Environmental Science and Pollution Research (2021) 28:17431–17444
https://doi.org/10.1007/s11356-020-12080-5

RESEARCH ARTICLE

Site selection for waste vegetable oil and waste battery collection boxes: a GIS-based hybrid hesitant fuzzy decision-making approach

Aslı Çalış Boyacı[1] · Aziz Şişman[2] · Köksal Sarıcaoğlu[3]

Received: 21 April 2020 / Accepted: 14 December 2020 / Published online: 4 January 2021

Abstract
The amount of municipal solid waste (MSW) has been increasing rapidly in the urban centres of developing countries during the last few decades; however, municipal solid waste management (MSWM) remains inadequate. One of the largest aspects of cost of the MSWM system is the collection of waste. This paper describes a methodology that combines geographic information systems (GIS), hesitant fuzzy linguistic term set (HFLTS), and the full multiplicative form of multi-objective optimization by ratio analysis (MULTIMOORA), to determine suitable locations for waste collection boxes (named AYPIKUT), which have been designed specifically for collection of domestic waste vegetable oil and waste batteries. It takes as case study, Atakum, a district of Samsun city, Turkey. As a solution to the problem, first, a total of 88 items have been identified for consideration by seven criteria elicited from the insights of experts, and spatial analyses were performed. Multi-criteria HFLTS was then used to determine weights of the criteria. Population density was the most significant criterion affecting the selection process, and proximity to housing complexes with more than 150 dwellings was the least important. According to the weights of the seven criteria, and three rules determined by the experts, 15 AYPIKUT locations were identified using GIS. As a final step, the alternative locations (A1–A15) were ranked with the MULTIMOORA method. A5 was the most suitable site, and A6 was the least suitable site for an AYPIKUT. The results indicated the ability of the proposed model to select the suitable locations for waste collection box.

Keywords Geographic information system (GIS) · HFLTS · MULTIMOORA · Municipal solid waste (MSW) · Site selection · Waste collection

Introduction

The population growth and rapid urbanization that have resulted from technological development and industrialization are increasing human activities all over the world (Ripa et al. 2017). In this process, the waste generated with the increasing consumption is threatening the environment and human health due to the amount and harmful content. According to the World Bank, as a result of the population growth, generation of municipal waste is expected to reach 2.2 billion tons worldwide by 2025. Managing waste is essential to create sustainable and liveable cities in the world (Özkan et al. 2019).

The amount of municipal solid waste (MSW), which typically includes household, garden/park, and commercial/industrial waste, has been increasing rapidly in urban centres of developing countries during the last few decades (Ripa et al. 2017; Rupani et al. 2019); however, municipal solid waste management (MSWM) remains inadequate (Henry et al. 2006; Zhang et al. 2010; Rupani et al. 2019). Landfill remains the main approach in many countries, for example, Chinese MSWM is 60.16% (Mian et al. 2017). In Iran, which is one of the countries where an effective waste management approach is lacking, the main method for the final waste disposal is the use of landfill, which is mostly carried out not in accordance with the environmental regulations (Rupani et al. 2019). Indian MSWM focuses on collection services rather than scientific treatment and disposal (Priti and Mandal 2019). MSWM is a significant item in the municipal budget, and approximately 65% to 80% of cost is spent on the collection and transportation of solid waste (Rızvanoğlu et al. 2020). The first condition for economic recovery from solid waste is separate collection, with

Responsible editor: Philippe Garrigues

✉ Aslı Çalış Boyacı
asli.calis@omu.edu.tr

[1] Department of Industrial Engineering, Ondokuz Mayıs University, 55139 Samsun, Turkey

[2] Department of Geomatics Engineering, Ondokuz Mayıs University, 55139 Samsun, Turkey

[3] İlkadım Municipality, Samsun, Turkey

the primary approach using individual collection boxes (Terazono et al. 2015; Pham Phu et al. 2019). Collection points can be created with collection boxes that ensure the separation of waste at source, and waste can be controlled within the framework of sustainable development principles. In Turkey, where the average amount of municipal waste per capita is 1.16 (kg/day), and the total amount of MSW collected by municipalities was 32.2 million tons in 2018 (TSI 2019), collection boxes for waste oil, especially domestic vegetable waste oil, and collection boxes of waste batteries are widely used within the MSWM system. In this context, in Turkey, the 'Regulation on the Control of Waste Vegetable Oil' was published in April 2005, and the 'Regulation on the Control of Waste Batteries and Accumulators' was published in August 2004 (TCA 2007).

For the first time in Turkey, a collection box was designed by the İlkadım District Municipality in Samsun in 2018 as part of a zero waste project, to collect domestic waste vegetable oil and waste batteries simultaneously. This waste vegetable oil and waste battery collection box was called an 'AYPIKUT', consisted of two parts (Fig. 1). Waste vegetable oil was collected in two ways, either poured directly into a vessel within the collection box (made to look like a vegetable oil bottle to attract attention) or left in a container, such as a glass or plastic bottles, that was deposited in the collection box. Waste batteries were collected in a part of the collection box that was designed to look like a battery, also in order to attract attention. The study was aimed to determine suitable locations for AYPIKUT in Atakum. Atakum is a district of Samsun located on the Black Sea coast of Turkey, with a population of 215,633 in 2019. Atakum has the highest population growth rate in Samsun city, with an annual growth of 6.4% for the last 5 years; 10,607 dwellings were sold in Atakum district in 2019. It was listed as the 23rd district in the most residential sales ranking among 923 districts of Turkey in 2019 (TSI 2020; GDLRC 2020). There has been a commensurate increase in municipal waste. This paper develops an analytical tool for use by local government that combines geographic information systems (GIS), multi-criteria hesitant fuzzy linguistic term set (multi-criteria HFLTS), and the full multiplicative form of multi-objective optimization by ratio analysis (MULTIMOORA), to determine suitable locations for AYPIKUT in Atakum. GIS can be considered an effective method to analyse spatial data in many areas of application, including various aspects of waste management (Rızvanoğlu et al. 2020). Multi-criteria decision-making (MCDM) approaches provide robustness and flexibility to address comparison problems involving multiple and varied units of measurement (Çalış Boyacı 2020). A combined GIS-MCDM method affords a practical approach that can manage time and costs whilst reducing errors and increasing the efficiency of the decision-making process (Eghtesadifard et al. 2020). Moreover combining MCDM methods and fuzzy sets provides a more accurate and systematic assessment. Decision-makers may have problems in identifying linguistic terms and may need flexibility in their evaluations. This challenge is overcome by the multi-criteria HFLTS method, ensuring that linguistic evaluations obtained from experts are effectively preserved without any loss of knowledge.

In the literature, most studies using GIS for MSW consider the landfill site selection (Sumathi et al. 2008; Guiqin et al. 2009; Şener et al. 2010; Nas et al. 2010; Gorsevski et al. 2012; Eskandari et al. 2015; Bahrani et al. 2016; Jamshidi-Zanjani and Rezaei 2017; Khodaparast et al. 2018; Kapilan and Elangovan 2018; Kamdar et al. 2019; Barzehkar et al. 2019; Aksoy and San 2019; Karimi et al. 2019; Eghtesadifard et al. 2020; Rezaeisabzevar et al. 2020; Rahimi et al. 2020). Some studies consider the optimization of the collection and transportation of MSW. For example, Kanchanabhan et al. (2010) developed a design for MSW collection using GIS including a vehicle tracking system, Kallel et al. (2016) developed optimized scenarios using GIS in order to improve the efficiency of waste collection and transportation, and Nguyen-Trong et al. (2017) proposed a model for optimizing MSW collection. Lella et al. (2017) presented methods for optimal collection and transportation of MSW using GIS techniques through network analysis. Amal et al. (2018) proposed spatial GIS-based genetic algorithm to optimize the route of solid waste collection. Rızvanoğlu et al. (2020) used linear programming and GIS to develop an optimal routing schedule for MSW collection and transportation. However, there are few studies on the selection of the sites for MSW collection boxes. Vijay et al. (2008) presented a GIS-based analysis of the location of collection bins in MSWM systems using *p*-median constrained model. Chalkias and Lasaridi (2009) developed a methodology for the reallocation of waste collection bins, making use of the GIS spatial

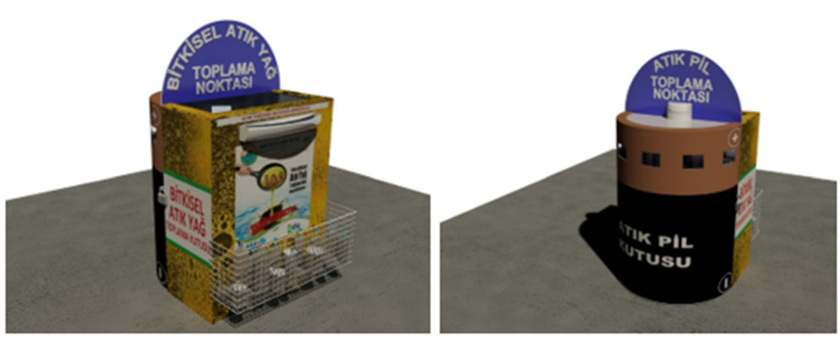


Fig. 1 The frontal and back views of the waste collection box (AYPIKUT)

analysis functions. Khan and Samadder (2016) presented a suitable solid waste collection bin allocation method based on GIS technology.

The HFLTS method has been applied in several areas, such as supplier selection (Liu and Rodríguez 2014; Fahmi et al. 2016), performance evaluation (Tüysüz and Şimşek 2017), service provider selection (Wei et al. 2015; Ghadikolaei et al. 2018), web tool development (Montes et al. 2015), technology selection (Wei and Liao 2016; Khishtandar et al. 2017), healthcare risk analysis (Liu et al. 2016), facility location selection (Feng et al. 2018), eco-friendly city selection (Çalış Boyacı 2020), and website evaluation (Özkan et al. 2020). The MULTIMOORA method also has wide applicability, such as personnel selection (Baležentis et al. 2012; Baležentis and Zeng 2013), industrial robot selection (Datta et al. 2013), evaluation of excavator technologies (Altuntaş et al. 2015), materials selection (Hafezalkotob and Hafezalkotob 2015), evaluation of bike-share stations (Kabak et al. 2018), and evaluation of smart bike-sharing programs (Tian et al. 2018), technological forecasting method selection (Dahooie et al. 2019), and landfill site selection (Rahimi et al. 2020). A summary of GIS-based MCDM studies is presented in Table 1. This shows that no GIS-based MCDM studies combine GIS, the multi-criteria HFLTS, and MULTIMOORA methods. This study fills this gap.

Methodology

This study proposes a methodology that combines GIS, multi-criteria HFLTS, and MULTIMOORA for evaluating the locations suitable for AYPIKUT. These three methods are explained, and the flow chart of the proposed method is given in this section.

Geographic information systems

Spatial data is one of the most important data types to provide understanding of the world. The GIS allows query, analysis, and display of spatial data. GIS has been defined in several ways. An early definition of a GIS was a tool using collecting, querying, analysing, transferring, storing, and displaying the data of the earth for a specific purpose (Burrough and McDonnell 1998). One of the more common uses of GIS is as an aid in decision problems involving multi-attribute or multi-objective land use allocation (Cromley and Hanink 2003).

Multi-criteria HFLTS method

Fuzzy logic and fuzzy set theory successfully deal with uncertain knowledge. However, when two or more sources of uncertainty occur simultaneously, the fuzzy sets remain limited (Rodríguez et al. 2012). Hesitant fuzzy sets, which can solve the difficulties in determining the membership degree of an element, are a generalization of fuzzy sets that permits us to represent the situation in which different membership functions are considered possible (Torra 2010). In the classical fuzzy linguistic approaches, a single expression which limits the experts should be selected. However, experts may hesitate to select the appropriate linguistic expression (Onar et al. 2016). Experts can use HFLTS when they hesitate between several linguistic expressions (Rodríguez et al. 2013).

A hesitant linguistic group decision-making model with a single criterion was suggested by Rodríguez et al. (2013). On the basis of this model, experts assess the alternatives based on a single criterion. Yavuz et al. (2015) extended this algorithm to take into account a multi-criteria decision-making problem, and the steps of the suggested algorithm are as follows:

Step 1. Define the semantics and syntax of the linguistic term set S. A set of seven terms, S, could be given by Eq. (1) (Rodríguez et al. 2013):

$$S = \left\{ \begin{array}{l} \text{no importance}(n), \text{very low importance}(vl), \\ \text{low importance}(l), \text{medium importance}(m), \\ \text{high importance}(h), \\ \text{very high importance}(vh), \\ \text{absolute importance}(a) \end{array} \right\} \quad (1)$$

Step 2. Define the context-free grammar G_H, where $G_H = \{V_N, V_T, I, P\}$. V_N is the set of nonterminal symbols, V_T is the set of terminals' symbols, I is the starting symbol, and P is the production rules that are defined in an extended Backus–Naur form (Rodríguez et al. 2012).

Step 3. Gather the preference relations p^k given by experts $k \in \{1, 2, \ldots, m\}$ for both criteria and alternatives.

Step 4. Transform the preference relations into HFLTS using E_{G_H} function.

Step 5. Obtain envelopes $\left[p_{ij}^{k-}, p_{ij}^{k+}\right]$ for each HFLTS.

Step 6. Select a linguistic aggregation operator φ and obtain the pessimistic and optimistic collective preference relations (P_C^-, P_C^+). The arithmetic mean given in Eq. (2) is used for φ:

$$\bar{x} = \Delta\left(\frac{1}{n}\sum_{i=1}^{n}\Delta^{-1}(s_i, \alpha_i)\right) = \Delta\left(\frac{1}{n}\sum_{i=1}^{n}\beta_i\right) \quad (2)$$

The S related 2-tuple set is characterized as $S = [0.5, 0.5)$. The $\Delta : [0, g] \rightarrow S$ function is provided by Eq. (3).

$$\Delta(\beta) = (s_i, \alpha_i) with \left\{ \begin{array}{l} i = round(\beta) \\ \alpha = \beta - i \end{array} \right\} \quad (3)$$

where round assigns to β the integer number $i \in \{0, 1, \ldots, g\}$ nearest to β and $\Delta^{-1} : \langle S \rangle \rightarrow [0, g]$ is specified by Eq. (4).

$$\Delta^{-1}(s_i, \alpha_i) = i + \alpha \quad (4)$$

Step 7. Compute the pessimistic and optimistic collective preferences for the alternatives by φ.

Table 1 Review of GIS-based MCDM studies in the literature

Author(s)	Method(s) used	Problem	Application region
Phua and Minowa (2005)	GIS, AHP	Forest conservation planning	Malaysia
Chang et al. (2008)	GIS, FMCDM	Landfill site selection	USA
Chen et al. (2010)	GIS, AHP	Land suitability assessment	Australia
Tavares et al. (2011)	GIS, AHP	Site selection for a solid waste incineration plant	Cape Verde
Othman et al. (2012)	GIS, AHP	Landslide hazard zonation mapping	Malaysia
Sánchez-Lozano et al. (2013)	GIS, AHP, TOPSIS	Evaluation of solar farms locations	Spain
Afzali et al. (2014)	GIS, ANP	Landfill site selection	Iran
Atici et al. (2015)	GIS, ELECTRE III, ELECTRE-TRI, SMAA-TRI	Wind power plant site selection	Turkey
Sánchez-Lozano et al. (2016a)	GIS, AHP, TOPSIS, ELECTRE TRI	Selection of photovoltaic solar farms sites	Spain
Sánchez-Lozano et al. (2016b)	GIS, FAHP, FTOPSIS	Wind farm site selection	Spain
Hariz et al. (2017)	GIS, AHP, VIKOR, PROMETHEE II	Site selection for healthcare waste incinerator	Kenya
Qiu et al. (2017)	GIS, AHP, WLC, OWA	Evaluation of land use suitability for livestock production	China
Sánchez-Lozano and Bernal-Conesa (2017)	GIS, AHP, TOPSIS	Evaluation of Natura 2000 network areas	Spain
Singh et al. (2017)	GIS, AHP	Determination of potential zones for rainwater harvesting	India
Villacreses et al. (2017)	GIS, OWA, OCRA, VIKOR, TOPSIS	Selection of places for installing wind power plants	Ecuador
Aydi (2018)	GIS, AHP	Evaluation of groundwater vulnerability to pollution	Tunisia
Erbaş et al. (2018)	GIS, FAHP, TOPSIS	Site selection for electric vehicle charging stations	Turkey
Kabak et al. (2018)	GIS, AHP, MOORA	Evaluation of bike-share stations	Turkey
Selim et al. (2018)	GIS, AHP	Site selection for avocado cultivation	Turkey
Balta and Ülgen Yenil (2019)	GIS, AHP	Determination of sustainable and optimum greenway routes	Turkey
Feyzi et al. (2019)	GIS, FANP, DEMATEL	Site selection for solid waste incineration power plant	Iran
Kanani-Sadat et al. (2019)	GIS, Fuzzy DEMATEL, ANP	Determination of flood-prone areas	Iran
Miglietta et al. (2019)	GIS, ELECTRE III	Evaluation of olive orchard planting systems	Italy
Mokhtara et al. (2019)	GIS, AHP	Selection of plus-energy buildings areas	Algeria
Ostovari et al. (2019)	GIS, AHP	Evaluation of land suitability for rapeseed farming	Iran
Ramya and Devadas (2019)	GIS, AHP, TOPSIS	Evaluation of locations for establishing agro-based industries	India
Vaissi and Sharifi (2019)	GIS, AHP	Selection of a protected area for the Kaiser's mountain newt	Iran
Eghtesadifard et al. (2020)	GIS, MOORA, WASPAS, COPRAS	Selection of municipal solid waste landfills	Iran
Rahimi et al. (2020)	GIS, BWM, MULTIMOORA	Sustainable landfill site selection for municipal solid waste	Iran

Step 8. Build the vector of intervals $\left(V^R = \left(p_1^R, p_2^R, \ldots, p_n^R\right)\right)$ for the collective preferences $\left(p_i^R = \left[p_i^-, p_i^+\right]\right)$.

Step 9. Normalize the obtained interval utilities.

Step 10. Calculate the weighted scores.

The MULTIMOORA method

The multi-objective optimization by ratio analysis (MOORA) method was introduced by Brauers and Zavadskas (2006). Brauers and Zavadskas (2010) extended this method, and it became more robust as MULTIMOORA (MOORA plus full multiplicative form). MOORA method consists of a ratio system and a reference point approach. In addition, where the priorities of the objectives of the model differ, the significance coefficient is used. MULTIMOORA is produced by adding the full multiplicative form to MOORA. This is not an independent MCDM method; it is based on the evaluation of other MOORA techniques and the ranking of the results by dominance.

The ratio system of MOORA The ratio system starts by showing the values of different alternatives according to different objectives or criteria in the decision matrix given in Eq. (5).

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{5}$$

where $i = 1, 2, \ldots, n$; n is the number of criteria, $j = 1, 2, \ldots, m$; m is the number of alternatives, x_{ij} is the response of alternative j on criterion i, x_{ij}^* is a dimensionless number representing the response of alternative j on criterion i, and this number usually belongs to the interval [0;1]. The matrix is normalized using Eq. (6).

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}} \tag{6}$$

If the desirable value of the indicator x_{ij}^* is maximum, it is added, and if the desirable value is minimum, it is subtracted. The total assessment of each alternative is calculated using Eq. (7) in which y_j^* is the total assessment of alternative j with respect to all criteria. $i = 1, 2, \ldots, g$ is the number of criteria that are maximized, and $i = g + 1, g + 2, .., n$ is the number of criteria that are minimized.

$$y_j^* = \sum_{i=1}^{g} x_{ij}^* - \sum_{i=g+1}^{n} x_{ij}^* \tag{7}$$

In principle, the decision-makers could give more importance to some criteria. Thus they could multiply the dimensionless number with a significance coefficient (s_i) as shown in Eq. (8).

$$y_j^* = \sum_{i=1}^{g} s_i x_{ij}^* - \sum_{i=g+1}^{n} s_i x_{ij}^* \tag{8}$$

The final preference is determined by an ordinal ranking in descending order of the y_j^* (Brauers and Zavadskas 2013).

The reference point theory of MOORA In the reference point theory, in addition to the ratio system, reference point (r_i) is determined for each criterion as the maximum points if the objective is maximization and the minimum points if the objective is minimization. The distance of these determined points with each x_{ij}^* is calculated by Eq. (9).

$$r_i - x_{ij}^* \tag{9}$$

The matrix created is calculated using the min-max metric of Tchebycheff given in Eq. (10). The results are ranked in ascending order. If the decision-maker assigns the relative importance to a criterion's response on an alternative, Eq. (11) is used.

$$\min_{(j)} \left\{ \max_{(i)} \left| r_i - x_{ij}^* \right| \right\} \tag{10}$$

$$\left| s_i r_i - s_i x_{ij}^* \right| \tag{11}$$

The full multiplicative form and MULTIMOORA In the full multiplicative form, the introduction of weights is meaningless unlike the ratio method and the reference point theory of MOORA. This approach is expressed by Eqs. (12), (13), and (14):

$$U_j' = \frac{A_j}{B_j} \tag{12}$$

$$A_j = \prod_{i=1}^{g} x_{ij} \tag{13}$$

$$B_j = \prod_{i=g+1}^{n} x_{ij} \tag{14}$$

where $i = 1, 2, \ldots, n$; n is the number of criteria, $j = 1, 2, \ldots, m$; m is the number of alternatives, g is the number of criteria to be maximized, $(n - g)$ is the number of criteria to be minimized, and U_j' is the utility of alternative j with criteria to be maximized and criteria to be minimized.

The MULTIMOORA is not a stand-alone method. The MULTIMOORA performs a final evaluation based on the dominance of the rankings determined according to the ratio system, the reference point theory, and the full multiplicative form. For details on the theory of ordinal dominance, readers may refer to Brauers and Zavadskas (2013).

Proposed approach

The proposed approach is explained in detail in this subsection. The flow chart of the proposed method adopted for the selection of AYPIKUT locations is given in Fig. 2. The proposed method consists of two phases including problem definition and data collection and GIS-based multi-criteria HFLTS and MULTIMOORA model (Fig. 2).

A case study of Atakum district

Problem definition and data collection

The AYPIKUT has been designed for collection of both domestic waste vegetable oil and waste batteries. This study focuses on determining suitable locations for the AYPIKUT in Atakum using GIS-based multi-criteria HFLTS and MULTIMOORA methods. Atakum, as a district of Samsun, covers a total of 355 km^2. The eastern coastal part of the district is the most densely populated. The study area is shown in Fig. 3.

In this study, experts determined the seven most important criteria affecting the choice of location of the AYPIKUT as C_j, where C1 is to be maximized and C2–C7 are to be minimized.

- C1: Population density
- C2: Proximity to public institutions
- C3: Proximity to housing complexes with more than 150 dwellings
- C4: Proximity to shopping malls
- C5: Proximity to tram stops
- C6: Proximity to schools
- C7: Proximity to parks

A total of 88 items have been identified for consideration by these criteria: 13 public institutions and organizations, 9 housing complexes, 3 shopping malls, 20 tram stops, 32 schools, and 11 parks or green areas. The location of the 88 items was obtained using a GNSS (Global Navigation Satellite System) handheld receiver and satellite images.

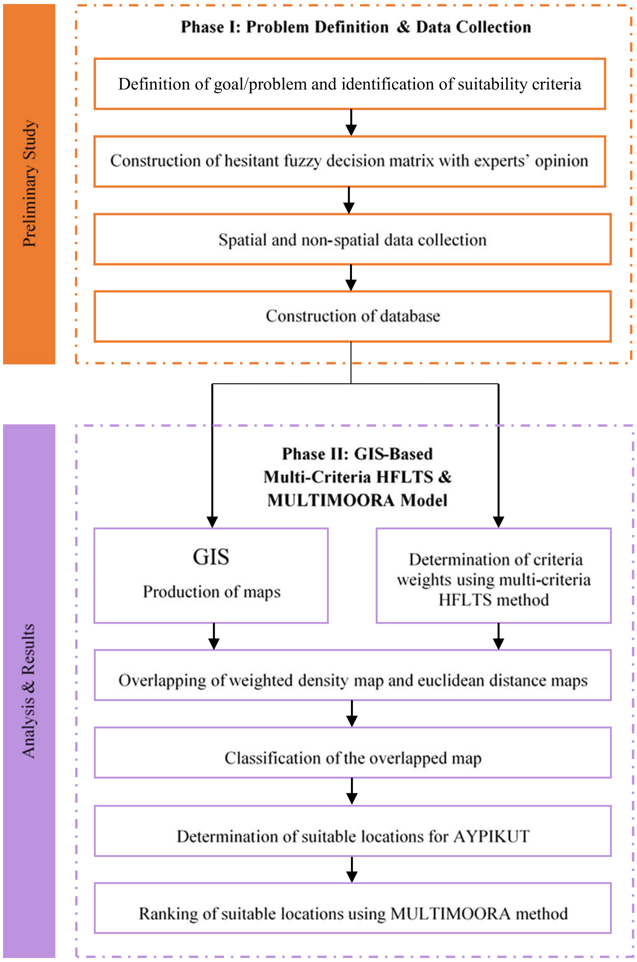


Fig. 2 The flow chart of the proposed method

Results and discussion

Production of maps

In the study, a few types of spatial analysis were done, and several types of maps were produced based on the population of 57 neighbourhoods and the location of 88 criteria. ArcGIS software was used to build the geodatabase and perform the spatial analysis for the criteria. The study used two types of spatial analysis: density analysis and distance analysis. Density analysis calculates and shows where features are concentrated, such as the population distribution in the city. Distance analysis determines the distance from the items; in this study, Euclidean distance analysis was used. The density analysis of the neighbourhoods and the Euclidean distance analysis of each criterion are presented in Fig. 4.

In Fig. 4a–g, dark zones have higher pixel value according to the results of Euclidean distance analysis and density analysis and indicate unsuitable locations depending on the purpose of the study.

Determination of the priorities of criteria

The weights of criteria were determined using the multi-criteria HFLTS method. Table 2 presents linguistic evaluations of the experts for the criteria. The comparative linguistic expressions generated by G_H were converted into HFLTS using E_{G_H} function. For instance, expert 1's preference of C1 with respect to C2 is 'greater than high importance' in linguistic terms (Table 2). This preference relation is transformed into HFLTS using E_{G_H} function, where E_{G_H} (greater than high importance) = {very high importance, absalute importance}, and it can be represented as a discrete set $\{vh, a\}$ and then as the interval $[vh, a]$. The envelopes obtained for the evaluations of three experts are presented in Table 7. In the next step, pessimistic and optimistic collective preference relations were obtained using the scale for the linguistic terms given in Table 3. In the scale, the value 0 means 'no importance', whilst the value 6 means 'absolute importance'. The pessimistic and optimistic collective preference values are presented in Tables 8 and 9, respectively. The arithmetic mean was used for the linguistic aggregation operator to obtain these collective preference relations. For

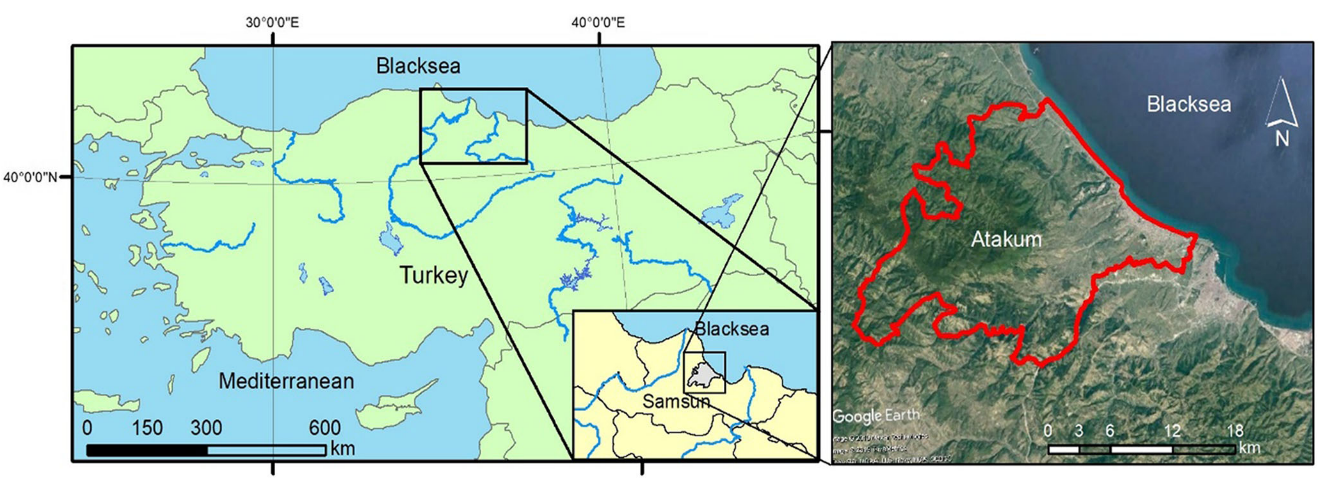


Fig. 3 The study area (Google Earth image ©)

example, the pessimistic collective preference value for C1 in relation to C2 is calculated as follows:

$$P^{-}_{C_{12}} = \Delta\left(\frac{1}{3}\left(\Delta^{-1}(vh,5) + \Delta^{-1}\left(h,4\right) + \Delta^{-1}\left(h,4\right)\right)\right)$$
$$= \Delta\left(\frac{1}{3}(5+4+4)\right) = \Delta(4.33) = (h,+0.33)$$

Similarly, the following process is performed to calculate the optimistic collective preference value for C1 with respect to C2:

$$P^{+}_{C_{12}} = \Delta\left(\frac{1}{3}\left(\Delta^{-1}(a,6) + \Delta^{-1}\left(a,6\right) + \Delta^{-1}\left(a,6\right)\right)\right)$$
$$= \Delta\left(\frac{1}{3}(6+6+6)\right) = \Delta(6) = (a,+0)$$

The weights of criteria given in Table 4 were obtained by using the values of the pessimistic and optimistic collective preferences. For example, the linguistic intervals,

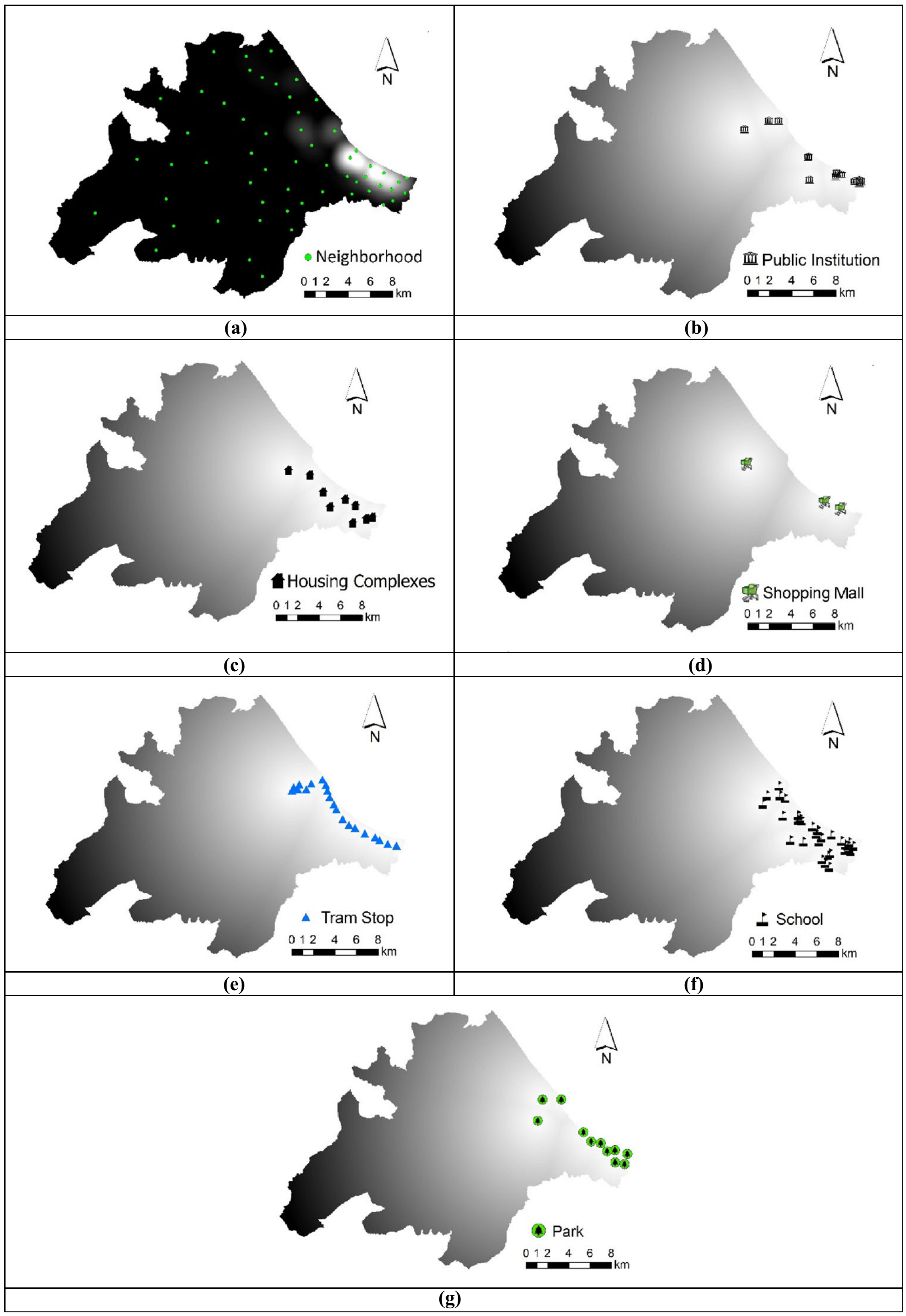


Fig. 4 GIS layer of each criterion: (**a**) population density (C1), (**b**) proximity to public institutions (C2), (**c**) proximity to housing complexes (C3), (**d**) proximity to shopping malls (C4), (**e**) proximity to tram stops (C5), (**f**) proximity to schools (C6), and (**g**) proximity to parks (C7)

Table 2 Expert evaluations for the criteria

	C1	C2	C3	C4	C5	C6	C7
Expert 1							
C1	–	Greater than *h*	Is *a*	Is *h*	Between *m* and *h*	Is *m*	Is *m*
C2	Lower than *l*	–	Is *h*	Between *vl* and *m*	At most *l*	At most *vl*	At most *vl*
C3	Is *n*	Is *l*	–	Is *l*	Is *vl*	At most *vl*	At most *vl*
C4	Is *l*	Between *m* and vh	Is *h*	–	Between *vl* and *m*	Is *l*	Is *l*
C5	Between *l* and *m*	At least *h*	Is *vh*	Between *m* and vh	–	Is *l*	Is *l*
C6	Is *m*	At least *vh*	At least *vh*	Is *h*	Is *h*	–	Is *m*
C7	Is *m*	At least *vh*	At least *vh*	Is *h*	Is *h*	Is *m*	–
Expert 2							
C1	–	At least *h*	Greater than *h*	Is *m*	At least *h*	At least *h*	Is *m*
C2	At most *l*	–	Is *vh*	Between *l* and *m*	Is *m*	Is *m*	Between *l* and *m*
C3	Lower than *l*	Is *vl*	–	At most *vl*	At most *l*	At most *l*	At most *vl*
C4	Is *m*	Between *m* and *h*	At least *vh*	–	Between *h* and *vh*	Between *h* and *vh*	Is *m*
C5	At most *l*	Is *m*	At least *h*	Between *vl* and *l*	–	Is *m*	Between *l* and *m*
C6	At most *l*	Is *m*	At least *h*	Between *vl* and *l*	Is *m*	–	Is *l*
C7	Is *m*	Between *m* and *h*	At least *vh*	Is *m*	Between *m* and *h*	Is *h*	–
Expert 3							
C1	–	At least *h*	Between *h* and *vh*	Is *a*	Is *h*	Between *h* and *vh*	At least *h*
C2	At most *l*	–	Between *l* and *m*	Is *h*	Is *l*	Is *m*	Is *m*
C3	Between *vl* and *l*	Between *m* and *h*	–	Greater than *h*	Is *l*	Is *m*	Between *h* and *vh*
C4	Is *n*	Is *l*	Lower than *l*	–	At most *l*	Between *vl* and *m*	Between *l* and *m*
C5	Is *l*	Is *h*	Is *h*	At least *h*	–	Is *h*	Is *vh*
C6	Between *vl* and *l*	Is *m*	Is *m*	Between *m* and *vh*	Is *l*	–	Is *h*
C7	At most *l*	Is *m*	Between *vl* and *l*	Between *m* and *h*	Is *vl*	Is *l*	–

interval utilities, midpoint, and weight are calculated for the first row in Table 4 as follows.

The pessimistic and optimistic collective preferences are (*h*,+ 0.06) and (*vh*,− 0.11) for C1. These preferences are expressed as the linguistic intervals [(*h*,+ 0.06),(*vh*,− 0.11)]. Next, the linguistic intervals are transformed into interval utilities. As *h* corresponds to 4, (*h*,+ 0.06) is expressed as 4.06. Similarly, *vh* corresponds to 5, and (*vh*,− 0.11) is expressed as 4.89. The midpoint refers to the point equidistant to these two points and is calculated as the arithmetic mean of the two points. This value is calculated as 4.47. Finally, the weight of C1 is obtained as 0.213 by normalizing this midpoint.

As shown in Table 4, C1 (population density) is the most significant criterion affecting the selection process with a weight of 0.213; C3 (proximity to housing complexes with more than 150 dwellings) is the least important with 0.081. Population density is a crucial criterion for locational analysis of MSW collection boxes. Studies done by Chalkias and Lasaridi (2009) and Khan and Samadder (2016) support our findings. Vijay et al. (2008), Chalkias and Lasaridi (2009), and Khan and Samadder (2016) considered only the road network of the study area to identify the optimized placement of bins. We considered the tram network of the study area in addition to the road network, and the results indicated that C5 (proximity to tram stops) was the second most important criterion after the population density.

Table 3 The scale for HFLTS

n	*vl*	*l*	*m*	*h*	*vh*	*a*
0	1	2	3	4	5	6

Table 4 Weights of the criteria

Criteria	Linguistic intervals	Interval utilities		Midpoints	Weights
C1	[(*h*,+ 0.06), (*vh*,− 0.11)]	4.06	4.89	4.47	0.213
C2	[(*l*,− 0.11), (*m*,− 0.33)]	1.89	2.67	2.28	0.109
C3	[(*vl*,+ 0.33), (*l*,+ 0.06)]	1.33	2.06	1.69	0.081
C4	[(*l*,+ 0.28), (*m*,+ 0.06)]	2.28	3.06	2.67	0.127
C5	[(*m*,0), (*h*,− 0.28)]	3.00	3.72	3.36	0.160
C6	[(*m*,− 0.06), (*h*,− 0.50)]	2.94	3.50	3.22	0.153
C7	[(*m*,+ 0.06), (*h*,−0.44)]	3.06	3.56	3.31	0.157

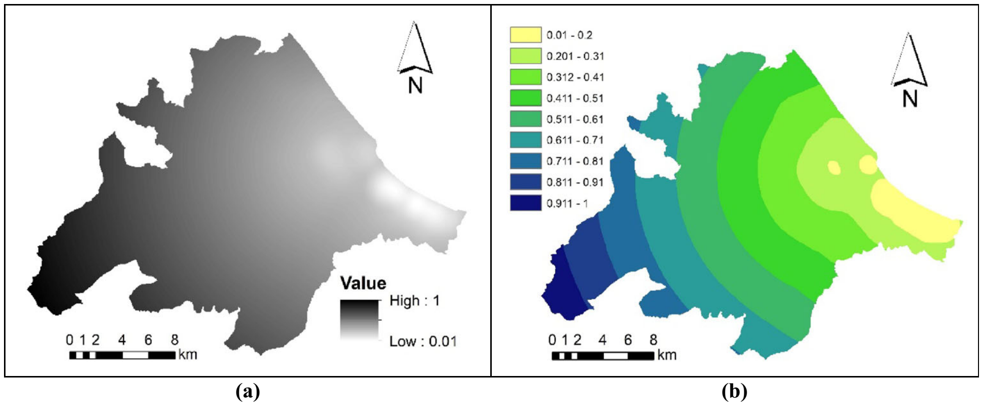


Fig. 5 (**a**) Weighted map and (**b**) classified weighted map

Identification of locations using GIS

A density-based criterion and distance-based six criteria were combined into a single normalized map using weights determined by the multi-criteria HFLTS method. The weighted map (Fig. 5a) was classified into 9 classes according to the range of value as shown in Fig. 5b. Areas with a value between 0 and 0.20 were identified as best for the locations of the AYPIKUT (Kabak et al. 2018).

The areas with a value between 0.01 and 0.20 shown in Fig 5b were further classified into 9 sub-classes using the weighted value (Fig. 6a, b). Suitable locations for the AYPIKUT were identified using the following three criteria:

- The AYPIKUT must be in a location with a weighted value less than 0.2.
- Each AYPIKUT must be at least 1000 m from every other AYPIKUT.
- The location of an AYPIKUT must be within 100 m of one criteria point and within 500 m of three criteria points.

Table 5 The values for AYPIKUT locations based on the criteria

Site	Normalized value							Final value
	C1	C2	C3	C4	C5	C6	C7	
A1	0.333	0.010	0.031	0.064	0.006	0.008	0.018	0.159
A2	0.462	0.039	0.008	0.063	0.029	0.011	0.018	0.137
A3	0.649	0.031	0.032	0.033	0.000	0.043	0.019	0.089
A4	0.620	0.006	0.035	0.002	0.024	0.017	0.007	0.092
A5	0.842	0.011	0.012	0.032	0.000	0.008	0.008	0.042
A6	0.268	0.076	0.002	0.091	0.069	0.010	0.057	0.197
A7	0.330	0.012	0.004	0.083	0.052	0.010	0.063	0.175
A8	0.992	0.054	0.003	0.021	0.002	0.013	0.023	0.016
A9	0.796	0.038	0.036	0.044	0.004	0.009	0.018	0.061
A10	0.964	0.019	0.026	0.071	0.002	0.021	0.028	0.029
A11	0.990	0.028	0.025	0.098	0.003	0.006	0.038	0.027
A12	0.523	0.068	0.025	0.139	0.002	0.027	0.070	0.144
A13	0.300	0.046	0.050	0.139	0.008	0.010	0.038	0.185
A14	0.201	0.012	0.091	0.131	0.004	0.013	0.018	0.198
A15	0.220	0.015	0.072	0.006	0.003	0.063	0.073	0.196

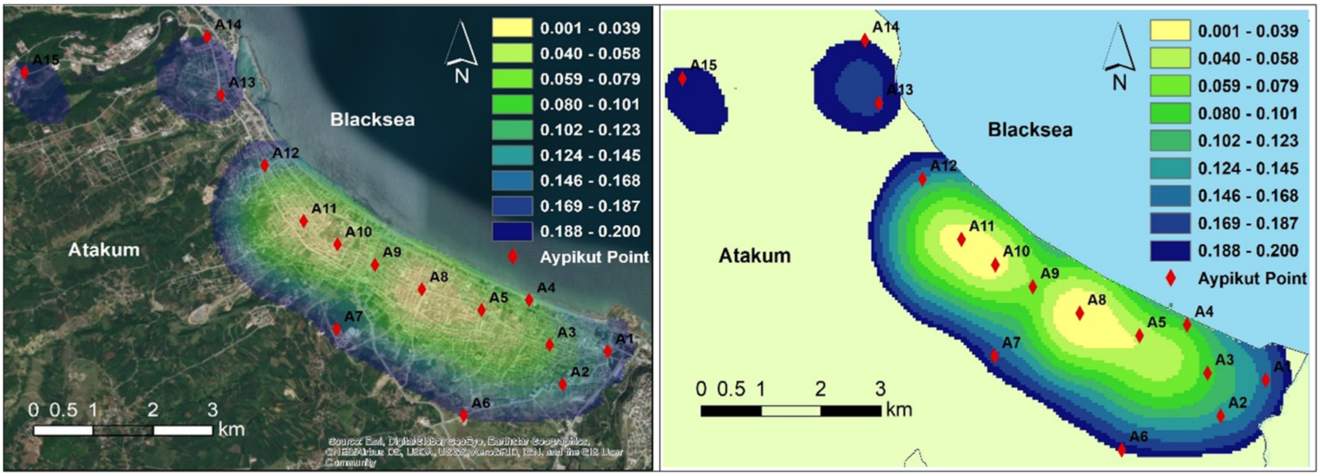
Fifteen (15) AYPIKUT locations (A1–A15) were identified using these criteria and taking into consideration the easily accessible places, as shown in Fig. 6a, b. Table 5 presents the normalized values for the 15 selected locations and confirms that all AYPIKUT locations had a value less than 0.2. A8 was found to have the best value based on C1, which was deemed the most important criterion for selection process, with a value of 0.016.

Ranking the alternatives using the MULTIMOORA method

The alternative AYPIKUT locations (A1–A15) were ranked with the MULTIMOORA method. The normalized values for AYPIKUT locations given in Table 5 were used to form the initial decision matrix, and calculations were made according to Eqs. (6), (7), (8), (9), (10), (11), (12), (13), and (14). Table 6 shows the rankings of the alternative AYPIKUT locations according to the ratio system (RS), the reference point theory (RPT), the full multiplicative form (FMF), and the final ranking of MULTIMOORA.

From Table 6, A5 is identified as the most suitable location, and A6 as the least suitable location for an AYPIKUT according to the MULTIMOORA method. Moreover, A1, A2, and A3 have the same rank. Unlike many MCDM approaches, the MULTIMOORA generates an integrative outcome by combining the results of three ranking methods. It is implemented effectively in site selection problems (Kabak et al. 2018; Rahimi et al. 2020; Lin et al. 2020).

The results indicated the ability of the proposed model to select suitable locations for the waste collection box. The model can be used in similar studies for the economic recovery of solid wastes.



(a) (b)

Fig. 6 (**a**, **b**) The suitable locations for AYPIKUT

Conclusion

MSWM is a significant item in the municipal budget, and most of the costs are spent on the collection and transportation of solid waste. The first condition for economic recovery from solid waste is separate collection, with the primary approach using collection boxes. This paper provides a scientific framework for determining AYPIKUT locations in the Atakum, which has the highest population growth rate in Samsun city. For the solution, first, a total of 88 items have been identified for consideration by seven criteria elicited from the insights of experts, and spatial analyses were performed. Then, multi-criteria HFLTS was applied to determine the weights of the criteria, and the possible suitable locations were determined using GIS. Finally, MULTIMOORA was used to evaluate the 15 suitable locations. The use of GIS-based multi-criteria HFLTS and MULTIMOORA affords a practical approach that increases the accuracy of site selection for AYPIKUT and the efficiency of the decision-making process whilst reducing the complexity of the research. Another advantage of the proposed approach is the use of linguistic term sets, as decision-makers often prefer linguistic assessment to form the decision matrix. Decision-makers may also have problems in identifying linguistic terms and may need flexibility in their evaluation. This challenge is overcome by context-free grammar, ensuring that the linguistic evaluation elicited from experts is effectively preserved without any loss of knowledge.

As future work, this study may be extended to other districts of Samsun and the other crowded cities in Turkey. Criteria may be amended and the number of criteria may be changed according to the characteristics of the study area. The number of required AYPIKUT may be determined according to the amount of waste produced daily and weekly, or by considering the per capita MSW generation rate and extent of the service area of an AYPIKUT.

Table 6 The rankings of alternatives

Sites	RS	RPT	FMF	MULTIMOORA
A1	7	8	9	7,8,9
A2	9	7	8	7,8,9
A3	8	10	7	7,8,9
A4	6	6	6	6
A5	1	1	4	1
A6	15	15	14	15
A7	12	13	11	13
A8	2	4	1	2
A9	3	2	5	3
A10	4	3	2	4
A11	5	5	3	5
A12	13	11	10	11
A13	11	9	12	10
A14	10	12	15	12
A15	14	14	13	14

Authors' contributions Aslı Çalış Boyacı: Term, conceptualization, methodology, validation, formal analysis, data curation, writing (original draft), writing (review and editing), and visualization.

Aziz Şişman: Software, methodology, formal analysis, data curation, writing (original draft), writing (review and editing), and visualization.

Köksal Sarıcaoğlu: Writing (review and editing).

All authors read and approved the final manuscript.

Data availability Not applicable.

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Appendix. Envelopes and collective preferences for HFLTS

Table 7 Envelopes obtained for HFLTS

	C1	C2	C3	C4	C5	C6	C7
Expert 1							
C1	–	[*vh*,*a*]	[*a*,*a*]	[*h*,*h*]	[*m*,*h*]	[*m*,*m*]	[*m*,*m*]
C2	[*n*,*vl*]	–	[*h*,*h*]	[*vl*,*m*]	[*n*,*l*]	[*n*,*vl*]	[*n*,*vl*]
C3	[*n*,*n*]	[*l*,*l*]	–	[*l*,*l*]	[*vl*,*vl*]	[*n*,*vl*]	[*n*,*vl*]
C4	[*l*,*l*]	[*m*,*vh*]	[*h*,*h*]	–	[*vl*,*m*]	[*l*,*l*]	[*l*,*l*]
C5	[*l*,*m*]	[*h*,*a*]	[*vh*,*vh*]	[*m*,*vh*]	–	[*l*,*l*]	[*l*,*l*]
C6	[*m*,*m*]	[*vh*,*a*]	[*vh*,*a*]	[*h*,*h*]	[*h*,*h*]	–	[*m*,*m*]
C7	[*m*,*m*]	[*vh*,*a*]	[*vh*,*a*]	[*h*,*h*]	[*h*,*h*]	[*m*,*m*]	–
Expert 2							
C1	–	[*h*,*a*]	[*vh*,*a*]	[*m*,*m*]	[*h*,*a*]	[*h*,*a*]	[*m*,*m*]
C2	[*n*,*l*]	–	[*vh*,*vh*]	[*l*,*m*]	[*m*,*m*]	[*m*,*m*]	[*l*,*m*]
C3	[*n*,*vl*]	[*vl*,*vl*]	–	[*n*,*vl*]	[*n*,*l*]	[*n*,*l*]	[*n*,*vl*]
C4	[*m*,*m*]	[*m*,*h*]	[*vh*,*a*]	–	[*h*,*vh*]	[*h*,*vh*]	[*m*,*m*]
C5	[*n*,*l*]	[*m*,*m*]	[*h*,*a*]	[*vl*,*l*]	–	[*m*,*m*]	[*l*,*m*]
C6	[*n*,*l*]	[*m*,*m*]	[*h*,*a*]	[*vl*,*l*]	[*m*,*m*]	–	[*l*,*l*]
C7	[*m*,*m*]	[*m*,*h*]	[*vh*,*a*]	[*m*,*m*]	[*m*,*h*]	[*h*,*h*]	–
Expert 3							
C1	-	[*h*,*a*]	[*h*,*vh*]	[*a*,*a*]	[*h*,*h*]	[*h*,*vh*]	[*h*,*a*]
C2	[*n*,*l*]	–	[*l*,*m*]	[*h*,*h*]	[*l*,*l*]	[*m*,*m*]	[*m*,*m*]
C3	[*vl*,*l*]	[*m*,*h*]	–	[*vh*,*a*]	[*l*,*l*]	[*m*,*m*]	[*h*,*vh*]
C4	[*n*,*n*]	[*l*,*l*]	[*n*,*vl*]	–	[*n*,*l*]	[*vl*,*m*]	[*l*,*m*]
C5	[*l*,*l*]	[*h*,*h*]	[*h*,*h*]	[*h*,*a*]	–	[*h*,*h*]	[*vh*,*vh*]
C6	[*vl*,*l*]	[*m*,*m*]	[*m*,*m*]	[*m*,*vh*]	[*l*,*l*]	–	[*h*,*h*]
C7	[*n*,*l*]	[*m*,*m*]	[*vl*,*l*]	[*m*,*h*]	[*vl*,*vl*]	[*l*,*l*]	–

Table 8 Pessimistic collective preferences

	C1	C2	C3	C4	C5	C6	C7
C1	–	(*h*,+ 0.33)	(*vh*,0)	(*h*,+ 0.33)	(*h*,− 0.33)	(*h*,− 0.33)	(*m*,+ 0.33)
C2	(*n*,0)	–	(*h*,− 0.33)	(*l*,+ 0.33)	(*l*,− 0.33)	(*l*,0)	(*l*,− 0.33)
C3	(*n*,+ 0.33)	(*l*,0)	–	(*l*,+ 0.33)	(*vl*,0)	(*vl*,0)	(*vl*,+ 0.33)
C4	(*l*,− 0.33)	(*m*,− 0.33)	(*m*,0)	–	(*l*,− 0.33)	(*l*,+ 0.33)	(*l*,+ 0.33)
C5	(*vl*,+ 0.33)	(*h*,− 0.33)	(*h*,+ 0.33)	(*m*,− 0.33)	–	(*m*,0)	(*m*,0)
C6	(*vl*,+ 0.33)	(*h*,− 0.33)	(*h*,0)	(*m*,− 0.33)	(*m*,0)	–	(*m*,0)
C7	(*l*,0)	(*h*,− 0.33)	(*h*,− 0.33)	(*m*,+ 0.33)	(*m*,−0.33)	(*m*,0)	–

Table 9 Optimistic collective preferences

	C1	C2	C3	C4	C5	C6	C7
C1	–	(*a*,0)	(*a*,− 0.33)	(*h*,+ 0.33)	(*vh*,− 0.33)	(*vh*,− 0.33)	(*h*,0)
C2	(*l*,− 0.33)	–	(*h*,0)	(*m*,+ 0.33)	(*l*,+ 0.33)	(*l*,+ 0.33)	(*l*,+ 0.33)
C3	(*vl*,0)	(*l*,+ 0.33)	–	(*m*,0)	(*l*,− 0.33)	(*l*,0)	(*l*,+ 0.33)
C4	(*l*,− 0.33)	(*h*,− 0.33)	(*h*,− 0.33)	–	(*m*,+ 0.33)	(*m*,+ 0.33)	(*m*,− 0.33)
C5	(*l*,+ 0.33)	(*h*,+ 0.33)	(*vh*,0)	(*h*,+ 0.33)	–	(*m*,0)	(*m*,+ 0.33)
C6	(*l*,+ 0.33)	(*h*,0)	(*vh*,0)	(*h*,− 0.33)	(*m*,0)	–	(*m*,0)
C7	(*m*,− 0.33)	(*h*,+ 0.33)	(*vh*,− 0.33)	(*h*,− 0.33)	(*m*,0)	(*m*,0)	–

References

Afzali A, Sabri S, Rashid M, Jamal MVS, Ludin ANM (2014) Inter-municipal landfill site selection using analytic network process. Water Resour Manag 28:2179–2194

Aksoy E, San BT (2019) Geographical information systems (GIS) and multi-criteria decision analysis (MCDA) integration for sustainable landfill site selection considering dynamic data source. Bull Eng Geol Environ 78:779–791

Altuntaş S, Dereli T, Yılmaz MK (2015) Evaluation of excavator technologies: application of data fusion based MULTIMOORA methods. J Civ Eng Manag 21(8):977–997

Amal L, Son LH, Chabchoub H (2018) SGA: spatial GIS-based genetic algorithm for route optimization of municipal solid waste collection. Environ Sci Pollut Res 25:27569–27582

Atici KB, Simsek AB, Ulucan A, Tosun MU (2015) A GIS-based multiple criteria decision analysis approach for windpower plant site selection. Util Policy 37:86–96

Aydi A (2018) Evaluation of groundwater vulnerability to pollution using a GIS based multi-criteria decision analysis. Groundw Sustain Dev 7:204–211

Bahrani S, Ebadi T, Ehsani H, Yousefi H, Maknoon R (2016) Modeling landfill site selection by multi-criteria decision making and fuzzy functions in GIS, case study: Shabestar, Iran. Environ Earth Sci 75:337

Baležentis T, Zeng S (2013) Group multi-criteria decision making based upon interval-valued fuzzy numbers: an extension of the MULTIMOORA method. Expert Syst Appl 40:543–550

Baležentis A, Baležentis T, Brauers WKM (2012) Personnel selection based on computing with words and fuzzy MULTIMOORA. Expert Syst Appl 39:7961–7967

Balta MÖ, Ülgen Yenil H (2019) Multi criteria decision making methods for urban greenway: the case of Aksaray, Turkey. Land Use Policy 89:104224

Barzehkar M, Dinan NM, Mazaheri S, Tayebi RM, Brodie G (2019) Landfill site selection using GIS-based multi-criteria evaluation (case study: SaharKhiz Region located in Gilan Province in Iran). SN Appl Sci 1:1082

Brauers WKM, Zavadskas EK (2006) The MOORA method and its application to privatization in a transition economy. Control Cybern 35(2):445–469

Brauers WKM, Zavadskas EK (2010) Project management by MULTIMOORA as an instrument for transition economies. Technol Econ Dev Econ 16(1):5–24

Brauers WKM, Zavadskas EK (2013) Multi-objective decision making with a large number of objectives. An application for Europe 2020. Int J Oper Res 10(2):67–79

Burrough PA, McDonnell RA (1998) Principles of geographical information systems. Oxford University Press.

Çalış Boyacı A (2020) Selection of eco-friendly cities in Turkey via a hybrid hesitant fuzzy decision making approach. Appl Soft Comput 89:106090

Chalkias C, Lasaridi K (2009) A GIS based model for the optimisation of municipal solid waste collection: the case study of Nikea, Athens, Greece. WSEAS Trans Environ Dev 10(5):640–650

Chang NB, Parvathinathan G, Breeden JB (2008) Combining GIS with fuzzy multicriteria decision-making for landfillsiting in a fast-growing urban region. J Environ Manag 87:139–153

Chen Y, Yu J, Khan S (2010) Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. Environ Model Softw 25:1582–1591

Cromley RG, Hanink DM (2003) Scale-independent land-use allocation modeling in raster GIS. Cartogr Geogr Inf Sci 30(4):343–350

Dahooie JH, Zavadskas EK, Firoozfar HR, Vanaki AS, Mohammadi N, Brauers WKM (2019) An improved fuzzy MULTIMOORA approach for multi-criteria decision making based on objective weighting method (CCSD) and its application to technological forecasting method selection. Eng Appl Artif Intell 79:114–128

Datta S, Sahu N, Mahapatra S (2013) Robot selection based on grey-MULTIMOORA approach. Grey Syst: Theory and Application 3(2):201–232

Eghtesadifard M, Afkhami P, Bazyar A (2020) An integrated approach to the selection of municipal solid waste landfills through GIS, *K*-means and multi-criteria decision analysis. Environ Res 185:109348

Erbaş M, Kabak M, Özceylan E, Çetinkaya C (2018) Optimal siting of electric vehicle charging stations: a GIS-based fuzzy multi-criteria decision analysis. Energy 163:1017–1031

Eskandari M, Homaee M, Mahmoodi S, Pazira E, Genuchten MTV (2015) Optimizing landfill site selection by using land classification maps. Environ Sci Pollut Res 22:7754–7765

Fahmi A, Kahraman C, Bilen Ü (2016) Electre I method using hesitant linguistic term sets: an application to supplier selection. Int J Comput Intell Syst 9(1):153–167

Feng XQ, Tan QY, Wei CP (2018) Hesitant fuzzy linguistic multi-criteria decision making based on possibility theory. Int J Mach Learn Cybern 9:1505–1517

Feyzi S, Khanmohammadi M, Abedinzadeh N, Aalipour M (2019) Multi-criteria decision analysis FANP based on GIS for siting municipal solid waste incineration power plant in the north of Iran. Sustain Cities Soc 47:101513

GDLRC, (2020) General Directorate of Land Registry and Cadastre https://www.tkgm.gov.tr/tr/icerik/iste-konutta-en-cok-satis-yapilan-ilceler, Accessed 19 June 2020

Ghadikolaei AS, Madhoushi M, Divsalar M (2018) Extension of the VIKOR method for group decision making with extended hesitant fuzzy linguistic information. Neural Comput & Applic 30:3589–3602

Gorsevski PV, Donevska KR, Mitrovski CD, Frizado JP (2012) Integrating multi-criteria evaluation techniques with geographic

information systems for landfill site selection: a case study using ordered weighted average. Waste Manag 32:287–296
Guiqin W, Li Q, Guoxue L, Lijun C (2009) Landfill site selection using spatial information technologies and AHP: a case study in Beijing, China. J Environ Manag 90:2414–2421
Hafezalkotob A, Hafezalkotob A (2015) Comprehensive MULTIMOORA method with target-based attributes and integrated significant coefficients for materials selection in biomedical applications. Mater Design 87:949–959
Hariz HA, Dönmez CÇ, Sennaroglu B (2017) Siting of a central healthcare waste incinerator using GIS-based multi-criteria decision analysis. J Clean Prod 166:1031–1042
Henry RK, Yongsheng Z, Jun D (2006) Municipal solid waste management challenges in developing countries – Kenyan case study. Waste Manag 26:92–100
Jamshidi-Zanjani A, Rezaei M (2017) Landfill site selection using combination of fuzzy logic and multiattribute decision-making approach. Environ Earth Sci 76:448
Kabak M, Erbaş M, Çetinkaya C, Özceylan E (2018) A GIS-based MCDM approach for the evaluation of bike-share stations. J Clean Prod 201:49–60
Kallel A, Serbaji MM, Zairi M (2016) Using GIS-based tools for the optimization of solid waste collection and transport: case study of Sfax City, Tunisia. J Eng 10:1–7
Kamdar I, Ali S, Bennui A, Techato K, Jutidamrongphan W (2019) Municipal solid waste landfill siting using an integrated GIS-AHP approach: a case study from Songkhla, Thailand. Resour Conserv Recycl 149:220–235
Kanani-Sadat Y, Arabsheibani R, Karimipour F, Nasseri M (2019) A new approach to flood susceptibility assessment in data-scarce and ungauged regions based on GIS-based hybrid multi criteria decision-making method. J Hydrol 572:17–31
Kanchanabhan TE, Mohaideen JA, Srinivasan S, Sundaram VLK (2010) Optimum municipal solid waste collection using geographical information system (GIS) and vehicle tracking for Pallavapuram municipality. Waste Manag Res 29(3):323–339
Kapilan S, Elangovan K (2018) Potential landfill site selection for solid waste disposal using GIS and multi-criteria decision analysis (MCDA). J Cent South Univ 25:570–585
Karimi H, Amiri S, Huang J, Karimi A (2019) Integrating GIS and multi-criteria decision analysis for landfll site selection, case study: Javanrood County in Iran. Int J Environ Sci Technol 16:7305–7318
Khan D, Samadder SR (2016) Allocation of solid waste collection bins and route optimisation using geographical information system: a case study of Dhanbad City, India. Waste Manag Res 34(7):666–676
Khishtandar S, Zandieh M, Dorri B (2017) A multi criteria decision making framework for sustainability assessment of bioenergy production technologies with hesitant fuzzy linguistic term sets: the case of Iran. Renew Sust Energ Rev 77:1130–1145
Khodaparast M, Rajabi AM, Edalat A (2018) Municipal solid waste landfill siting by using GIS and analytical hierarchy process (AHP): a case study in Qom city, Iran. Environ Earth Sci 77:52
Lella J, Mandla VR, Zhu X (2017) Solid waste collection/transport optimization and vegetation land cover estimation using Geographic Information System (GIS): a case study of a proposed smart-city. Sustain Cities Soc 35:336–349
Lin M, Huang C, Xu Z (2020) MULTIMOORA based MCDM model for site selection of car sharing station under picture fuzzy environment. Sustain Cities Soc 53:101873
Liu HB, Rodríguez RM (2014) A fuzzy envelope for hesitant fuzzy linguistic term set and its application to multicriteria decision making. Inf Sci 258:220–238
Liu HC, You JX, Li P, Su Q (2016) Failure mode and effect analysis under uncertainty: an integrated multiple criteria decision making approach. IEEE Trans Reliab 65(3):1380–1392
Mian MM, Zeng X, Nasry ANB, Al-Hamadani SMZF (2017) Municipal solid waste management in China: a comparative analysis. J Mater Cycles Waste Manag 19:1127–1135
Miglietta PP, Micale R, Sciortino R, Caruso T, Giallanza A, La Scalia G (2019) The sustainability of olive orchard planting management for different harvesting techniques: an integrated methodology. J Clean Prod 238:117989
Mokhtara C, Negrou B, Settou N, Gouareh A, Settou B (2019) Pathways to plus-energy buildings in Algeria: design optimization method based on GIS and multi-criteria decision-making. Energy Procedia 162:171–180
Montes R, Sánchez AM, Villar P, Herrera F (2015) A web tool to support decision making in the housing market using hesitant fuzzy linguistic term sets. Appl Soft Comput 35:949–957
Nas B, Cay T, Iscan F, Berktay A (2010) Selection of MSW landfill site for Konya, Turkey using GIS and multi-criteria evaluation. Environ Monit Assess 160:491–500
Nguyen-Trong K, Nguyen-Thi-Ngoc A, Nguyen-Ngoc D, Dinh-Thi-Hai V (2017) Optimization of municipal solid waste transportation by integrating GIS analysis, equation-based, and agent-based model. Waste Manag 59:14–22
Onar SÇ, Büyüközkan G, Öztayşi B, Kahraman C (2016) A new hesitant fuzzy QFD approach: an application to computer workstation selection. Appl Soft Comput 46:1–16
Ostovari Y, Honarbakhsh A, Sangoony H, Zolfaghari F, Maleki K, Ingram B (2019) GIS and multi-criteria decision-making analysis assessment of land suitability for rapeseed farming in calcareous soils of semi-arid regions. Ecol Indic 103:479–487
Othman AN, Naim WM, Noraini S (2012) GIS based multi criteria decision making for landslide hazard zonation. Procedia Soc Behav Sci 35:595–602
Özkan B, Özceylan E, Sarıçiçek İ (2019) GIS-based MCDM modeling for landfill site suitability analysis: a comprehensive review of the literature. Environ Sci Pollut Res 26:30711–30730
Özkan B, Özceylan E, Kabak M, Dağdeviren M (2020) Evaluating the websites of academic departments through SEO criteria: a hesitant fuzzy linguistic MCDM approach. Artif Intell Rev 53:875–905
Pham Phu ST, Fujiwara T, Hoang MG, Pham VD, Tran MT (2019) Waste separation at source and recycling potential of the hotel industry in Hoi An city, Vietnam. J Mater Cycles Waste Manag 21: 23–34
Phua MH, Minowa M (2005) A GIS-based multi-criteria decision making approach to forest conservation planning at a landscape scale: a case study in the Kinabalu Area, Sabah, Malaysia. Landsc Urban Plan 71:207–222
Priti, Mandal K (2019) Review on evolution of municipal solid waste management in India: practices, challenges and policy implications. J Mater Cycles Waste Manag 21:1263–1279
Qiu L, Zhu J, Pan Y, Hu W, Amable GS (2017) Multi-criteria land use suitability analysis for livestock development planning in Hangzhou metropolitan area, China. J Clean Prod 161:1011–1019
Rahimi S, Hafezalkotob A, Monavari SM, Hafezalkotob A, Rahimi R (2020) Sustainable landfill site selection for municipal solid waste based on a hybrid decision-making approach: fuzzy group BWM-MULTIMOORA-GIS. J Clean Prod:248, 119186
Ramya S, Devadas V (2019) Integration of GIS, AHP and TOPSIS in evaluating suitable locations for industrial development: a case of Tehri Garhwal district, Uttarakhand, India. J Clean Prod 238: 117872
Rezaeisabzevar Y, Bazargan A, Zohourian B (2020) Landfill site selection using multi criteria decision making: Influential factors for comparing locations. J Environ Sci 93:170–184
Ripa M, Fiorentino G, Vacca V, Ulgiati S (2017) The relevance of site-specific data in life cycle assessment (LCA). The case of the municipal solid waste management in the metropolitan city of Naples (Italy). J Clean Prod 142:445–460

Rızvanoğlu O, Kaya S, Ulukavak M, Yeşilnacar Mİ (2020) Optimization of municipal solid waste collection and transportation routes, through linear programming and geographic information system: a case study from Şanlıurfa, Turkey. Environ Monit Assess 192:9

Rodríguez RM, Martínez L, Herrera F (2012) Hesitant fuzzy linguistic term sets for decision making. IEEE Trans Fuzzy Syst 20(1):109–119

Rodríguez RM, Martínez L, Herrera F (2013) A group decision making model dealing with comparative linguistic expressions based on hesitant fuzzy linguistic term sets. Inf Sci 241:28–42

Rupani PF, Delarestaghi RM, Abbaspour M, Rupani MM, EL-Mesery HS, Shao W (2019) Current status and future perspectives of solid waste management in Iran: a critical overview of Iranian metropolitan cities. Environ Sci Pollut Res 26:32777–32789

Sánchez-Lozano JM, Bernal-Conesa JA (2017) Environmental management of Natura 2000 network areas through the combination of Geographic Information Systems (GIS) with multi-criteria decision making (MCDM) methods. Case study in south-eastern Spain. Land Use Policy 63:86–97

Sánchez-Lozano JM, Teruel-Solano J, Soto-Elvira PL, García-Cascales MS (2013) Geographical information systems (GIS) and multi-criteria decision making (MCDM) methods for the evaluation of solar farms locations: case study in south-eastern Spain. Renew Sust Energ Rev 24:544–556

Sánchez-Lozano JM, García-Cascales MS, Lamata MT (2016a) GIS-based onshore wind farm site selection using fuzzy multi-criteria decision making methods. Evaluating the case of southeastern Spain. Appl Energy 171:86–102

Sánchez-Lozano JM, García-Cascales MS, Lamata MT (2016b) Comparative TOPSIS-ELECTRE TRI methods for optimal sites for photovoltaic solar farms. Case study in Spain. J Clean Prod 127:387–398

Selim S, Koc San D, Selim C, San BT (2018) Site selection for avocado cultivation using GIS and multi-criteria decision analyses: case study of Antalya, Turkey. Comput Electron Agric 154:450–459

Şener Ş, Şener E, Nas B, Karagüzel R (2010) Combining AHP with GIS for landfill site selection: a case study in the Lake Beysşehir catchment area (Konya, Turkey). Waste Manag 30:2037–2046

Singh LK, Jha MK, Chowdary VM (2017) Multi-criteria analysis and GIS modeling for identifying prospective water harvesting and artificial recharge sites for sustainable water supply. J Clean Prod 142: 1436–1456

Sumathi VR, Natesan U, Sarkar C (2008) GIS-based approach for optimized siting of municipal solid waste landfill. Waste Manag 28: 2146–2160

Tavares G, Zsigraiová Z, Semiao V (2011) Multi-criteria GIS-based siting of an incineration plant for municipal solid waste. Waste Manag 31:1960–1972

TCA, Turkish Court of Accounts (2007) Waste management in Turkey: national regulations and evaluation of implementation results. Performance Audit Report, Ankara, pp 1–76

Terazono A, Oguchi M, Iino S, Mogi S (2015) Battery collection in municipal waste management in Japan: challenges for hazardous substance control and safety. Waste Manag 39:246–257

Tian ZP, Wang JQ, Wang J, Zhang HY (2018) A multi-phase QFD-based hybrid fuzzy MCDM approach for performance evaluation: a case of smart bike-sharing programs in Changsha. J Clean Prod 171: 1068–1083

Torra V (2010) Hesitant fuzzy sets. Int J Intell Syst 25:529–539

TSI, Turkish Statistical Institute (2019) http://www.turkstat.gov.tr/PreTablo.do?alt_id=1019, Accessed 15April 2020

TSI, Turkish Statistical Institute (2020) https://biruni.tuik.gov.tr/medas/?kn=95&locale=tr, Accessed 17 September 2020

Tüysüz F, Şimşek B (2017) A hesitant fuzzy linguistic term sets based AHP approach for analyzing the performance evaluation factors: an application to cargo sector. Complex Intell Syst 3:167–175

Vaissi S, Sharifi M (2019) Integrating multi-criteria decision analysis with a GIS based siting procedure to select a protected area for the Kaiser's mountain newt, Neurergus kaiseri (Caudata: Salamandridae). Glob Ecol Conserv 20:e00738

Vijay R, Gautam A, Kalamdhad A, Gupta A, Devotta S (2008) GIS-based locational analysis of collection bins in municipal solid waste management systems. J Environ Eng Sci 7:39–43

Villacreses G, Gaona G, Martínez-Gómez J, Jijón DJ (2017) Wind farms suitability location using geographical information system (GIS), based on multi-criteria decision making (MCDM) methods: the case of continental Ecuador. Renew Energy 109:275–286

Wei C, Liao H (2016) A multigranularity linguistic group decision-making method based on hesitant 2-tuple sets. Int J Intell Syst 31(6):612–634

Wei CP, Ren ZL, Rodríguez RM (2015) A hesitant fuzzy linguistic TODIM method based on a score function. Int J Comput Intell Syst 8(4):701–712

Yavuz M, Öztayşi B, Onar SÇ, Kahraman C (2015) Multi-criteria evaluation of alternative-fuel vehicles via a hierarchical hesitant fuzzy linguistic model. Expert Syst Appl 42:2835–2848

Zhang DQ, Tan SK, Gersberg RM (2010) Municipal solid waste management in China: status, problems and challenges. J Environ Manag 91:1623–1633