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Research Article

A Comprehensive Analysis of Location Selection Problem for Underground Waste Containers Using Integrated MC-HFLTS&MAIRCA and MABAC Methods

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Abstract

Underground waste container systems are the systems that operate vertically in confined spaces and provide the collection of all waste and garbage under the ground and that prevent the spread of scent and water around. Underground waste containers have many advantages compared to classic waste containers. They prevent the formation of viruses and bacteria-based illnesses that may be exposed due to the inner coating of the tank under the ground, save space, save time in the collection of waste and collect the wastes hygienically and untouched. Moreover, they contribute to recycling due to on-site waste sorting with more than one container taking a small place. The use of underground waste containers with many advantages as mentioned above is gradually increasing. In this respect, the purpose of this study is to determine the criteria that are effective in placing underground waste containers, to calculate the criteria weights and to evaluate alternative locations where waste containers will be placed for a particular region. As a result of the literature review, no study was conducted on the location selection for underground waste containers. In this study, the integrated MC-HFLTS&MAIRCA method was used to evaluate alternatives and select the best location for underground waste containers. This method may increase the flexibility of expressing linguistic information and define the difference between the ideal and empirical values. According to the results obtained, the most important criteria was determined as infrastructure efficiency (C_5), amount of waste (C_3) and population density (C_2), number of the institution of public/private organization (C_4) and distance to waste disposal point (C_1), respectively. The alternative order is as $A_3>A_1>A_2$. According to the results obtained in the calculation, the first location where underground waste containers will be placed is Yakutiye district (A_3) and Lalapaşa neighborhood (B_3). The comparison analysis was performed using MABAC method to check the validity of the results. A_3 and B_3 alternatives are the best one and the order of location for underground waste containers is the same in MC-HFLTS&MAIRCA and MC-HFLTS&MABAC methods.

Keywords: Hesitant fuzzy linguistic term set, location selection, underground waste container, MAIRCA, MABAC.

Entegre MC-HFLTS & MAIRCA ve MABAC Yöntemleri Kullanılarak Yeraltı Çöp Konteynerleri İçin Kapsamlı Bir Yer Seçimi Problemi Analizi

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Öz

Yeraltı çöp konteyner sistemleri, dar alanlarda düşey konumda çalışarak tüm çöp ve atıkların yer altında toplanmasını sağlayan ve etrafa koku ve su yayılmasını önleyen sistemlerdir. Yeraltı çöp konteynerlerinin klasik çöp konteynerlerine göre birçok avantajı bulunmaktadır. Bunlar; yer altındaki haznenin iç kaplaması sayesinde maruz kalınabilecek virüs ve bakteri kaynaklı hastalıkların oluşmasını önlemesi, yerden tasarruf sağlaması, çöp toplamada zaman tasarrufu sağlaması, çöplerin el değmeden hijyenik olarak toplanmasıdır. Ayrıca, daha az yer kaplayan birden fazla konteyner ile yerinde atık ayrıştırması sayesinde geri dönüşüme katkı sağlamaktadır. Bunlar gibi birçok avantajı olan yer altı çöp konteynerlerinin kullanımı giderek artmaktadır. Bu doğrultuda bu çalışmanın amacı yer altı çöp konteynerlerinin yerleştirilmesinde etkili olan kriterlerin belirlenmesi, kriter ağırlıklarının hesaplanması ve belirli bir bölge için çöp konteynerlerinin yerleştirileceği alternatif yerlerin değerlendirilmesidir. Literatür taraması sonucunda, yeraltı çöp konteynerleri için yer seçimi konusunda bir çalışma yapılmamıştır. Bu çalışmada, birleşik MC-HFLTS & MAIRCA yöntemi yeraltı çöp konteynerleri için alternatiflerin değerlendirilmesi ve en iyi yerin seçilmesinde kullanılmıştır. Bu yöntem, dilsel bilgiyi ifade etme esnekliğini artırabilir, ideal ve ampirik değerler arasındaki farkın tanımlar. Elde edilen sonuçlara göre, en önemli kriter, altyapı uygunluğu (C5), ardından atık miktarı (C3) ve sırasıyla nüfus yoğunluğu (C2), kamu / özel kuruluş kurum sayısı (C4) ve atık imha noktasına uzaklık (C1) olarak belirlenmiştir. Alternatif sırası A3> A1> A2 şeklindedir. Hesaplamada elde edilen sonuçlara göre, yeraltı atık konteynerlerinin kurulacağı ilk yer Yakutiye (A3) ilçesi ve Lalapaşa mahallesi (B_3)'dir. Sonuçların geçerliliğini kontrol etmek için MABAC yöntemi kullanılarak karşılaştırma analizi yapılmıştır. MC-HFLTS & MAIRCA ve MC-HFLTS & MABAC yöntemlerinde, A_3 ve B_3 alternatifleri en iyisidir ve yeraltı çöp konteynerleri için alternatif sırası aynıdır.

Anahtar Kelimeler: Kararsız bulanık dilsel terim seti, Yer seçimi, Yeraltı çöp konteyneri, MAIRCA, MABAC.

1. Introduction

The reduction of natural resources and the threat of environmental pollution have increased the importance of recycling due to global warming and increasing population. Underground waste containers are named as compact systems consisting of large or small trash cans that appear above-ground and these trash cans have a reservoir 10-20 times more than their size. In this respect, using these innovative containers prevents the trash cans and trash from dropping around, as well as the collection of this debris, and eliminating the problems of smells and insects and flies. The above part of the underground waste containers contributes to the beauty of the living space with its aesthetic appearance, while the underground chamber provides protection in the tank against the leaks due to its inner coating, and since this chamber is placed under the ground, it prevents the occurrence of viruses and bacteria caused by the accumulation of waste on the streets and the distribution of impurities. The accumulation of underground waste saves space as well as facilitates pedestrian and vehicle transitions on the streets. Because the waste can be emptied in less than two minutes by the waste trucks that municipalities are currently using, thus time is saved. Moreover, hygiene and job security can be ensured since municipal workers are emptying the underground waste bin without touching. The advantages of underground waste containers and the characteristics of conventional waste containers are compared and summarized in Figure 1.

Figure 1. Comparison of underground waste containers and classic waste containers

In this study, the problem of placing underground waste containers with many advantages mentioned above is discussed. The determination of the location of underground waste containers is an important decision-making problem since it contains more than one contradictory criteria. In this context, districts where underground waste containers would be placed first, then neighborhoods in Erzurum province of Turkey, were prioritized using Multi-Criteria Hesitant Fuzzy Linguistic Term Set (MC-HFLTS) and Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA) among Multiple Criteria Decision Making (MCDM) methods. Moreover, a comparative analysis was performed using MABAC method in order to test the consistency of the results and the reliability of the method.

This study uses three MCDM methods: MC-HFLTS to define the weights of criteria, and MAIRCA and MABAC to choose the best alternative. There are several main reasons why we chose these methods. The reason for selecting MC-HFLTS was that it offers a DM a comparative and rich linguistic term set to express himself/herself more explicitly in cases of hesitation. Thus, the evaluation becomes more accurate due to the use of phrases that are relevant to hesitant human nature.

MAIRCA and MABAC methods are novel methods in comparison to other MCDM methods. Both methods also have similar working principles. MAIRCA method determines the difference between the ideal weight and the empirical weight. The value where this value is minimal is selected as the best one, while MABAC method determines the ideal and anti-ideal distances to the respective regions. The alternative with the greatest sum of its distances to the values that correspond to the ideal region is selected. This is why these methods were used in this study in order to measure the proximity and/or distance to the ideal. Furthermore, the reason why these methods were selected was that these were relatively novel in comparison to other methods, and it was aimed to determine the effectiveness of these methods in comparison.

The remainder of this study is organized as follows: Section 2 provides the literature related to applications of MC-HFLTS, MAIRCA and MABAC methods. MC-HFLTS, MAIRCA methods used in this study are described in Section 3. Section 4 illustrates the process of selecting the best location for the underground waste containers. Section 5 provides a comparison analysis with the MABAC method. Conclusions and future research directions are provided in the final section.

2. Literature Review

The literature review is given in three different groups. First of all, application studies using MC-HFLTS method are given. Then, studies using MAIRCA method are given. Finally, the studies using MAIRCA and MABAC methods in practice and comparison analysis are given.

Application studies using MC-HFLTS included the selection of alternative-fuelled vehicles for medical home providers (Yavuz *et al.,* 2015), the evaluation of alternatives to life insurance policies (Adem & Dağdeviren, 2016), site selection for wind turbines (Aktaş & Kabak, 2016) and site selection for courthouses (Topraklı *et al*., 2016), the evaluation of mental workload (Adar & Delice, 2017), human error analysis in banking sector (Adar & Delice, 2018), selection of the best healthcare waste treatment technology (Adar & Delice, 2019), selection of cargo distribution company (Adar & Delice, 2019).

Considering literature, the studies on MAIRCA method are as follows: DEMATEL-MAIRCA model is used for selection of railway level crossings in order to invest in security equipment (Pamucar et al., 2014), MAIRCA method is combined with Geographic information systems (GIS) by (Gigovic et al., 2016) and the model application is presented for the choice of sites for Ammunition Depots. The hybrid DEMATEL-ANP-MAIRCA model was improved based on Interval Rough Numbers (IRN) by (Pamucar et al., 2017) and demonstrated using the example of the bidder selection process in the state administration public procurement procedure. The Rough DEMATEL-ANP-MAIRCA (R'AMATEL-MAIRCA) method is proposed by (Chatterje et al., 2018) and it is used to assess the performance of suppliers for green supply chain implementation in the electronics industry. A military airport location selection by AHP integrated PROMETHEE and VIKOR methods is presented by (Sennaroğlu and Celebi, 2018). The results of the integrated method are compared with the results of MAIRCA, MABAC and COPRAS methods. IR-MABAC model was used for the evaluation of university websites and was compared to Fuzzy MAIRCA method (Pamucar et al., 2018). Finally, rough MAIRCA method is used for supplier choice in a company manufacturing PVC carpentry product (Stojic et al., 2018). The studies using MAIRCA and MABAC methods in practice and comparison analysis are given in Table 1.

Table 1. Studies using MAIRCA and MABAC methods

Authors	MCDM methods	Based on	Comparison methods	Case study
Pamucar et al., 2014	DEMATEL-MAIRCA	-	-	Selection of railway level crossings
Pamucar and Cirovic, 2015)	DEMATEL-MABAC	-	SAW, COPRAS, TOPSIS, MOORA, VIKOR	Selection of transport and handling resources
Gigovic et al., 2016	MAIRCA	-	VIKOR, TOPSIS, MOORA, COPRAS	Selection of sites for ammunition depots
Bozanic and Pamucar, 2016	AHP-MABAC	Fuzzy set	Sensitivity analysis	Facility site selection
Roy et al., 2016	AHP-MABAC	Rough set	Rough TOPSIS, Rough AHP-VIKOR	Evaluation of cities for medical tourism

Roy et al., 2016	MABAC	Trapezoidal interval type-2 fuzzy numbers (TrIT2FNs)	TrIT2FNs TOPSIS	Selection of candidate
Xue et al., 2016	MABAC	Interval-valued intuitionistic fuzzy (IVIF)	IVIF-ELECTRE, IVIF-TOPSIS	Material selection for product design
Pamucar et al., 2014	DEMATEL-ANP-MAIRCA	Interval rough numbers (IRN)	F-TOPSIS, F-VIKOR, F-MABAC, F-TODIM, F-ELECTRE I	Evaluation of alternative solutions
Yu et al., 2017	MABAC	Interval Type-2 fuzzy numbers	Extended ELECTRE, TOPSIS, MABAC	Selection of hotel on tourism websites
Delice and Can, 2017	MABAC	Stochastic	Classical MABAC	Prioritize potential failure modes (FMs)
Gigovic et al., 2017	DANP-MABAC	-	VIKOR, TOPSIS, COPRAS	Selecting the location of wind farms
Shi et al., 2017	Cloud model and MABAC	-	F-VIKOR, MULTIMOORA	Assessment health-care waste treatment technologies
Debnath et al., 2017	Grey DEMATEL-MABAC	-	MABAC, IVIF-MABAC, TOPSIS-Grey, Grey VIKOR	Selection of strategic project portfolios
Stevic et al., 2017	BWM- SAW	Rough set	AHP-BWM, MABAC, TOPSIS, SAW and based on Rough methods	Selection of wagons
Stevic et al., 2017	DEMATEL, EDAS	-	Rough COPRAS, Rough MULTIMOORA, Rough AHP	Supplier selection
Chatterje et al., 2018	DEMATEL-ANP-MAIRCA (R'AMATEL-MAIRCA)	-	R-MAIRCA, R-VIKOR, R-TOPSIS, R-COPRAS	Evaluation performance of suppliers
Sennaroğlu and Celebi, 2018	AHP-PROMETHEE, VIKOR	-	MAIRCA, MABAC, COPRAS	Military airport location selection
Stojic et al., 2018	AHP-WASPAS	Rough set	R-SAW, R-EDAS, R-MABAC, R-VIKOR, R-MAIRCA, R-MULTIMOORA	Supplier selection concerning a company's
Pamucar et al., 2018	BWM (Best-Worst Method)-MABAC	Interval-valued fuzzy rough numbers (IVFRNs)	MABAC, COPRAS, VIKOR	Evaluating firefighting aircraft
Pamucar et al., 2018	AHP-MABAC	Interval rough set	F-TOPSIS, F-VIKOR, F-COPRAS, F-MAIRCA, F-TODIM	Evaluating university web pages

Pamucar et al., 2018	BWM-WASPAS, IRN-BWM-MABAC	Interval rough number (IRN)	IRN-WASPAS, F-MABAC, IRN-MABAC, WASPAS, MABAC	Assessment of third-party logistics provider
Wang et al., 2018	Prospect Theory-based MABAC	-	PFNP (Picture Fuzzy Normalized Projection)-VIKOR	Risk ranking of energy performance contracting project
Ji et al., 2018	MABAC-ELECTRE method	Single-valued neutrosophic linguistic sets	Extended TOPSIS, Fuzzy MABAC	Outsourcing provider choice
Can and Toktaş, 2018	DEMATEL-MABAC	Fuzzy set	-	Risk assessment
Liang et al., 2019	MABAC	Triangular fuzzy numbers (TFNs)	TOPSIS and TODIM, Fuzzy TOPSIS, Fuzzy TODIM	Risk assessment of rockburst
Liu et al., 2019	MABAC	Interval-valued intuitionistic fuzzy sets	Fuzzy VIKOR, IF-TOPSIS	Healthcare risk analysis
Wang et al., 2019	AHP-EW (Entropy Weight)-MABAC	-	Sensitivity analysis for MABAC	Demands-matching for reverse logistics
Adar & Delice, 2019	MC-HFLTS MABAC&MAIRCA	Hesitant fuzzy linguistic term set	VIKOR, TOPSIS	Selection of the best healthcare waste treatment technology
Adar & Delice, 2019	MC-HFLTS &MAIRCA	Hesitant fuzzy linguistic term set	MABAC, TOPSIS, VIKOR	Selection of the best cargo distribution company

As can be seen from the table, MABAC and MAIRCA methods are not combined with HFLTS information. Moreover, as a result of the literature review, no studies related to the location of underground waste containers were found. The problem of location selection for underground waste containers was discussed for the first time in this study. This study is original in terms of this case and the integrated methods used.

3. An Integrated MC-HFLTS&MAIRCA Methods

In this study, the integrated MC-HFLTS&MAIRCA method is used to evaluate and choose the best location for underground waste containers. This integrated method contains three stages. These are explained as follows:

Stage 1. Data collection

In this stage, the aim of the study, evaluation criteria and alternatives are determined, then the hierarchy of decision-making problem is constructed. Decision-makers that have knowledge and experience relevant to the subject are identified.

Stage 2. Determination criteria weights using MC-HFLTS

Firstly, definitions for HFLTS are shown in the following (Yavuz et al., 2015; Rodriguez et al., 2012; Rodriguez et al., 2014).

Definition 1: Assume that, Y is a set of reference, a function of *l* is an HFS on Y, that changes of values in [0, 1]: $l: Y \rightarrow \{[0,1]\}$.

Definition 2: $M = \{\mu_1, \mu_2, \ldots, \mu_n\}$ is a set of *n* membership functions. HFS is related to M, l_M and is shown as: $l_M(y) = \bigcup_{\mu \in M} \{\mu(y)\}$

.

Definition 3: L_S is an HFLTS and ordered a finite subset of linguistic terms $S=\{s_0,s_1,\dots,s_g\}$. Linguistic term set of $S=\{s_0,s_1,\dots,s_g\}$ has the conditions as follows:

- $S: s_i \le s_j \;\; if \;\; i \le j$ shows the order,
- $Neg(s_i)=s_j$ and $j=g-1$ show a negation operator,
- $\max(s_i,s_j)=s_i \;\; and \;\; \min(s_i,s_j)=s_j \;\; if \;\; i \ge j$ show a maximization operator and a minimization operator, respectively.

Definition 4: In a HFLTS, L_{S^+} and L_{S^-} show the upper limit and lower limit, respectively. These can be shown as follows: $L_{S^+}=\max(s_i)=s_j, \;\; s_i \in L_S$ and $s_i \le s_j \;\; \forall_i$, $L_{S^-}=\min(s_i)=s_j, \;\; s_i \in L_S$ and $s_j \le s_i \;\; \forall_i$.

Definition 5: $env(L_S)$ is the envelope of an HFLTS and it is a linguistic interval. This interval consists upper limit and lower limit as this: $env(L_S)=[L_{S^-},L_{S^+}], \;\; L_{S^-} \le L_{S^+}$.

MC-HFLTS includes the linguistic terms which are based on a fuzzy envelope and pays attention to the specialists' indecision about defining their degrees of membership. Moreover, the complicated problems of MCDM, which are hierarchical, could be solved with this method.

$z \in \{1,2,\dots,\tau\}$ represents the number of any criterion.

Step 1: Define the semantics and syntax of the linguistic term set S. S consists of 'No importance (ni), very low importance (vli), low importance (li) medium importance (mi), high importance (hi), very high importance (vhi), absolute importance (ai).

$$S=\left\{\begin{array}{l} no\ importance\ (ni), very\ low\ importance\ (vli) \\ low\ importance\ (li), medium\ importance\ (mi), \\ high\ importance\ (hi), very\ high\ importance\ (vhi), \\ absolute\ importance\ (ai) \end{array}\right\} \tag{1}$$

Step 2: Determine the context-free grammar G_L. It consists of elements $V_N, V_T, I \;\; and \;\; P$. These are defined as follows:

$V_N=\{\langle \text{primary term}\rangle, \langle \text{composite term}\rangle, \langle \text{unary relation}\rangle, \langle \text{binary relation}\rangle, \langle \text{conjunction}\rangle\}$

$V_T=\{\text{lower than,greater than,at least,at most,between,and,} s_0, s_1, ..., s_g\}$,

$I \in V_N$. V_N contains nonterminal symbols, V_T contains terminals' symbols, *I* means the starting symbol, and P means the creation rules which provide primary term or composite term. So, selecting I as any nonterminal symbol and using P could be created linguistic expressions, such as, 'at least high, at most medium'.

The rules of the creation of the context-free grammar are presented in Equation 2:

$$P=\left\{\begin{array}{l} I=\langle primary\ term\rangle \mid \langle composite\ term\rangle, \\ \langle composite\ term\rangle ::= \langle unaryrelation\rangle\langle primary\ term\rangle \mid \\ \langle binary\ relation\rangle\langle primary\ term\rangle\langle conjunction\rangle\langle primary\ term\rangle, \\ primary\ term ::= s_0 \mid s_1 \mid ... \mid s_g, \langle unary\ relation\rangle ::= \\ lower\ than \mid greater\ than \mid at\ least \mid at\ most, \\ \langle binary\ relation\rangle ::= between, \langle conjunction\rangle ::= and \end{array}\right\} \tag{2}$$

The symbol *I* can consist of the primary term or composite term. Composite term composes of unary relation and primary term or binary relation, primary relation, conjunction and primary term.

Step 3: Make the preference relations (PRs) into HFLTS.

Collect the PRs p^k given by DMs $k \in \{1,2,...,m\}$ for criteria. The PRs into HFLTS transform using the E_{GL}.

Step 4: Obtain an envelope $[p^{k-}{}_{ij}, p^{k+}{}_{ij}]$ for each HFLTS. Envelope values can be found using 2-tuples operations.

Step 5: Define the pessimistic and optimistic collective PRs.

A linguistic aggregation operator λ is selected. The pessimistic (P_C^-) and optimistic (P_C^+) collective PRs are obtained using the λ. In this study, arithmetic mean is used for the linguistic aggregation operator (Yavuz et al., 2015; Rodriguez et al., 2012).

$$\overline{y} = \Delta\left(\frac{1}{n}\sum_{i=1}^{n}\Delta^{-1}(s_i,\alpha_i\right) = \Delta\left(\frac{1}{n}\sum_{i=1}^{n}\beta_i\right) \tag{3}$$

The function $\Delta:[0,g]\rightarrow S$ is shown Equation (4), where $S = Sx[0.5, 0.5]$.

$$\Delta(\beta) = (s_i,\alpha) \quad \begin{cases} \text{i=round(β)} \\ \text{α=β-i} \end{cases} \tag{4}$$

where $i \in \{0,1,...,g\}$, $\Delta^{-1}:\langle S\rangle \rightarrow [0,g]$ is determined by Equation (5):

$$\Delta^{-1}(s_i,\alpha) = i+\alpha \tag{5}$$

Step 6: Calculate a pessimistic and optimistic collective preference.

The pessimistic and optimistic collective preferences are calculated for each criterion by λ.

Step 7: Construct a vector of intervals of collective choices for the criteria.

Step 8: Determine the criteria weights.

The obtained interval utilities are normalized and then weighted scores are found.

Stage 3. Selection of the best location using MAIRCA method

MAIRCA was improved in 2014 by the Center for Logistics Research at the University of Defense in Belgrade (Pamucar et al., 2014). MAIRCA method determines the difference between the ideal weight and empirical weight. The value, where this value is minimal, is selected as the best one. MAIRCA method is created in six steps (Gigovic et al., 2016):

Step 9. Construct the formation of the initial decision matrix (X).

In the initial decision matrix, the criteria values x_{ij}, $(i=1,2,\ldots,n; \quad j=1,2,\ldots,m)$ are determined by DMs.

$$X = \begin{matrix} & C & C & \ldots & C \\ A_1 & x & x & \ldots & x \\ A_2 & x & x & \ldots & x \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ A_m & x & x & \ldots & x \end{matrix} \tag{6}$$

Initially, decision matrix is defined according to the aggregation of DMs decisions or personal preferences of the DMs. In this study, it is obtained by aggregation of DMs preferences.

Step 10: Define the preference according to the alternative selection P_{A_i}.

The possibility of any alternative selection is not considered by DMs throughout this process. At first, DMs assumed that the alternative selection was the equal probability, so the probability of selecting one of the possible m alternatives was shown by Eq. (7).

$$P_{A_i} = \frac{1}{m}; \quad \sum_{i=1}^{m} P_{A_i} = 1, \quad i = 1,2,...,m \tag{7}$$

Here, m indicates the total number of alternatives.

In the process, suppose that DM is neutral against risk. Namely, all the choices are equal according to the choice of alternatives $(P_{A_1} = P_{A_2} = \ldots = P_{A_m})$.

Step 11. Calculate the theoretical evaluation of matrix elements (T_p).

T_p is found as the multiplication of the P_{A_i} and criteria weights (the weights that are calculated using MC-HFLTS) w_i, $i=1,2,\ldots,n$. It is shown in Equation (8).

$$T_p = \begin{array}{c} \\ P_{A_1} \\ P_{A_2} \\ \dots \\ P_{A_m} \end{array} \begin{array}{c} \begin{array}{cccc} w_1 & w_2 & \dots & w_n \end{array} \\ \begin{bmatrix} t_{p11} & t_{p12} & \dots & t_{p1n} \\ t_{p21} & t_{p22} & \dots & t_{p2n} \\ \dots & \dots & \dots & \dots \\ t_{pm1} & t_{pm2} & \dots & t_{pmn} \end{bmatrix} \end{array} = \begin{array}{c} \\ P_{A_1} \\ P_{A_2} \\ \dots \\ P_{A_m} \end{array} \begin{array}{c} \begin{array}{cccc} w_1 & w_2 & \dots & w_n \end{array} \\ \begin{bmatrix} P_{A_1} w_1 & P_{A_1} w_2 & \dots & P_{A_1} w_n \\ P_{A_2} w_1 & P_{A_2} w_2 & \dots & P_{A_2} w_n \\ \dots & \dots & \dots & \dots \\ P_{A_m} w_1 & P_{A_m} w_2 & \dots & P_{A_m} w_n \end{bmatrix} \end{array} \tag{8}$$

Step 12. Calculate the real evaluation matrix (T_r).

The elements of T_r are calculated as the multiplication of the elements of the T_p and elements of the X using Equation (9)-(10).

For the "benefit" type criteria; $t_{rij} = t_{pij} \left(\frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \right)$ (9)

For the "cost" type criteria; $t_{rij} = t_{pij} \left(\frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \right)$ (10)

Here, x_{ij} is the elements of the initial decision matrix. And x_i^+, x_i^- are the maximum values and minimum values of the criterion by its alternatives, respectively.

Step 13. Calculate the total gap matrix (G).

The elements of G are found as the difference between theoretical and real evaluations. It is shown in Equation (11).

$$G = T_p - T_r = \begin{bmatrix} g_{11} & g_{12} & \dots & g_{1n} \\ g_{21} & g_{22} & \dots & g_{2n} \\ \dots & \dots & \dots & \dots \\ g_{m1} & g_{m2} & \dots & g_{mn} \end{bmatrix} = \begin{bmatrix} t_{p11} - t_{r11} & t_{p12} - t_{r12} & \dots & t_{p1n} - t_{r1n} \\ t_{p21} - t_{r21} & t_{p22} - t_{r22} & \dots & t_{p2n} - t_{r2n} \\ \dots & \dots & \dots & \dots \\ t_{pm1} - t_{rm1} & t_{pm2} - t_{rm2} & \dots & t_{pmn} - t_{rmn} \end{bmatrix} \tag{11}$$

where $g_{ij} \in \left[0, \left(t_{pij} - t_{rij}\right)\right]$. It is shown in Equation (12):

$$g_{ij} = \begin{Bmatrix} 0, & if \quad t_{pij} > t_{rij} \\ t_{pij} - t_{rij}, & if \quad t_{pij} > t_{rij} \end{Bmatrix} \tag{12}$$

If the alternative A_i for the criterion C_i has a theoretical evaluation value equal to the real evaluation value, then the gap is $g_{ij} = 0$. So, the alternative A_i for the criterion C_i is the best (ideal) alternative $\left(A_i^+\right)$.

Step 14. Calculate the final values of the criteria functions (Q_i) for the alternatives.

The values of the Q_i are obtained from the sum of gaps (g_{ij}) for the alternatives using Equation (13).

$$Q_i = \sum_{j=1}^{n} g_{ij}, \quad i = 1, 2, \dots, m \tag{13}$$

MC-HFLTS & MAIRCA method was used for application of underground waste container location selection and comparison analysis was performed with MC-HFLTS & MABAC method. MABAC method steps are given in Figure 2 (Pamučar and Ćirović, 2015). Comparison analysis was performed using this integrated method. MABAC method determines the ideal and anti-ideal distances to the respective regions. The alternative with the greatest sum of its distances to the values that correspond to the ideal region is selected.

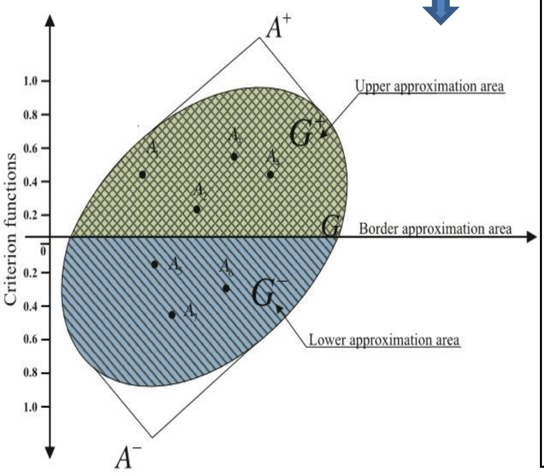
STAGE OF THE APPLICATION STUDY

Stage 1. Determination of Decision-Makers, Alternatives and Criteria

Stage 2. Determination of Criteria Weights by the MC-HFLTS Method

Stage 3. Ranking Alternatives by the MAIRCA Method

Stage 4. Comparative Analysis with the MABAC Method



Steps of the MABAC Method for comparative analysis (Pamučar & Ćirović, 2015)

Step 15: Create a normalized decision matrix.

$$n_{ij} = \frac{x_{ij} - x^{-}_{i}}{x^{+}_{i} - x^{-}_{i}}, \quad n_{ij} = \frac{x_{ij} - x^{+}_{i}}{x^{-}_{i} - x^{+}_{i}} \tag{14-15}$$

Step 16: Create a weighted decision matrix using criteria weights obtained from HFLTS.

$$v_{ij} = w_i \left(n_{ij} + 1 \right) \tag{16}$$

Step 17: Create a boundary similarity area matrix (G)

$$g_i = \left(\prod_{j=1}^{m} v_{ij} \right)^{1/m} \qquad G = \begin{matrix} C_1 & C_2 & \dots & C_n \\ [g_1 & g_2 & \dots & g_n] \end{matrix} \tag{17-18}$$

Step 18: Determine the distance of the alternatives from the boundary similarity area for matrix elements

$$Q = V - G = \begin{bmatrix} v_{11} - g_1 & v_{12} - g_2 & \dots & v_{1n} - g_n \\ v_{21} - g_1 & v_{22} - g_2 & \dots & v_{2n} - g_n \\ \dots & \dots & \dots & \dots \\ v_{m1} - g_1 & v_{m2} - g_2 & \dots & v_{mn} - g_n \end{bmatrix} = \begin{bmatrix} q_{11} & q_{12} & \dots & q_{1n} \\ q_{21} & q_{22} & \dots & q_{2n} \\ \dots & \dots & \dots & \dots \\ q_{m1} & q_{m2} & \dots & q_{mn} \end{bmatrix} \tag{19}$$

Step 19: Calculate the criteria function values of the alternatives and list the alternatives.

$$S_i = \sum_{j=1}^{n} q_{ij}, \quad j = 1, 2, ..., n, \quad i = 1, 2, \dots, m \tag{20}$$

Figure 2. Steps of MABAC method for comparative analysis

4. Application

The underground waste container system is an important part of the work that facilitates human life with innovative and contemporary solutions. Underground waste containers resemble an iceberg. Since the reservoir, in which the waste is collected, remains underground, this system eliminating image and environmental pollution is an important advantage, especially in areas where pedestrian and vehicle traffic is dense. The use of underground waste container systems, which is the most healthy and modern method of collecting waste, is increasing day by day. Because of these advantages, the Metropolitan Municipality Environmental Protection and Control Unit is increasing the installation of underground waste containers day by day. However, this study was conducted in order to provide benefit to the decision makers in determining which regions have priority in the installation of these containers.

In this context, districts where underground waste containers would be placed first in Erzurum province of Turkey, then neighborhoods were prioritized by using MC-HFLTS and MAIRCA among MCDM methods. MC-HFLTS method, which presents a flexible and rich linguistic term set to decision-maker while he/she is analyzing the study, is used to determine the criteria weights. MAIRCA method, which determines the best alternative by measuring the gap value between the theoretical evaluation and the real evaluation value, was used to sort the alternatives.

Stage 1: In this study, 3 decision-makers (from Metropolitan Municipality Environmental Protection and Control Unit), 5 criteria which are shown in Figure 3 and, 3 alternative districts (Aziziye (A_1), Palandöken (A_2), Yakutiye (A_3)) for underground waste containers were defined. These districts are the central districts of Erzurum.

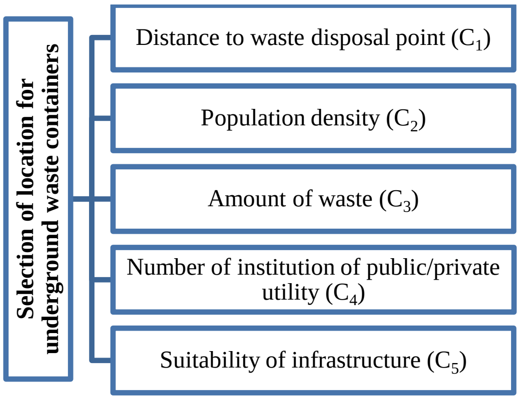


Figure 3. The hierarchy of criteria for location selection of underground waste containers

Stage 2: Firstly, data were collected, then an integrated MC-HFLTS method stages were implemented. Step 1 and Step 2 are described as in the method.

Step 3: Matrices were created by the views of DMs received. These are shown in Tables 2, 3 and 4.

Table 2. Preference relations of DM_1 for criteria

DM_1	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**
C_1	-	Betw. vli and li	At most vli	At most vli	ni
C_2	Betw. hi and vhi	-	li	At least mi	li
C_3	At least vhi	hi	-	hi	Betw. li and mi
C_4	At least vhi	At most mi	li	-	li
C_5	ai	hi	Betw. mi and hi	hi	-

Table 3. Preference relations of DM_2 for criteria

DM_2	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**
C_1	-	vli	At most vli	li	Betw. ni and vli
C_2	vhi	-	mi	mi	At most mi
C_3	At least vhi	mi	-	At least mi	Betw. li and mi
C_4	hi	mi	At most mi	-	li
C_5	Betw. vhi and ai	At least mi	Betw. mi and hi	hi	-

Table 4. Preference relations of DM_3 for criteria

DM_3	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**
C_1	-	Betw. li and mi	vli	Betw. vli and li	Betw. li and mi
C_2	Betw. mi and hi	-	mi	mi	Betw. mi and hi
C_3	vhi	mi	-	mi	Betw. li and mi
C_4	Betw. hi and vhi	mi	mi	-	mi
C_5	Betw. mi and hi	Betw. li and mi	Betw. mi and hi	mi	-

Step 4: For each HFLTS, the envelope is obtained $[p^{k-}_{ij}, p^{k+}_{ij}]$ (Table 6, 7 and 8). The scale for the linguistic terms is given in Table 5.

Table 5. The scale for the linguistic terms

ni	vli	li	mi	hi	vhi	ai
0	1	2	3	4	5	6

Table 6. The envelopes obtained for HFLTSs by DM_1

DM_1	C_1	C_2	C_3	C_4	C_5
C_1	-	(vli, li)	(ni, vli)	(ni, vli)	(ni, ni)
C_2	(hi, vhi)	-	(li, li)	(mi, ai)	(li, li)
C_3	(vhi, ai)	(hi, hi)	-	(hi, hi)	(li, mi)
C_4	(vhi, ai)	(ni, mi)	(li, li)	-	(li, li)
C_5	(ai, ai)	(hi, hi)	(mi, hi)	(hi, hi)	-

Table 7. The envelopes obtained for HFLTSs by DM_2

DM_2	C_1	C_2	C_3	C_4	C_5
C_1	-	(vli, vli)	(ni, vli)	(li, li)	(ni, vli)
C_2	(vhi, vhi)	-	(mi, mi)	(mi, mi)	(mi, mi)
C_3	(vhi, ai)	(mi, mi)	-	(mi, ai)	(li, mi)
C_4	(hi, hi)	(mi, mi)	(ni, mi)	-	(li, li)
C_5	(vhi, ai)	(mi, ai)	(mi, hi)	(hi, hi)	-

Table 8. The envelopes obtained for HFLTSs by DM_3

DM_3	C_1	C_2	C_3	C_4	C_5
C_1	-	(li, mi)	(vli, li)	(vli, li)	(li, mi)
C_2	(mi, hi)	-	(mi, mi)	(mi, mi)	(mi, hi)
C_3	(vhi, vhi)	(mi, mi)	-	(mi, mi)	(li, mi)
C_4	(hi, vhi)	(mi, mi)	(mi, mi)	-	(mi, mi)
C_5	(mi, hi)	(li, mi)	(mi, hi)	(mi, mi)	-

Step 5: Obeying the rounding rules in Equation 4 and 5 and using the arithmetic mean operator given in Equation 3, decision makers' views on the criteria are combined, and pessimistic and optimistic preferences are obtained (Table 9-10).

Table 9. Pessimistic collective preferences for criteria

DM_1	C_1	C_2	C_3	C_4	C_5
C_1	-	(vli, +0.33)	(ni, +0.33)	(vli, 0)	(vli, -0.33)

C_2	(hi, 0)	-	(mi, -0.33)	(mi, 0)	(mi, -0.33)
C_3	(vhi, 0)	(mi, +0.33)	-	(mi, +0.33)	(li, 0)
C_4	(hi, +0.33)	(li, 0)	(li, -0.33)	-	(li, +0.33)
C_5	(vhi, -0.33)	(mi, 0)	(mi, 0)	(hi, -0.33)	-

Table 10. Optimistic collective preferences for criteria

DM_1	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**
C_1	-	(li, 0)	(vli, +0.33)	(li, -0.33)	(vli, +0.33)
C_2	(vhi, -0.33)	-	(mi, -0.33)	(hi, 0)	(mi, 0)
C_3	(ai, -0.33)	(mi, +0.33)	-	(hi, +0.33)	(mi, 0)
C_4	(vhi, 0)	(mi, 0)	(mi, -0.33)	-	(li, +0.33)
C_5	(vhi, +0.33)	(hi, +0.33)	(hi, 0)	(hi, -0.33)	-

Step 6-7-8: Collective optimistic and pessimistic preferences for each criterion were obtained by linguistic aggregation operator λ Then, the preference interval-valued obtained in terms of linguistics was given in numerical values (Table 11). The midpoint of the range values was found, and then the weight values were obtained by normalizing the values (Table 11).

Table 11. Linguistic intervals and weights for the criteria

Criteria	**Linguistic Intervals**	**Midpoints**	**Weights**
C_1	[(vli, -0.175), (li, -0.4175)]	1.2038	0.0794
C_2	[(mi, +0.085), (hi, -0.415)]	3.3350	0.2200
C_3	[(mi, +0.415), (hi, +0.0825)]	3.7488	0.2472
C_4	[(mi, -0.4175), (mi, +0.25)]	2.9163	0.1923
C_5	[(hi, -0.415), (hi, +0.3325)]	3.9588	0.2611

According to the results obtained, the most important criterion was determined as Suitability of infrastructure (C_5), Amount of waste (C_3), and Population density (C_2), Number of the institution of public/private utility (C_4) and Distance to waste disposal point (C_1), respectively.

Stage 3: At this stage, alternatives were evaluated using MAIRCA method. In applying MAIRCA method, the criteria weights which are calculated by MC-HFLTS are used.

Step 9: For the evaluation of the alternatives, the linguistic and numerical scale given in Table 12 are used and the matrix of paired comparison was formed (Table 13). The values of the criteria are defined as the initial decision matrix for alternatives.

Table 12. The scale for the alternative assessment

Very poor (VP)	**Poor (P)**	**Med. Poor (MP)**	**Fair (F)**	**Med. Good (MG)**	**Good (G)**	**Very Good (VG)**
0	1	2	3	4	5	6

Table 13. Linguistic assessment of DMs

DM1	**C1**	**C2**	**C3**	**C4**	**C5**
A1	VG	MP	G	G	MG
A2	MG	VG	F	MG	F
A3	MG	VG	MG	VG	G
DM2	**C1**	**C2**	**C3**	**C4**	**C5**
A1	VG	MP	VG	MG	G
A2	MG	G	MG	F	MG
A3	MG	VG	G	G	G
DM3	**C1**	**C2**	**C3**	**C4**	**C5**
A1	VG	MP	G	G	MG
A2	MG	G	F	MG	MG
A3	MG	VG	MG	VG	VG

Linguistic terms in the matrix given in Table 13 are written in numerical values and the calculations are made. DMs' opinions are combined using Arithmetic aggregation operator and the evaluation matrix in Table 14 are eventually formed.

Step 10: After the creation of the initial decision matrix, the choices of the alternative is found by using Equation (7);

$$P_{A_i} = \frac{1}{m} = \frac{1}{3} = 0.3300 \tag{14}$$

Table 14. Aggregated evaluation matrix

Alt/Cri.	**C1**	**C2**	**C3**	**C4**	**C5**
A1	6,0000	2,0000	5,3333	4,6667	4,3333
A2	4,0000	5,3333	3,3333	3,6667	3,6667
A3	4,0000	6,0000	4,3333	5,6667	5,3333
Xi-	**4,0000**	**2,0000**	**3,3333**	**3,6667**	**3,6667**
Xi+	**6,0000**	**6,0000**	**5,3333**	**5,6667**	**5,3333**

Step 11: The calculation T_p matrix elements which are shown in Table 15 is performed according to Equation (8).

$$t_{p11} = P_{A_1} . w_1 = 0.3300 x 0.0794 = 0.0265 \tag{15}$$

Table 15. Matrix of the found theoretical assessment

Alt/Cri.	**C1**	**C2**	**C3**	**C4**	**C5**
A1	0.0265	0.0733	0.0824	0.0641	0.0870
A2	0.0265	0.0733	0.0824	0.0641	0.0870

A_3	0.0265	0.0733	0.0824	0.0641	0.0870

Step 12: The matrix elements of the real assessment (T_r) were found and these elements were shown in Table 16. They are found by multiplying matrix T_p with normalized elements of the initial matrix which presented in Table 14. Elements' normalization is completed by using Eq. (9) (for others) and Eq. (10) (only C_1).

Table 16. Matrix of the found real assessment

Alt/Cri.	C_1	C_2	C_3	C_4	C_5
A_1	0.0000	0.0000	0.0824	0.0321	0.0348
A_2	0.0265	0.0611	0.0000	0.0000	0.0000
A_3	0.0265	0.0733	0.0412	0.0641	0.0870

Step 13: The total gap matrix elements were found using Eq. (11) and these elements were presented in Table 17.

Table 17. The total gap matrix

Alt/Cri.	C_1	C_2	C_3	C_4	C_5
A_1	0.0265	0.0733	0.0000	0.0321	0.0522
A_2	0.0000	0.0122	0.0824	0.0641	0.0870
A_3	0.0000	0.0000	0.0412	0.0000	0.0000

Step 14: The difference between the theoretical and real evaluations is the smallest alternative (i.e. the value of the gap value nearest to zero) is chosen as the best alternative. By using Eq. 13, the gap values $\left(Q_i\right)$ for the alternatives were calculated and these values are shown in Table 18.

Table 18. Alternative ranking according to MAIRCA method

Alternatives	Q_i	Rank
A_1	0.1841	2
A_2	0.2458	3
A_3	0.0412	1

A_3 having the lowest gap value is the best alternative. The alternative order is as follows: $A_3 > A_1 > A_2$. According to the results obtained in the calculation, the first location for underground waste containers is the district of Yakutiye (A_3). Yakutiye District has eight neighborhoods with more than 10.000 population. These are "Kazım Karabekir Paşa (B_1), Kurtuluş (B_2), Lalapaşa (B_3), Muratpaşa (B_4), Ömer Nasuhi Bilmen (B_5), Rabia Ana (B_6), Şükrüpaşa (B_7) and Üniversite (B_8)" neighborhoods. The hierarchy of location selection for underground waste containers (for neighborhoods) is shown in Figure 4.

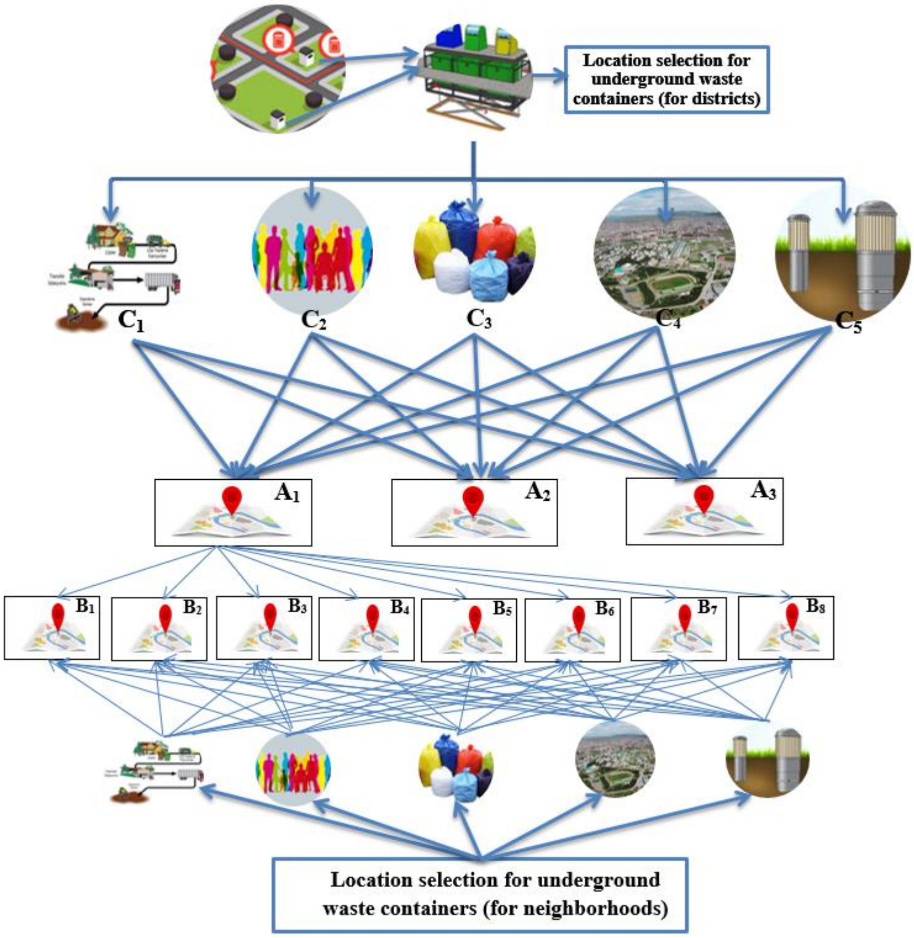


Figure 4. The hierarchy of location selection for underground waste containers (for neighborhoods)

According to five criteria, these eight alternatives are evaluated by applying MAIRCA method steps. The ranking of alternatives is obtained as Table 19.

Table 19. Alternative ranking according to MAIRCA method

Alternatives	Q_i	**Ranking**
B_1	0.1094	8
B_2	0.0644	4
B_3	0.0327	1
B_4	0.1014	7
B_5	0.0837	5
B_6	0.0915	6
B_7	0.0371	2
B_8	0.0434	3

The alternative order is as follows: $B_3 > B_7 > B_8 > B_2 > B_5 > B_6 > B_4 > B_1$. According to the results obtained in the calculation, the first location for underground waste containers is the neighborhood of Lalapaşa (B_3). The important second and third places were Şükrüpaşa and University neighborhoods.

5. Comparison Analysis

The comparison analysis is performed using MABAC method in this section. MAIRCA and MABAC methods are novel methods in comparison to other MCDM methods. Both methods also have similar working principles. MAIRCA method determines the difference between the ideal weight and the empirical weight. The value where this value is minimal is selected as the best one, while MABAC method determines the ideal and anti-ideal distances to the respective regions. The alternative with the greatest sum of its distances to the values that correspond to the ideal region is selected. This is why these methods were used in this study for these two methods in order to measure the proximity and/or distance to the ideal. In the following, the location prioritization application by MABAC method is shown in detail.

Step 15. The normalized decision matrix given in Table 20 was obtained by the normalization of the combined decision matrix values in Table 14 using Equation 14 and 15.

Table 20. Normalization decision matrix

Alt/Cri.	C_1	C_2	C_3	C_4	C_5
A_1	0,000	0,000	1,000	0,500	0,400
A_2	1,000	0,833	0,000	0,000	0,000
A_3	1,000	1,000	0,500	1,000	1,000

Step 16. Weighted decision matrix using Equation 16 and criterion weights obtained from HFLTS are created as in Table 21.

Table 21. Weighted decision matrix

Alt/Cri.	C_1	C_2	C_3	C_4	C_5
A_1	0,079	0,220	0,494	0,288	0,366
A_2	0,159	0,403	0,247	0,192	0,261
A_3	0,159	0,440	0,371	0,385	0,522

Step 17. The boundary similarity area matrix (G) was created using Equations 17 and 18 (Table 22).

Table 22. Weighted decision matrix

Criteria	C_1	C_2	C_3	C_4	C_5
G	0,126	0,339	0,357	0,277	0,368

Step 18-19. For matrix elements, the distances of alternatives from the boundary similarity area were determined using Equation 19. The criteria function values of the alternatives were calculated using Equation 20 and the alternative ranking was obtained (Table 23).

Table 23. Alternative ranking according to MABAC method

Alt/Cri.	C_1	C_2	C_3	C_4	C_5	Q_i	Ranking
A_1	-0,047	-0,119	0,138	0,011	-0,002	-0,019	2
A_2	0,033	0,064	-0,109	-0,085	-0,107	-0,204	3
A_3	0,033	0,101	0,014	0,107	0,154	0,409	1

MABAC method steps in Figure 2 were repeated to prioritize districts. Alternative ranking according to the MABAC method for the neighborhood is shown in Table 24.

Table 24. Alternative ranking according to the MABAC method

Alternatives	Q_i	**Ranking**
B_1	-0.2732	8
B_2	0.0867	4
B_3	0.3404	1
B_4	-0.2097	7
B_5	-0.0679	5
B_6	-0.1301	6
B_7	0.3051	2
B_8	0.2549	3

In the methods (MC-HFLTS&MAIRCA and MC-HFLTS&MABAC), A_3 and B_3 alternatives are the best one and the ranking of location for underground waste containers is the same.

6. Conclusions and Discussion

The determination of the location of underground waste containers is an important decision-making problem since it contains more than one contradictory criterion. In this context, districts where underground waste containers would be placed first, then neighborhoods in the province of Erzurum, were prioritized by using Multi-Criteria Hesitant Fuzzy Linguistic Term Set (MC-HFLTS) and Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA) among Multiple Criteria Decision-Making methods. Moreover, a comparative analysis was performed by using the MABAC method in order to test the consistency of the results and the reliability of the method.

MC-HFLTS includes a free set of terms, which allows the decision-maker to provide flexibility and richness in expressing his thinking, while at the same time allowing him to respond appropriately to his hesitant nature, i.e. to increase consistency. This hesitancy, which decision-makers often face, is handled by a context-free grammar. This provides a practical approach, which efficiently aggregates the decision-makers' linguistic assessments without losing any information in experts' evaluations.

Conventional waste containers used in the above-mentioned areas cause negativities such as visual pollution, the risk of infection from insects and leaking water, unpleasant smell spreading around, wastes spreading around due to less capacity and lack of capacity, etc. Therefore, underground waste containers are more superior than conventional waste containers with underground waste containers in terms of having more advantages such as more regular and clean appearance, less insect and infection risk, less unpleasant smell and more capacity. For these reasons, conventional waste containers are replaced by underground waste containers. In this case, the question which region primarily needs underground waste containers arises. In order to find an answer to this question, decision-making methods were used, 3 central districts and neighborhoods with the highest population in Erzurum were considered in this study and the locations where the containers would be placed were prioritized.

It may be said that this study differs from other studies. As a result of the literature review, there was no study about the location selection for underground waste containers. This study is original in terms of this case and the integrated methods used.

In future studies, it is thought that location for underground waste containers will be evaluated by using other MCDM methods. In addition, the number of alternative/criterion can be increased. On the other hand, after the underground garbage containers are placed in the selected places, the distances from these points to the waste disposal point can be considered as a routing problem.

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