vertical disintegration. Rev Econ Stat. 1999; 81(2):314-25. [DOI:10.1162/003465399558102]

[5] Ravix JL. Localization, innovation and entrepreneurship: An appraisal of the analytical impact of Marshall's notion of industrial atmosphere. J Innov Econ Manag. 2014; 14(2):63-81. [DOI:10.3917/jie.014.0063]

[6] Guzman L. Localization factors from Japanese firms in automotive-related industries in Mexico. Procedia Econ Financ. 2015; 30:265-70. [DOI:10.1016/S2212-5671(15)01294-0]

[7] Atthirawong W, MacCarthy B. An application of the analytical hierarchy process to international location decision-making. Paper presented at: 7th Annual Cambridge International Manufacturing Symposium: Restructuring Global Manufacturing. 13 September 2002; Cambridge, England. [Link]

[8] Opricovic S, Tzeng GH. Extended VIKOR method in compromise with outranking methods. Eur J Operat Res. 2007; 178(2):514-29. [DOI:10.1016/j.ejor.2006.01.020]

[9] Li DF. Fuzzy Closeness approach to fuzzy multi-attribute decision making. Fuzzy Optim Decis Making. 2007; 6(3):237-54. [DOI:10.1007/s10700-007-9010-1]

[10] Xia HC, Li DF, Ji-Yan Zh, Wang JM. Fuzzy LINMAP method for multi-attribute decision making under fuzzy environments. J Comput Syst Sci. 2006; 72(4):741- 59. [DOI:10.1016/j.jcss.2005.11.001]

[11] Rao RV. A decision making methodology for material selection using an improved compromise ranking method. Mater Des. 2008; 29(10):1949-54. [DOI:10.1016/j.matdes.2008.04.019]

[12] Chu MT, Shyu J, Tzeng GH, Khosla R. Comparison among three analytical methods for knowledge communities group-decision analysis, Expert Syst Appl. 2007; 33(4):1011-24. [DOI:10.1016/j.eswa.2006.08.026]

[13] Zadeh LA. Fuzzy sets. Inform Control. 1965; 8(3):338-53. [DOI:0.1016/S0019-9958(65)90241-X]

[14] Amiri M. [Group decision for machine tool selection using fuzzy VIKOR method (Persian)]. Ind Manag Stud. 2007; 6(16):167-88. [Link]

[15] Oveisi S, Afzali A. [Selecting municipal solid waste landfill site in Kashan City using OWA and TOPSIS fuzzy methods (Persian)].Desert Ecosystem Eng J. 2020; 9(27):79-92. [Link]

[16] Chalik A. Evaluation of social media platforms using best-worst method and fuzzy VIKOR methods: A case study of travel agency. Iran J Manag Stud. 2020; 13(4):645-72. [Link]

[17] Sadeghi Z, Rezaee Jafari M, Ghasemi Nejad A. [Investigating the pollution of renewable power plants with AHP, TOPSIS and VIKOR analysis approach (Persian)]. J Environ Sci Technol. 2021; 22(8):43-58. [Link]

[18] Ariafar SH, Agoush L, Kalavani KH, Rahimisadegh R. [Selection of electroshock device supplier using TOPSIS, VIKOR, and SAW multicriteria decision-making methods in Afzalipour Hospital, Kerman (Persian)]. Hakim Res J. 2020; 23(3):344-52. [Link]

[19] Chezgi J, Soheili E. [Application of TOPSIS and VIKOR decision making models in site selection of flood spreading projects in arid and semi-arid region (Persian)]. Desert Manag. 2021; 8(16):169-82. [Link]

[20] Rahmani S, Omidvari M. [Assessing safety risk in electricity distribution processes using ET & BA improved technique and its ranking by VIKOR and TOPSIS models in fuzzy environment (Persian)]. J Health Saf Work. 2016; 6(1):1-12. [Link]

[21] Khajavi SH, Fattahi Nafchi H. [A comparative study of combined efficient algorithms to evaluate the financial performance of companies in Tehran stock exchange using fuzzy approach (Persian)]. Ind Manag J. 2015; 7(2):285-304. [DOI:10.22059/IMJ.2015.57202]

[22] Mohtashami A, Miri-Asl M. [Proposing a hybrid model of fuzzy multi attribute decision making for prioritizing and selecting maintenance strategies (Persian)]. J Dev Evolut Manag. 2017; 1396(28):63-70. [Link]

[23] Tarokh MJ, Aryanezhad MBGH, Ekhtiari M, yazdani M. [Credit risk management under uncertainty using a fuzzy VIKOR method (Persian)]. Int J Ind Eng Prod Manag. 2014; 25(1):15-30. [Link]

[24] Radmehr A, Araghinejad SH. [Application of fuzzy spatial multi criteria decision making approach in determination of the flood vulnerable zones (case study: Tehran Urban Basin) (Persian)]. Water Soil Sci. 2014; 24(4):115-28. [Link]

[25] Shafaei AH, Rabani y, Hashemiyan N. [Assessing of siteselection effective parameters based on sustainable development principles using fuzzy delphi analytical hierarchy process (FDAHP) (Persian)]. Paper presented at: The 8th Symposium on Advances in Science and Technology. 18 December 2013; Mashhad, Iran. [Link]

[26] Momeni M. [New topics in operations research(Persian)]. Tehran: University Tehran; 2006. [Link]

[27] Opricovic S, Tzeng GH. Multi-criteria planning of postearthquake sustainable reconstruction. Comput Aided Civ Infrastruct Eng. 2002; 17(3):211-20. [DOI:10.1111/1467-8667.00269]

[28] Opricovic S, Tzeng GH. Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. Eur J Operat Res. 2004; 156(2):445-55. [DOI:10.1016/S0377-2217(03)00020-1]

[29] Opricovic S. Multicriteria optimization of civil engineering systems [PhD dissertation]. Faculty of Civil Engineering, Belgrade, Serbia; 1998. https://www.researchgate.net/publication/285667455_Multicriteria_optimization_of_civil_engineering_systems

[30] Opricovic S. Fuzzy VIKOR with an application to water resources planning. Expert Syst Appl. 2011; 38(10):12983-90. [DOI:10.1016/j.eswa.2011.04.097]

[31] Chen CT, Lin CT, Huang SF. A fuzzy approach for supplier evaluation and selection in supply chain management. Int J Prod Econ. 2006; 102(2):289- 301. [DOI:10.1016/j.ijpe.2005.03.009]

[32] Huang JJ, Tzeng GH, Liu HH. A revised VIKOR model for multiple criteria decision making - the perspective of regret theory. In: Shi Y, Wang S, Peng Y, Li J, Zeng Y (editor). Cutting-edge research topics on multiple criteria decision making. Berlin Heidelberg: Springer; 2009. [DOI:10.1007/978-3-642-02298-2_112]

[33] Chen SJ, Hwang CL. Fuzzy multiple attribute decision making: Methods and applications. In: Fandel G, Trockel W, editors. Lecture notes in economics and mathematical systems. Berlin: Springer-Verlag; 1992. [DOI:10.1007/978-3-642-46768-4]

[34] Krohling RA, Campanharo VC. Fuzzy TOPSIS for group decision making: A case study for accidents with oil spill in the sea. Expert Syst Appl. 2011; 38(4):4190-7. [DOI:10.1016/j.eswa.2010.09.081]