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Selection of eco-friendly cities in Turkey via a hybrid hesitant fuzzy decision making approach

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ABSTRACT

Environmental pollution can be defined as the alteration and deterioration of the natural structure and composition of the environment. Industrialization and population density in cities increase environmental pollution. Today, environmental pollution, a common problem in all countries, has reached dimensions that threaten nature and human health. In this context, this study focuses on the selection of eco-friendly cities in Turkey according to criteria such as average PM_{10} values at air quality measurement stations, forest area per km^2, and percentage of population receiving waste services, using the hesitant fuzzy linguistic term set (HFLTS)-based additive ratio assessment (ARAS) method. The multi-criteria HFLTS method is used to determine the weights assigned to environmental criteria. The ARAS method is used to obtain the final ranking of 81 cities in Turkey. Empirical results demonstrate that the proposed approach is viable in selecting eco-friendly cities.

1. Introduction

Diversified environmental problems such as the effects of rapidly developing technology and industry, population growth, and unconscious consumption of natural resources threaten nature and human health. Air pollution is a primary concern, causing widespread environmental effects. The use of fossil fuels, especially coal, impacts air quality and human health.

Air pollution results from harmful substances in the air rising above a threshold concentration with adverse effects on humans and ecosystems. Particulate matter (PM) is a complex combination of organic and inorganic substances and an air pollutant with a severe impact on human health [1]. PM_{10} and other particles with a diameter less than 10 μm may cause inflammation of the lungs, or heart and lung diseases [2]. As such, PM_{10} concentrations are monitored in air quality measurement stations to prevent or reduce the damaging effects of air pollution on the environment and human health.

Forests are one of the most important sources of oxygen, and help reduce air pollution. They also make substantial economic contributions, supplying products and services that provide jobs and protect the environment [3]. Forests clean the air and provide rainfall. In addition, the roots of trees in forests prevent soil erosion and floods. Forests contribute to the national economy by extending the economic life of dams. Forests cover approximately 30% of the world's land area [4]. However, this percentage is constantly decreasing. For environmental sustainability, it is necessary to protect forest areas and increase their size.

Another major problem for the environment is waste. Human activities inevitably lead to waste [5]. In addition to deteriorating natural resources, the amount of waste left in the environment can increase rapidly. Many factors cause environmental pollution, such as the proliferation of wastes that remain unresolved in nature and undergo changes in their properties. Waste management, the recovery and disposal of waste, is an important issue for any municipality along with water and energy management [6]. Urban waste management, properly recycling and disposing of waste without contributing to environmental pollution, is an important public service [7].

Lists rating cities based on quality of life, business climate, or market potential have emerged since the late 1980s [8]. City rankings based on insight into the strengths and weaknesses of cities can encourage cities to learn from each other, trigger a discussion process on regional development strategies, and be used for city planning and development [9,10].

According to the United Nations report, the world's population is expected to reach 9.7 billion in 2050, and two-thirds of the population is expected to live in cities [39]. A large proportion of Turkey's population lives in urban areas. Approximately 92% of the population lives in cities and towns, and approximately 8% lives in villages [40]. Cities will have to manage growing needs in infrastructure, water, environmental cleaning, employment, health services, security, and transportation. To meet these needs and to create opportunities for urban development, the concept of smart systems has emerged. The goal of smart systems is

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Table 1
Summary of HFLTS studies in the literature.

Author(s)		Method(s) Used	Objective/Problem	Type
Rodríguez et al.	[11]	HFLTS	Method proposal	Illustrative
Beg & Rashid	[12]	HFLTS, TOPSIS	Method proposal	Illustrative
Rodríguez et al.	[13]	HFLTS, Group decision making	Method proposal	Illustrative
Chen & Hong	[14]	HFLTS	Method proposal	Illustrative
Liao et al.	[15]	HFLTS	Evaluation of the quality of movies	Illustrative
Liu & Rodríguez	[16]	HFLTS, OWA operator, Fuzzy TOPSIS	Supplier selection	Illustrative
Liao & Xu	[17]	HFLTS, TOPSIS, VIKOR	Selection of an ERP system	Illustrative
Montes et al.	[18]	HFLTS	Development of a web tool for the housing market	Case Study
Wang et al.	[19]	HFLTS, ELECTRE	Method proposal	Illustrative
Wei et al.	[20]	HFLTS, TODIM	Evaluation of the telecommunications service providers	Illustrative
Wei & Liao	[21]	HFLTS, MTWA and MTOWA operators	Selection of the treatment technology for the disposal of healthcare waste	Case Study
Yavuz et al.	[22]	Multi-criteria HFLTS	Evaluation of alternative-fuel vehicles	Case Study
Chen et al.	[23]	Proportional HFLTS (PHFLTS)	Evaluation of the university faculty	Illustrative
Da & Xu	[24]	HFLTS	Urban waterfront redevelopment	Case Study
Fahmi et al.	[25]	HFLTS, ELECTRE I	Supplier selection	Illustrative
Liu et al.	[26]	HFLTS, FMEA	Healthcare risk analysis	Case Study
Gou et al.	[27]	HFLTS, Bonferroni mean operator	Hospital selection	Case Study
Gou et al.	[28]	Double hierarchy HFLTS (DHHFLTS), MULTIMOORA	Evaluation of the implementation status of haze controlling measures	Case Study
Khishtandar et al.	[29]	HFLTS	Assessment of bioenergy production technologies	Case Study
Tüysüz & Şimşek	[30]	HFLTS, AHP	Performance evaluation	Case Study
Adem et al.	[31]	HFLTS, SWOT	Assessment of occupational safety risks in the life cycle of wind turbine	Case Study
Ghadikolaei et al.	[32]	Extended HFLTS (EHFLTS), VIKOR	Telecommunications service provider selection	Illustrative
Feng et al.	[33]	HFLTS, PROMETHEE	Facility location selection	Illustrative
Liao et al.	[34]	HFLTS, ELECTRE II	Method proposal	Illustrative
Huang et al.	[35]	Proportional HFLTS (PHFLTS), QFD	Method proposal	Illustrative
Aktaş & Kabak	[36]	HFLTS, AHP, TOPSIS	Evaluation of the solar power plant location sites	Case Study
Montserrat-Adell et al.	[37]	Free double hierarchy HFLTS (FDHHFLTS), TOPSIS	Method proposal	Illustrative
Wu et al.	[38]	HFLTS, VIKOR, TOPSIS	Method proposal	Illustrative

to invest in technology to improve environmental conditions in cities by promoting economic growth and social development. The Ministry of Environment and Urban Planning has defined the concept of sustainable cities as a vision for planning and directing studies on smart systems on a national scale.

Determining sustainability scores to select eco-friendly cities by measuring performance based on environmental conditions is a challenging task that requires appropriate scientific approaches [41]. In this context, multi-criteria decision-making (MCDM) approaches ensure robustness and flexibility to address comparison problems involving multiple and varied units of measurement. However, it is difficult to model and solve real-world decision-making problems because of uncertain conditions. Fuzzy logic and fuzzy set theory have been proposed to address uncertainty [42]. Fuzzy set theory is also used to address uncertainty and compare alternatives in solving MCDM problems. This study utilizes a hybrid fuzzy MCDM framework to evaluate and compare the performance of 81 cities in Turkey according to specified environmental criteria. MCDM methods and fuzzy logic are successfully used to evaluate the cities based on environmental criteria in the literature [43–45]. This study focuses mainly on the selection of eco-friendly cities in Turkey using a multi-criteria hesitant fuzzy linguistic term set (HFLTS)-based additive ratio assessment (ARAS), which is an MCDM method.

The HFLTS method is implemented effectively in several areas in the literature, such as supplier selection, hospital selection, healthcare risk analysis, facility location selection, and performance evaluation (Table 1). The ARAS method is used because of its wide applicability in the literature, such as personnel selection, supplier selection, evaluation of financial performance, evaluation of websites, and selection of optimum process parameters (Table 2). As observed in Tables 1 and 2, considering the most

Table 2
Review of ARAS studies in the literature.

Author(s)		Method(s) Used	Problem	Application Region
Zavadskas & Turskis	[46]	Crisp ARAS	Evaluation of microclimate in office rooms	Vilnius, Lithuania
Turskis & Zavadskas	[47]	FAHP, ARAS-F	Selection of logistics centre location	EU
Turskis & Zavadskas	[48]	ARAS-G	Supplier selection	Lithuania
Bakshi & Sarkar	[49]	AHP, ARAS	Project selection	India
Keršulienė & Turskis	[50]	SWARA, ARAS-F	Personnel selection	Lithuania
Dadelo et al.	[51]	Crisp ARAS	Assessment of elite security personnel	Vilnius, Lithuania
Zavadskas et al.	[52]	AHP, ARAS, TOPSIS, COPRAS	Selection of pile-column technology	Lithuania
Chatterjee & Bose	[53]	ARAS-F, Fuzzy COPRAS	Selection of vendors for wind farm	India
Kutut et al.	[54]	AHP, ARAS	Grading of heritage buildings	Vilnius, Lithuania
Sliogeriene et al.	[55]	AHP, ARAS	Choice of energy generation technologies	Lithuania
Keršulienė & Turskis	[56]	FAHP, ARAS-F	Assessment of chief accounting officer	Lithuania
Zamani et al.	[57]	ANP, ARAS-F	Brand extension strategy selection in the food industry	Iran
Ghadikolaei et al.	[58]	FAHP, ARAS-F, Fuzzy VIKOR,	Evaluation of the financial performance of Iranian companies	Iran
Akhavan et al.	[59]	ARAS-F, Fuzzy COPRAS, Fuzzy MOORA, Fuzzy TOPSIS	Selection of strategic alliance partner	Iran
Stanujkic	[60]	IVFN, ARAS	Faculty website selection	Serbia
Medineckiene et al.	[61]	AHP, ARAS	Selection of office building	Sweden
Zavadskas et al.	[62]	AHP, ARAS-F	Selection of deep-water port	Western Europe
Varmazyar et al.	[63]	DEMATEL, ANP, ARAS, COPRAS, MOORA, TOPSIS	Performance evaluation of research and technology organizations	Iran
Liao et al.	[64]	FAHP, ARAS-F, Multi-segment goal programming	Supplier selection in the green supply chain	Taiwan, R.O.C.
Štreimikienė et al.	[65]	AHP, ARAS	Choice of electricity generation technologies	Lithuania
Baležentis & Štreimikienė	[66]	WASPAS, ARAS, TOPSIS, Monte Carlo simulation	Ranking of energy generation scenarios	EU
Stanujkic et al.	[67]	SWARA, ARAS, ARCAS	Sales personnel selection	Bulgaria
Büyüközkan & Göçer	[68]	IVIF ARAS, IVIF AHP	DSC supplier selection of freight companies	Turkey
Dahooie	[69]	SWARA, ARAS-G	Personnel selection	Iran
Ecer	[70]	FAHP, ARAS	Evaluation of mobile banking services	Turkey
Singaravel et al.	[71]	ARAS	Selection of optimum process parameters	India
Fu	[72]	AHP, ARAS, Multi-choice goal programming	Catering supplier selection	Taiwan, R.O.C.

relevant streams of research, no studies have used both multi-criteria HFLTS and ARAS methods. This study is expected to fill this gap in the literature.

The rest of this paper is arranged as follows. Section 2 introduces the multi-criteria HFLTS-based ARAS method for the selection of eco-friendly cities. Section 3 describes the implementation of the proposed method in Turkey, including a sensitivity analysis. The findings are discussed in Section 4. Section 5 provides conclusions and suggestions for future work.

2. Methodology

In this study, a hybrid multi-criteria HFLTS approach is proposed to select eco-friendly cities. The multi-criteria HFLTS method is used to determine the criteria weights, and the ARAS method is used to rank the cities. This section explains these two methods.

2.1. Multi-criteria hesitant fuzzy linguistic term set (HFLTS) method

Fuzzy logic and fuzzy set theories successfully address uncertainty. However, when two or more sources of uncertainty occur simultaneously, the fuzzy cluster remains limited. In this context, a hesitant linguistic group decision-making model with a single criterion was suggested by Rodriguez et al. [13]. Based on this model, m experts assess n alternatives based on a single criterion. Yavuz et al. extended this algorithm to take a multi-criteria decision-making problem into account. The stages of the suggested algorithm are as follows [22]:

Stage 1: Define the semantics and syntax of the linguistic term set S.

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

Stage 2: Define the context-free grammar G_H, where $G_H = \{V_N, V_T, I, P\}$.

$$V_N = \left\{ \begin{array}{l} \langle\text{primary term}\rangle, \langle\text{composite term}\rangle, \langle\text{unary relation}\rangle, \\ \langle\text{binary relation}\rangle, \langle\text{conjunction}\rangle \end{array} \right\} \quad (2)$$

$$V_T = \{\text{lower than, greater than, at least, at most, between, and}, s_0, s_1, \ldots, s_g\} \quad (3)$$

$\mathrm{I} \in \mathrm{V_N}$

$$P = \left\{ \begin{array}{l} I = \langle \text{primary term} \rangle \,|\langle \text{composite term} \rangle\ , \\ \langle \text{composite term} \rangle ::= \\ \langle \text{unary relation} \rangle \langle \text{primary term} \rangle \,|\langle \text{binary relation} \rangle \\ \langle \text{primary term} \rangle \langle \text{conjunction} \rangle \langle \text{primary term} \rangle, \\ \text{primary term} ::= s_0 \left| s_1 \ldots \right| s_g,\ \langle \text{unary relation} \rangle ::= \\ \text{lower than} \,|\text{greater than} \,|\text{at least} \,|\text{at most}, \\ \langle \text{binary relation} \rangle ::= \text{between},\ \langle \text{conjunction} \rangle ::= \text{and} \end{array} \right\} \quad (4)$$

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

Stage 4: Transform the preference relations into HFLTS using the E_{GH} function.

Stage 5: Obtain the envelope $\left[p_{ij}^{k-}, p_{ij}^{k+}\right]$ for each HFLTS.

Stage 6: Select a linguistic aggregation operator φ and obtain the pessimistic and optimistic collective preference relations P_C^- and P_C^+. The arithmetic mean is used for φ:

$$\bar{x} = \Delta\left(\frac{1}{n}\sum_{i=1}^{n}\Delta^{-1}(s_i, \alpha_i)\right) = \Delta\left(\frac{1}{n}\sum_{i=1}^{n}\beta_i\right) \quad (5)$$

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

$$\Delta(\beta) = (s_i, \alpha_i)\ with \left\{ \begin{array}{l} i = round(\beta) \\ \alpha = \beta - i \end{array} \right\} \quad (6)$$

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

$$\Delta^{-1}(s_i, \alpha_i) = i + \alpha \quad (7)$$

Stage 7: Compute a pessimistic and optimistic collective preference for each alternative by φ.

Stage 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 $\left(p_i^R = \left[p_i^-, p_i^+\right]\right)$.

Stage 9: Normalize the obtained interval utilities.

2.2. Additive ratio assessment (ARAS) method

Zavadskas and Turskis submitted the ARAS method for the solution of MCDM problems in 2010. Based on this technique, a utility function value that determines the complicated relative. efficiency of a feasible alternative is directly proportional to the comparative impact of the main criteria values and weights [46].

The first phase of the ARAS method is the formation of the decision-making matrix. As with other MCDM techniques, the problem to be solved is depicted by the following matrix of preferences for m feasible alternatives (rows) classified under n criteria (columns)

$$X = \begin{bmatrix} x_{01} & \cdots & x_{0j} & \cdots & x_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}$$

$$i = 0, 1, 2, \ldots, m;\ j = 1, 2, \ldots, n \quad (8)$$

where the number of alternatives is represented by m, and the number of criteria that describes the alternatives is represented by n. In the decision matrix, x_{ij} represents the performance value of the alternative i in terms of the criterion j, and x_{0j} is the optimal value of criterion j.

In the decision problem, if the optimal value of criterion j is not known,

$$x_{0j} = \max_i x_{ij},\ if\ \ \max_i x_{ij}\ is\ preferable \quad (9)$$

$$x_{0j} = \min_i x_{ij}^*,\ if\ \ \min_i x_{ij}^*\ is\ preferable \quad (10)$$

In the second phase, all initial criteria values are normalized, and x'_{ij} is defined as the normalized criterion j rating. The normalized matrix X' is written as follows:

$$X' = \begin{bmatrix} x'_{01} & \cdots & x'_{0j} & \cdots & x'_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x'_{i1} & \cdots & x'_{ij} & \cdots & x'_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x'_{m1} & \cdots & x'_{mj} & \cdots & x'_{mn} \end{bmatrix}$$

$$i = 0, 1, 2, \ldots, m; j = 1, 2, \ldots, n \quad (11)$$

The criteria whose preferred values are maximum are normalized using Eq. (12).

$$x'_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \quad (12)$$

The criteria whose preferred values are minimum are normalized using the double-stage procedure indicated in Eq. (13).

$$x_{ij} = \frac{1}{x_{ij}^*};\ x'_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \quad (13)$$

In the third phase, the normalized-weighted matrix $\widehat{X}$ is formed as Eq. (14), and these criteria can be assessed with weights $0 < w_j < 1$. The sum of the weights w_j is limited as in Eq. (15).

$$\widehat{X} = \begin{bmatrix} \widehat{x}_{01} & \cdots & \widehat{x}_{0j} & \cdots & \widehat{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \widehat{x}_{i1} & \cdots & \widehat{x}_{ij} & \cdots & \widehat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \widehat{x}_{m1} & \cdots & \widehat{x}_{mj} & \cdots & \widehat{x}_{mn} \end{bmatrix}$$

$$i = 0, 1, 2, \ldots, m; j = 1, 2, \ldots, n \quad (14)$$

$$\sum_{j=1}^{n} w_j = 1 \quad (15)$$

The normalized-weighted values of the criteria $\widehat{x}_{ij}$ are calculated according to Eq. (16).

$$\widehat{x}_{ij} = x'_{ij} w_j; \qquad i = 0, 1, 2, \ldots, m \quad (16)$$

The next phase is to determine the values of the optimality function. S_i is the value of the optimality function of alternative i, and it is calculated using Eq. (17).

$$S_i = \sum_{j=1}^{n} \widehat{x}_{ij},\ i = 0, 1, \ldots, m \quad (17)$$

The best result has the greatest value and the worst result has the smallest value. Taking the calculation process into account, the greater the value of the optimality function S_i, the more efficient the alternative. In the last phase, the degree of the alternative utility is defined by a comparison of the variant with

Table 3
Pairwise linguistic evaluations of the experts for the criteria.

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

the best S_0. The utility degree K_i of an alternative a_i is calculated using Eq. (18).

$$K_i = \frac{S_i}{S_0},\ i = 0, 1, \ldots, m \tag{18}$$

K_i is in the interval [0, 1] and can be ordered in an increasing sequence.

3. Application of the proposed methodology

In this section, the application of the proposed methodology is explained in detail and a sensitivity analysis is performed to show the robustness of the decision-making process. The flow chart of the proposed method adopted for the eco-friendly city selection problem is given in Fig. 1. The proposed method consists of three phases including problem definition, determination of criteria weights using the multi-criteria HFLTS method, and evaluation of the alternatives using the ARAS method.

3.1. Defining the problem

The vast majority of Turkey's population lives in cities. Aside from the advantages of living in cities, climate change, pollution, and water and energy scarcity are problems caused by urbanization. In this study, 81 cities in Turkey are evaluated according to environmental criteria that directly affect health and sustainable life to determine the eco-friendly cities.

Data used in this study were obtained from indicator values of the well-being index for cities published by the Turkish Statistical Institute (TurkStat) [73]. In this study, there are 81 alternatives and five criteria. The alternatives are 81 cities in Turkey, the criteria are represented by C_j.

- C1: Average of PM_{10} values of the air monitoring stations (air pollution) ($\mu g/m^3$)
- C2: Forest area per km^2 (%)
- C3: Percentage of population receiving waste services (%)
- C4: Percentage of households with noise problems from the street (%)
- C5: Satisfaction rate with municipal cleaning services (%)

In light of the criteria, the decision hierarchy is formed as shown in Fig. 2.

Table 4
Envelopes obtained for HFLTS.

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

Table 5
The scale for HFLTS.

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

3.2. Multi-criteria HFLTS method for determining the weights of criteria

The weights of criteria are determined using the multi-criteria HFLTS method. In this context, the semantics and syntax of the linguistic term set are defined, and the context-free grammar is built. Preference relations of experts are collected. Table 3 presents pairwise linguistic evaluations of three experts for the criteria. The expert evaluations in Table 3 are first presented as discrete sets, then converted into intervals. For instance, Expert 1's preference of C1 with respect to C2 is 'at most low importance' in linguistic terms, and can be represented as a discrete set $\{n, vl, l\}$, and then as the interval $[n, l]$. The envelopes obtained for the evaluations of three experts are presented in Table 4.

In the next stage, pessimistic and optimistic collective preference relations are obtained using the scale for the linguistic terms given in Table 5. In the scale, the value 0 means 'no importance', the value 3 means 'medium importance', and the value 6 means 'absolute importance'. The values 1, 2, 4 and 5 correspond to 'very low importance', 'low importance', 'high importance' and 'very

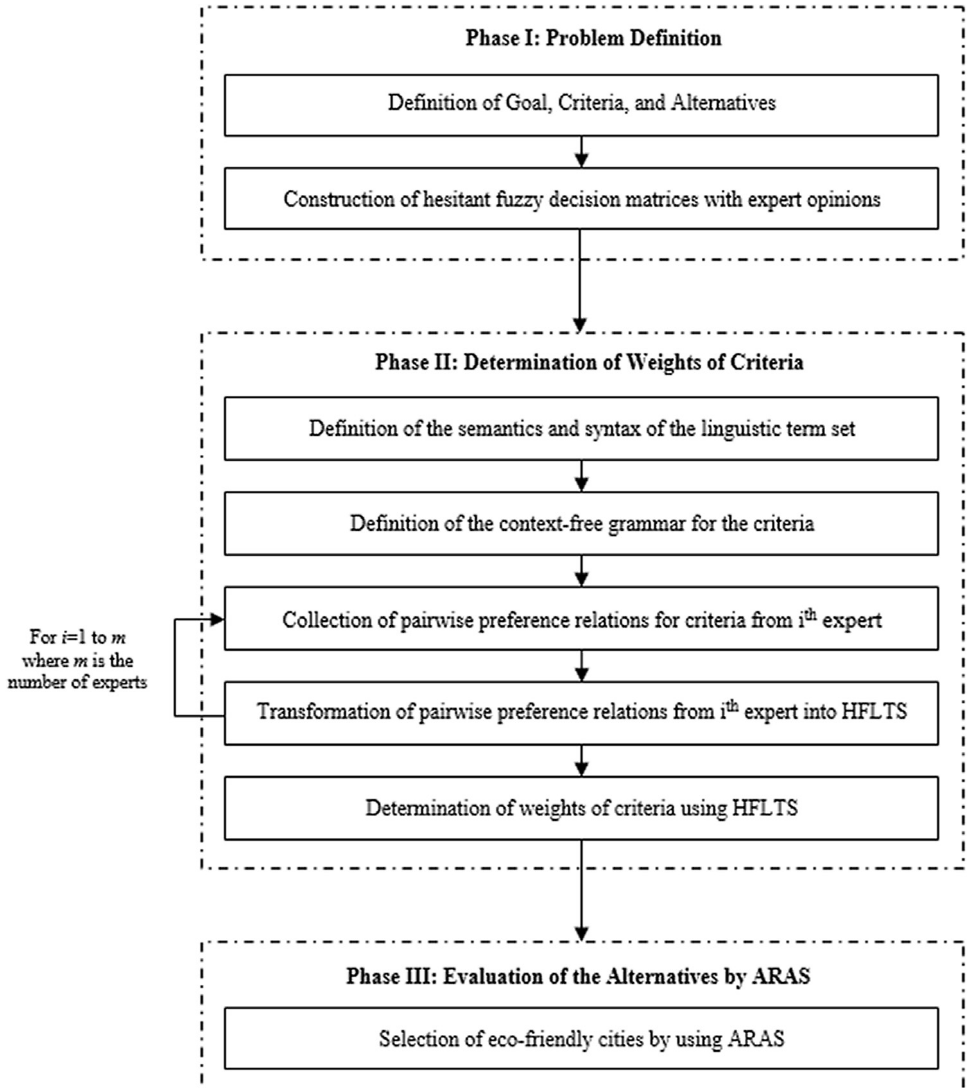

Fig. 1. The flow chart of the proposed hybrid multi-criteria HFLTS method.

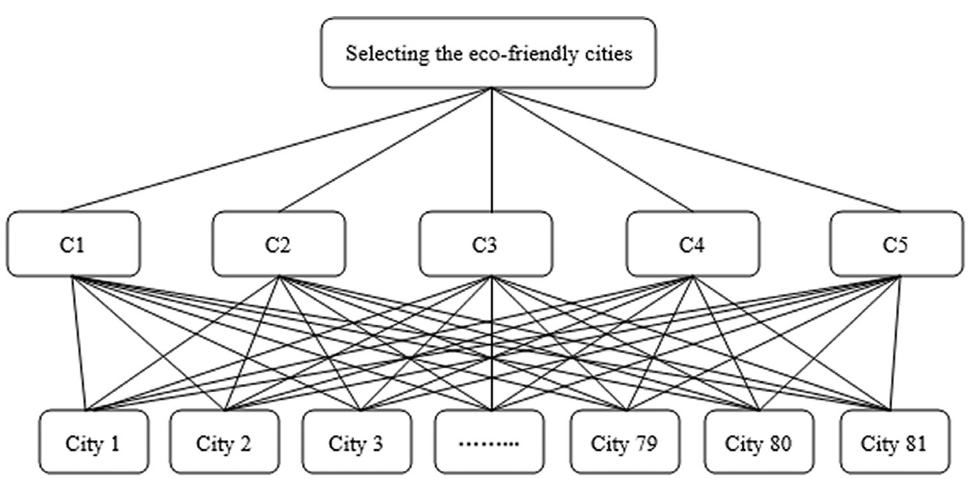

Fig. 2. The decision hierarchy.

Table 6
Pessimistic collective preferences.

	C1	C2	C3	C4	C5
C1	–	$(l, -0.33)$	$(l, +0.33)$	$(vh, -0.33)$	$(m, +0.33)$
C2	$(m, 0)$	–	$(l, 0)$	$(h, -0.33)$	$(m, +0.33)$
C3	$(m, 0)$	$(m, 0)$	–	$(h, +0.33)$	$(l, +0.33)$
C4	$(vl, -0.33)$	$(vl, +0.33)$	$(vl, +0.33)$	–	$(l, -0.33)$
C5	$(m, -0.33)$	$(l, +0.33)$	$(m, 0)$	$(m, 0)$	–

Table 7
Optimistic collective preferences.

	C1	C2	C3	C4	C5
C1	–	$(m, 0)$	$(m, 0)$	$(vh, +0.33)$	$(m, +0.33)$
C2	$(h, +0.33)$	–	$(m, 0)$	$(vh, -0.33)$	$(h, -0.33)$
C3	$(h, -0.33)$	$(h, 0)$	–	$(vh, -0.33)$	$(m,0)$
C4	$(vl, +0.33)$	$(l, +0.33)$	$(l, -0.33)$	–	$(m,0)$
C5	$(m, -0.33)$	$(m, -0.33)$	$(h, -0.33)$	$(h, +0.33)$	–

Table 8
Weights of the criteria.

Criteria	Linguistic intervals	Interval utilities		Midpoints	Weights
C1	$[(m, 0);(h, -0.33)]$	3.00	3.67	3.33	0.222
C2	$[(m, 0);(h, -0.08)]$	3.00	3.92	3.46	0.231
C3	$[(m, +0.17);(h, -0.17)]$	3.17	3.83	3.50	0.233
C4	$[(vl, +0.25);(l, +0.08)]$	1.25	2.08	1.67	0.111
C5	$[(m, -0.25);(m, +0.33)]$	2.75	3.33	3.04	0.203

high importance', respectively. The pessimistic and optimistic collective preference values are calculated as shown in Tables 6 and 7, respectively. The arithmetic mean is used for the linguistic aggregation operator to obtain these collective preference relations. For example, the pessimistic collective preference value for C1 in relation to C2 is calculated as follows:

$$P^-_{C_{12}} = \Delta\left(\frac{1}{3}\left(\Delta^{-1}(n, 0) + \Delta^{-1}(l, 2) + \Delta^{-1}(m, 3)\right)\right)$$
$$= \Delta\left(\frac{1}{3}(0 + 2 + 3)\right) = \Delta\,(1.67) = (l, -0.33)$$

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

$$P^+_{C_{12}} = \Delta\left(\frac{1}{3}\left(\Delta^{-1}(l, 2) + \Delta^{-1}(l, 2) + \Delta^{-1}(vh, 5)\right)\right)$$
$$= \Delta\left(\frac{1}{3}(2 + 2 + 5)\right) = \Delta\,(3.00) = (m, 0)$$

The weights of criteria presented in Table 8 are obtained by using the values of the pessimistic and optimistic collective preferences determined in the previous stage. For example, the linguistic intervals, interval utilities, midpoint, and weights are calculated for the first row in Table 8 as follows.

The pessimistic and optimistic collective preferences are $(m, 0)$ and $(h, -0.33)$ for C1. These preferences are expressed as the linguistic intervals $[(m, 0); (h, -0.33)]$. Next, the linguistic intervals are transformed into interval utilities. As m corresponds to 3, $(m, 0)$ is expressed as 3.00. Similarly, h corresponds to 4, and $(h, -0.33)$ is expressed as 3.67. The midpoint refers to the point equidistant to these two points and is calculated as the arithmetic mean of the two points. For the first row, this value is calculated as 3.33. Finally, the criteria weight is obtained as 0.222 by normalizing this midpoint.

As shown in Table 8, C3 and C2 are the most significant criteria affecting the selection process with weights of 0.233 and 0.231, respectively, while C4 has the least important weight value of 0.111.

3.3. ARAS method for ranking the alternatives

The alternatives are ranked using the ARAS method. The initial decision matrix given in Appendix A is created according to the indicator values of the well-being index. As observed in Appendix A, preferable values of C1 and C4 are minima, while preferable values of C2, C3, and C5 are maxima. The weighted-normalized decision matrix given in Appendix B is formed according to the criteria weights obtained by the multi-criteria HFLTS method. The utility degrees and ranking of the alternatives are obtained by the multi-criteria HFLTS-based ARAS method (see Table 9). According to the utility degree (K_i) given in Table 9, Kastamonu is the most eco-friendly city and Iğdır is the least eco-friendly city, in terms of the environmental criteria. Kastamonu has 75% of the optimal alternative performance level, Artvin has 74%, Karabük has 70%, and Iğdır has only 24%.

3.4. Sensitivity analysis

A sensitivity analysis is carried out to examine the changes in the ranking of alternatives as a result of changes in criteria weight values. For this purpose, the criteria weight values are changed in accordance with two different scenarios and the alternatives are revaluated. Fig. 3 presents the ranking according to criteria weights obtained by the multi-criteria HFLTS method, the ranking obtained by Scenario 1 (S1), where all criteria have equal weight, and the ranking obtained by Scenario 2 (S2), where the weight value of the criterion with the highest weight (C3) and the weight value of the criterion with the lowest weight (C4) are replaced.

In Fig. 3, it is observed that under the two scenarios, Kastamonu remains the optimal choice, and Artvin remains the second choice. Similarly, Muş and Iğdır remain the last two choices. In S1, the rankings of Kastamonu, Artvin, Sinop, Kırklareli, Balıkesir, Denizli, Erzincan, Van, Şanlıurfa, Adıyaman, Kars, Muş, and Iğdır are unchanged; in S2, the rankings of Kastamonu, Artvin, Adıyaman, Muş, and Iğdır are unchanged. The cities whose rank has most changed are Afyonkarahisar, Çankırı, Isparta, and Çorum in S1, and Afyonkarahisar, Ardahan, Çankırı, and Çorum in S2. Additionally, it is observed that Karabük and Tunceli, third place and fourth place, respectively, in the ranking obtained by the proposed method, have been displaced in the rankings obtained by S1 and S2. Generally, changes in criteria weights do not have a significant effect on the ranking of alternatives.

4. Results and discussion

In 2015, TurkStat conducted an index study to measure, compare, and monitor the lives of urban individuals with a well-being index for cities in Turkey [73]. In the study, which included 11 dimensions in total, calculations were made according to the hierarchical equal weighting method.

The results of the environmental dimension of the well-being index, the results of the proposed method, and the results of the scenarios created for the sensitivity analysis are given in Appendix C. According to the results, Kastamonu scored highest, with an environmental index value of 0.811, followed by Karabük with 0.795 and Bilecik with 0.756. Iğdır scored lowest, with an environmental index value of 0.196. Iğdır is preceded by Muş with 0.247 and Hakkâri with 0.311.

When the results are evaluated, Kastamonu is the first alternative according to all rankings and Iğdır is the last. Iğdır is preceded by Muş for all rankings. Yalova ranks fifth according to both the proposed method in this study and the environmental index. Artvin, second place in the proposed method, is eighth in the index. Karabük, third place in the proposed method, is second in the index. Because the multi-criteria HFLTS-based ARAS

Table 9
Solution results.

Alternative	K	Rank	Alternative	K	Rank	Alternative	K	Rank
Kastamonu	0.7533	1	Adana	0.5674	28	Kırşehir	0.4792	55
Artvin	0.7418	2	Kocaeli	0.5671	29	Yozgat	0.4784	56
Karabük	0.7018	3	Isparta	0.5658	30	Düzce	0.4744	57
Tunceli	0.6932	4	Trabzon	0.5625	31	Kilis	0.4644	58
Yalova	0.6830	5	Çorum	0.5605	32	Gaziantep	0.4594	59
Sinop	0.6622	6	Çankırı	0.5586	33	Ankara	0.4522	60
Rize	0.6467	7	Tokat	0.5537	34	Erzincan	0.4472	61
Bilecik	0.6399	8	Kırıkkale	0.5480	35	Diyarbakır	0.4417	62
Muğla	0.6348	9	Bursa	0.5478	36	Edirne	0.4395	63
Amasya	0.6342	10	Osmaniye	0.5413	37	Niğde	0.4335	64
Kütahya	0.6277	11	Samsun	0.5378	38	Mardin	0.4269	65
Kırklareli	0.6263	12	Bartın	0.5344	39	Nevşehir	0.4203	66
Bolu	0.6226	13	Şırnak	0.5339	40	Van	0.4188	67
Antalya	0.6217	14	Ordu	0.5229	41	Siirt	0.4178	68
Uşak	0.6082	15	Giresun	0.5220	42	Kayseri	0.4137	69
Zonguldak	0.6000	16	Hatay	0.5216	43	Ardahan	0.4077	70
Eskişehir	0.5985	17	Bingöl	0.5211	44	Şanlıurfa	0.3995	71
Mersin	0.5983	18	Sivas	0.5193	45	Bitlis	0.3983	72
Balıkesir	0.5960	19	Kahramanmaraş	0.5079	46	Bayburt	0.3841	73
Çanakkale	0.5953	20	Karaman	0.5015	47	Adıyaman	0.3787	74
Manisa	0.5953	21	Afyonkarahisar	0.4966	48	Batman	0.3592	75
Denizli	0.5921	22	Malatya	0.4956	49	Aksaray	0.3538	76
İstanbul	0.5827	23	Tekirdağ	0.4952	50	Hakkari	0.3357	77
İzmir	0.5752	24	Erzurum	0.4916	51	Kars	0.3297	78
Sakarya	0.5744	25	Elazığ	0.4887	52	Ağrı	0.3260	79
Burdur	0.5728	26	Konya	0.4867	53	Muş	0.2747	80
Aydın	0.5701	27	Gümüşhane	0.4818	54	Iğdır	0.2407	81

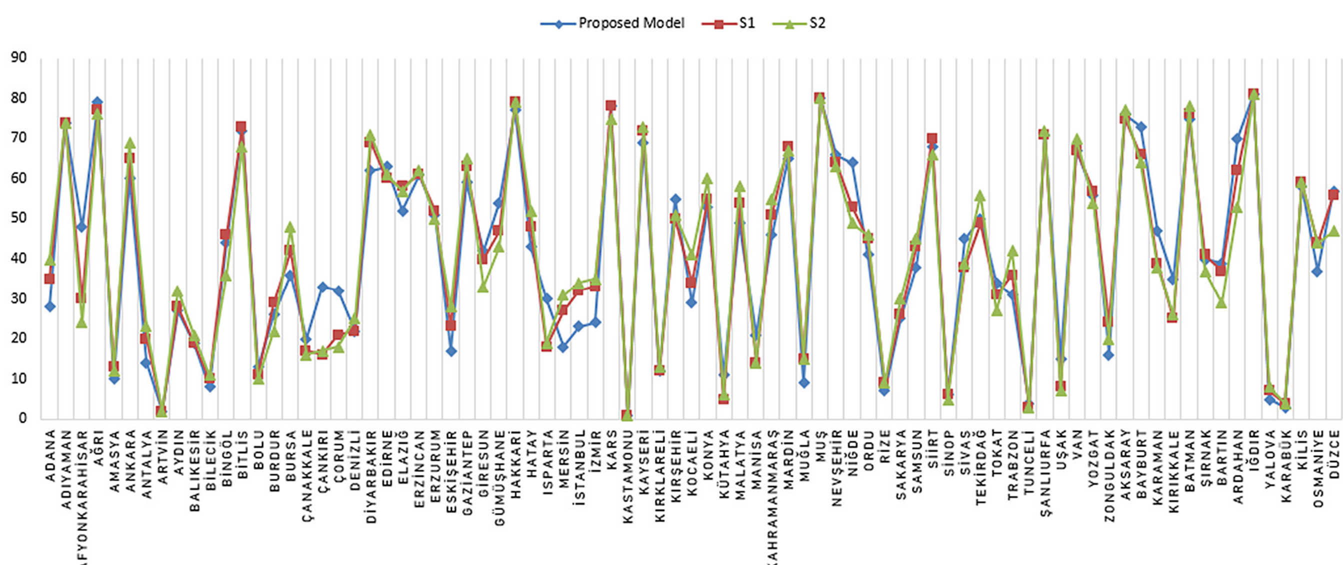

Fig. 3. Sensitivity analysis results.

method proposed in this study yields rankings similar to the index study conducted by TurkStat, it can be presented as an alternative approach that avoids the inherent drawbacks of the index study.

5. Conclusions and future works

In this study, a multi-criteria HFLTS-based ARAS approach was proposed for selecting eco-friendly cities in Turkey according to specified environmental criteria. The integration of these two methods provides a more accurate and systematic assessment in the decision-making process. Overall, the main advantage of the proposed method is that it allows decision-makers to approach complex decision-making problems with a highly methodological basis for decision support. Another practical advantage of the proposed method is the use of linguistic term sets because decision-makers often prefer linguistic evaluations to form the decision matrix. In addition, they may have difficulty defining linguistic terms and may need flexibility in their assessments. This obstacle, often encountered by decision-makers, is avoided through context-free grammar, ensuring that linguistic assessments collected from experts are effectively maintained without any loss of knowledge.

The environmental indicators of the well-being index study performed by TurkStat were used to generate the data set. The weights of five criteria were obtained using the multi-criteria HFLTS method. The ARAS method was utilized to rank the alternatives. According to the results, Kastamonu, Artvin, and Karabük are the most eco-friendly cities in Turkey. Except for Tunceli, the cities in the Eastern and Southeastern Anatolia regions rank near the bottom in terms of environmental criteria.

A sensitivity analysis was performed to examine changes in the ranking of alternatives as a result of changes in criteria weight values, and to show the robustness of the decision-making process. For this purpose, the weight values of the criteria were changed in accordance with two different scenarios, and the alternatives were revaluated. It was observed that changes in criteria weights did not have a significant effect on the rank of alternatives. Kastamonu remained the optimal choice under the two scenarios. Similarly, Muş and Iğdır remained least desirable choices.

Consequently, it is appropriate to use the proposed method to evaluate cities according to environmental criteria and to offer direction on smart city studies. However, there is a shortcoming concerning the data in this study. A second-hand source provided the data instead of gathering data directly from the cities. For future work, the number of criteria may be increased, and data can be collected directly from cities. Furthermore, the proposed method can be compared to other fuzzy MCDM methods.

Declaration of competing interest

No author associated with this paper has disclosed any potential or pertinent conflicts which may be perceived to have impending conflict with this work. For full disclosure statements refer to https://doi.org/10.1016/j.asoc.2020.106090.

CRediT authorship contribution statement

Aslı Çalış Boyacı: Writing - original draft, Writing - review & editing.

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Appendix A. Supplementary data

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