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A New Fuzzy Approach for Analyzing the Smartness of Cities: Case Study for Turkey

Melike Erdoğan*1

Abstract

Smart cities, developed as alternative to classical urbanism, are areas where information and communication technologies are used to make places more livable, sustainable and efficient. If a city offers solutions to problems related to governance, people, economy, mobility, environment and living issues, it can be defined as "smart city". The smartness of cities can be measured on these six basic axes. By analyzing the smartness of cities, evaluations can be made on the quality of life, health, public safety, environment and services. Hereby, appropriate measures can be taken against problems and strategies can be developed to increase the smartness of cities. This paper proposes a new decision making analysis to evaluate and compare the smartness of cities. For this aim, we considered the cities which are the candidates to be smart areas in Turkey. At this point, we applied multi-criteria decision-making (MCDM) analysis to evaluate criteria and alternatives in the decision process. We also utilized from fuzzy logic to model the uncertainty in the best way. Furthermore, we applied extended version of ordinary fuzzy sets which is named spherical fuzzy sets for the first time with QUALIFLEX method. Thus, one of the most comprehensive qualitative analyses ever made in the evaluation of smart cities is revealed and the usability of spherical fuzzy sets by MCDM methods is demonstrated. In addition, a sensitivity analysis was used to examine the robustness of the proposed method. As a result, a novel fuzzy decision-making approach has been proposed in the evaluation of smart cities.

Keywords: decision making, QUALIFLEX, smartness of cities, spherical fuzzy sets

1. INTRODUCTION

The smart city is a concept model with many "smart" sub-elements using technological developments to improve the living conditions of citizens. In recent years, the concept of the smart city has appeared as an area where expectations and calculations about social futures are made [1]. Because it is predicted that 70% of the world's population will reside in urban areas by 2050 and cities exhibit complex dynamics and require new solutions, the "smart city" model, which aims to deal with these problems, is becoming more and more important [2]. Since the demand of the high-density city population for energy, transportation, water supply, buildings and public spaces is higher, cities have to be "smarter" in the presence of the mentioned problems [3]. The idea behind

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the smart city is not only that a city's physical infrastructures and donations characterize an urban area and its functions, but it is also not easy to describe as information communication and social infrastructure. [4]. A smart city is a subject that is frequently handled both in practice and academia because of its potential to refer to several negative effects of rapid urbanization, industrialization and consumerism practices [5]. Because of different disciplines and sectoral perspectives, consensus on the definition of smart city could still not be built [5]. The definition of smart city is expanding and changing, recently this concept has been used in the same sense as information technology cities [6]. The smart city is the place that effectively uses strategic planning methods and innovative answers to improve the quality of life of their public, including ecological, cultural, political, institutional, social and economic components [5].

Besides many definitions of smart city concept, if a city applies solutions based on communication and information technologies to problems in six dimensions such as mobility, people, environmental, governance, quality of life and basic services and economy, it is regarded as "smart" [6-7]. With these axes, a smart city is much more than a digital city where attention is particularly focused on information and communication technology elements to enable data and information connectivity and exchange in an urban environment [4]. Considering these axes, the smart city is not only evaluated for the automation of services, buildings, traffic systems, it is also evaluated on behalf of undertakings to monitor, understand, analyze and plan the city in order to improve efficiency, equality and quality of life for citizens [7]. For a city to be considered a smart city, it should include initiatives and projects in its development plans [6]. The smartness measurement of cities is connected to the quality of life, health, public safety, disaster management, environmental aspects and services [8]. It is necessary to measure the smartness of cities in order to take appropriate actions in developing smartness features. The smartness of the cities can be measured with indicators under these six axes. Thus, many goals can be achieved, such as preparing action plans for smart cities, developing strategies, or comparing the smartness of cities. Using these six basic axes related to smart cities, studies on comparing the smartness of the cities were carried out. However, most of the studies are only based on qualitative analysis. The survey is one of the most used approaches in this sense. One of the approaches that allow the opportunity to examine and analyze these six axes together in evaluating and comparing the smartness of the cities is to use multi-criteria decision-making methods (MCDM). MDCM is an approach that aims to determine the most appropriate alternative or ranking of the alternatives in the decision environment where multiple, contradictory and interactive criteria exist. When trying to make a satisfactory decision with ambiguous and incomplete data, indecision, the presence of linguistic variables and multi-criteria, a decision maker should apply to MCDM methods under fuzzy environment [9]. The fuzzy set theory proposed by Zadeh [10] is one of the most effective ways to deal with vagueness and uncertainty [11]. In literature, MCDM methods which are classified as traditional and fuzzy are frequently used for the ranking of alternatives in decision problems. However traditional MCDM methods are insufficient in addressing linguistic uncertainty. Therefore MCDM methods are applied with fuzzy sets to consider the linguistic uncertainty better [12]. In most real-life MCDM problems, linguistic expressions are used to evaluate alternatives based on specified criteria, since the available information tends to be ambiguous, subjective or imprecise [13]. In the evaluation of the smartness of cities, situations such as the fact that there are conflicting criteria that cannot be measured numerically, and besides, situations, where alternatives are desired to be ranked in the presence of these criteria, make the problem a fuzzy MCDM problem. Based on all these, we have adopted the fuzzy MCDM approach in the evaluation and comparison of the smartness of cities in this paper. For this aim, we applied an extended version of the ordinary fuzzy sets which is named spherical fuzzy sets for the first time with QUALIFLEX MCDM method. This study fills an important gap in the literature, as it is one of the most detailed studies in the field of application area and the first time QUALIFLEX method are applied under spherical fuzzy environment. Thus, one of the most comprehensive quantitative analyses ever made in the evaluation of smart cities are revealed and the usability of spherical fuzzy sets by MCDM methods are demonstrated. For this reason, we believe that this paper is a prominent study for researchers and practitioners who are working on the implementation of MCDM methods within the framework of extended fuzzy sets in the specified area.

The rest of the paper is organized as follows. Section 2 presents the relevant literature on the problem and solution methodology that we adopted. Section 3 describes the proposed methodology. Section 4 contains the application for the evaluation of the smartness of cities in Turkey with the proposed methodology. Section 5 shows the results of the sensitivity analysis for the real case study. Finally, conclusions and future suggestions are presented in Section 6.

2. LITERATURE REVIEW

Many studies can be seen in the literature on the concept of smart city and the analysis of the smartness of the cities. Most of them carried out using questionnaires in the smartness analysis of cities. In a significant number of studies, six axes which are governance, people, economy, mobility, environment, and living were also taken into consideration in the evaluation of the smartness for the cities. Prominent studies in evaluating the smartness of the cities can be summarized as follows. Yigitcanlar and Kamruzzaman [5] aimed to incorporate a causal link between urban smartness and new ways of working, for instance working from home, and discover whether changes in urban smartness have remodeled the way residents go to work. Calderón et al. [6] prepared a survey to explain the current state of smartness and perceived readiness of Latin American Cities. Carli et al. [7] offered a two-dimensional study to classify the performance indicators of a smart city in determining technologies that can be adopted for the smart measurement and monitoring of a smart city. McKenna [14] analyzed the multidimensionality of smart cities by looking at relationships and interdependencies by associating the dimensions of smartness. Marsal-Llacuna [15] presented a set of indicators that serve to measure the newly accepted international definition in smart cities, and this set of indicators be used to measure the smartness of the city of Girona, Spain. Ahvenniemi and Huovila [16] showed a new perspective to discussions on various city concepts by investigating how smartness and sustainability are displayed in the city strategies of the six cities of Finland using content analysis. Hajduk [17] examined the diversity of smartness of European cities based on International Standards 37120 Norms on sustainable development of communities. Lima et al. [18] explored the main rules of the Brazilian City Statue, which have significant potential for having smarter and more sustainable Brazilian cities, and used a survey to prioritize the sixteen directives of the City Statue. Baykurt and Raetzsch [1] studied what smartness has done in the field by examining how media visions expected in policy decisions and local practices have been interpreted and acted upon since the early 2000s. Bernardino et al. [3] analyzed to what extent the heritage of European Capitals of Culture increased the smartness of cities and applied a qualitative method based on semi-structured interviews and desk research to evaluate its impact on the dimensions of the smart city. Axelsson and Granath [19] aimed to establish a structure that considers stakeholders and smartness dimensions in city planning and was applied to investigate the complexity of city planning on the development of a city area where a new planning method was applied in Sweden. Al-Nasrawi et al. [20] explored what smartness is and the method of assessment to apprehend the performance of the smart sustainable cities concept and pointed out that the smartness of cities is not limited to the application of smart solutions that meet the needs of citizens. Dall'O et al. [21] proposed a method for assessing smartness through indicators applicable to small and medium-sized cities, complying with the ISO 37120 standard and inspired by environmental indicators used in the EU's Sustainable Energy Action Plan. El Khayat and Fashal [22] dealt with the problems of how to place smart city components internally and how smart cities are placed relative to each other and their publics with the tools of optimization and Geographic Information Systems. Corsini et al. [23] evaluated economic and socio-demographic variables and smart city characteristics of 63 European cities using factor analysis and as a result of the study, they showed that there is no correlation between the city size and the smart city features, between economic wealth and smart city features.

Spherical fuzzy sets, which are an extension of the ordinary fuzzy sets adopted in this paper, were proposed by Kutlu Gündoğdu and Kahraman [24]. Since it is a newly developed method, there are only limited studies in the literature. Kutlu Gündoğdu and Kahraman [25] introduced accuracy functions; arithmetic and aggregation operations for spherical fuzzy sets with interval values, and then used the interval-valued spherical fuzzy TOPSIS method for selecting 3D printers. Kahraman et al. [26] applied spherical fuzzy MCDM approach for the selection process of debt collection firms in Turkey. Boltürk [27] handled the Automated Storage and Retrieval Systems technology selection problem by applying spherical fuzzy TOPSIS and neutrosophic fuzzy TOPSIS methods. Kutlu Gündoğdu and Kahraman [28] presented spherical fuzzy AHP method to show the applicability and validity of a problem of renewable energy location selection. Barukab et al. [29] developed the TOPSIS method under global fuzzy clusters when both the weight of the decision-makers and the criteria were not fully known and made an illustrative example for the robot selection problem. Kutlu Gündoğdu and Kahraman [30] applied the VIKOR method to the warehouse location selection problem by extending it under spherical fuzzy sets. Liu et al. [31] extended the MABAC (Multi-Attributive Border Approximation area Comparison) and TODIM (Interactive and Multi-Criteria Decision Making Portuguese abbreviation) methods into the linguistic spherical fuzzy environment for the evaluation of shared bicycles in China. Kutlu Gündoğdu and Kahraman [32] identified spherical fuzzy distances based on the parameters of membership, nonmembership and hesitancy and developed spherical fuzzy CODAS (COmbine Distance Based Assessment) method, demonstrating applicability in an illustrative example. Kahraman et al. [33] adopted the spherical fuzzy TOPSIS method in developing a quality house approach in comparing firms. Kutlu Gündoğdu [34] extended the MULTIMOORA method with spherical fuzzy numbers and used neutrosophic MULTIMOORA and intuitionistic fuzzy TOPSIS methods in the study where they exemplified the solution of the method. Yang et al. [35] developed the spherical normal fuzzy Bonferroni average operator and the weighted Bonferroni average operator and created an MCDM approach based on spherical normal fuzzy information and the proposed operators. They used the proposed approach to confirm the applicability in the antivirus mask selection problem according to the COVID-19 pandemic. Unlike all these studies, we have expanded the QUALIFLEX method for the first time with spherical fuzzy numbers. Besides, a comprehensive decision-making approach is proposed for the first time using extended fuzzy sets means that it is analyzed with a much more detailed decision-making approach among other the smart city assessment studies examined. Therefore, we believe that this study is a prominent paper in terms of both the adopted method and application area.

3. PROPOSED METHODOLOGY

In this section, the methodology that we proposed in the evaluation of the smartness of the cities is explained in the following subsections. Firstly, information about spherical fuzzy numbers was given, then the spherical fuzzy QUALIFLEX method developed in this study was introduced.

3.1. Spherical Fuzzy Sets

Spherical fuzzy sets are defined by three parameters membership, non-membership and hesitancy parameters (μ, ϑ, π). In spherical fuzzy sets, while the squared sum of membership, non-membership and hesitancy parameters can be between 0 and 1, each of them can be defined between 0 and 1 independently to satisfy that their squared sum is at most equal to 1 [24], [36], [37].

In this section, the definition of spherical fuzzy sets and summarize spherical distance measurement, arithmetic operations, aggregation operators and defuzzification operations are explained [24], [26], [38].

Definition 1. A spherical fuzzy set $\tilde{A}_s$ of the universe of discourse U is given by

$$\tilde{A}_s = \left\{ \left\langle u, (\mu_{\tilde{A}_s}(u), \vartheta_{\tilde{A}_s}(u), \pi_{\tilde{A}_s}(u)) \mid u \in U \right\rangle \right\} \quad (1)$$

where

$$\mu_{\tilde{A}_s} : U \to [0,1], \quad \vartheta_{\tilde{A}_s} : U \to [0,1], \quad \pi_{\tilde{A}_s} : U \to [0,1],$$

and

$$0 \le \mu^2_{\tilde{A}_s} + \vartheta^2_{\tilde{A}_s} + \pi^2_{\tilde{A}_s} \le 1 \qquad \forall u \in U \quad (2)$$

For each u, the numbers $\mu^2_{\tilde{A}_s}, \vartheta^2_{\tilde{A}_s}$ and $\pi^2_{\tilde{A}_s}$ are the degree of membership, nonmembership and hesitancy of u to $\tilde{A}_s$, respectively [24], [25], [28], [30], [32].

Definition 2. Basic Operators

Union;

$$\tilde{A}_s \cup \tilde{B}_s = \Big\{ \max\{\mu_{\tilde{A}_s}, \mu_{\tilde{B}_s}\}, \min\{\vartheta_{\tilde{A}_s}, \vartheta_{\tilde{B}_s}\}, \Big\{ \min\Big(1 - \big((\max\{\mu_{\tilde{A}_s}, \mu_{\tilde{B}_s}\})^2 + (\min\{\vartheta_{\tilde{A}_s}, \vartheta_{\tilde{B}_s}\})^2\big)\Big)^{1/2}, \max\left\{\pi_{\tilde{A}_s}, \pi_{\tilde{B}_s}\right\}\Big\}\Big\} \quad (3)$$

Intersection;

$$\tilde{A}_s \cap \tilde{B}_s = \Big\{ \min\{\mu_{\tilde{A}_s}, \mu_{\tilde{B}_s}\}, \max\{\vartheta_{\tilde{A}_s}, \vartheta_{\tilde{B}_s}\}, \max\Big\{\Big(1 - \big((\min\{\mu_{\tilde{A}_s}, \mu_{\tilde{B}_s}\})^2 + (\max\{\vartheta_{\tilde{A}_s}, \vartheta_{\tilde{B}_s}\})^2\big)\Big)^{1/2}, \min\left\{\pi_{\tilde{A}_s}, \pi_{\tilde{B}_s}\right\}\Big\}\Big\} \quad (4)$$

Addition;

$$\tilde{A}_s \oplus \tilde{B}_s = \Big\{ \left(\mu^2_{\tilde{A}_s} + \mu^2_{\tilde{B}_s} - \mu^2_{\tilde{A}_s}\mu^2_{\tilde{B}_s}\right)^{1/2}, \upsilon_{\tilde{A}_s}\upsilon_{\tilde{B}_s}, \left(\left(1-\mu^2_{\tilde{B}_s}\right)\pi^2_{\tilde{A}_s} + \left(1-\mu^2_{\tilde{A}_s}\right)\pi^2_{\tilde{B}_s} - \pi^2_{\tilde{A}_s}\pi^2_{\tilde{B}_s}\right)^{1/2} \Big\} \quad (5)$$

Multiplication;

$$\tilde{A}_s \otimes \tilde{B}_s = \Big\{ \mu_{\tilde{A}_s}\mu_{\tilde{B}_s}, \left(\upsilon^2_{\tilde{A}_s} + \upsilon^2_{\tilde{B}_s} - \upsilon^2_{\tilde{A}_s}\upsilon^2_{\tilde{B}_s}\right)^{1/2}, \left(\left(1-\upsilon^2_{\tilde{B}_s}\right)\pi^2_{\tilde{A}_s} + \left(1-\upsilon^2_{\tilde{A}_s}\right)\pi^2_{\tilde{B}_s} - \pi^2_{\tilde{A}_s}\pi^2_{\tilde{B}_s}\right)^{1/2} \Big\} \quad (6)$$

Multiplication by a scalar; $\lambda > 0$

$$\lambda.\tilde{A}_s = \Big\{ \left(1 - \left(1-\mu^2_{\tilde{A}_s}\right)^{\lambda}\right)^{1/2}, \upsilon^{\lambda}_{\tilde{A}_s}, \left(\left(1-\mu^2_{\tilde{A}_s}\right)^{\lambda} - \left(1-\mu^2_{\tilde{A}_s} - \pi^2_{\tilde{A}_s}\right)^{\lambda}\right)^{1/2} \Big\} \quad (7)$$

λ. Power of $\tilde{A}_s$; λ > 0

$$\tilde{A}_s^{\lambda} = \Big\{ \mu^{\lambda}_{\tilde{A}_s}, \left(1 - \left(1-\upsilon^2_{\tilde{A}_s}\right)^{\lambda}\right)^{1/2}, \left(\left(1-\upsilon^2_{\tilde{A}_s}\right)^{\lambda} - \left(1-\upsilon^2_{\tilde{A}_s} - \pi^2_{\tilde{A}_s}\right)^{\lambda}\right)^{1/2} \Big\} \quad (8)$$

Definition 3. For these spherical fuzzy sets $\tilde{A}_s = (\mu_{\tilde{A}_s}, \upsilon_{\tilde{A}_s}, \pi_{\tilde{A}_s})$ and $\tilde{B}_s = (\mu_{\tilde{B}_s}, \upsilon_{\tilde{B}_s}, \pi_{\tilde{B}_s})$, the followings are valid under the condition $\lambda, \lambda_1, \lambda_2 > 0$.

i. $\tilde{A}_s \oplus \tilde{B}_s = \tilde{B}_s \oplus \tilde{A}_s$ (9)

ii. $\tilde{A}_s \otimes \tilde{B}_s = \tilde{B}_s \otimes \tilde{A}_s$ (10)

iii. $\lambda(\tilde{A}_s \oplus \tilde{B}_s) = \lambda\tilde{A}_s \oplus \lambda\tilde{B}_s$ (11)

iv. $\lambda_1\tilde{A}_s \oplus \lambda_2\tilde{A}_s = (\lambda_1 + \lambda_2)\tilde{A}_s$ (12)

v. $(\tilde{A}_s \otimes \tilde{B}_s)^{\lambda} = \tilde{A}_s^{\lambda} \otimes \tilde{B}_s^{\lambda}$ (13)

vi. $\tilde{A}_s^{\lambda_1} \otimes \tilde{A}_s^{\lambda_2} = \tilde{A}_s^{\lambda_1+\lambda_2}$ (14)

Definition 4. Spherical Weighted Arithmetic Mean (SWAM) with respect to, $w=(w_1,w_2,..,w_n);\quad w_i\in[0,1];\ \sum_{i=1}^{n}w_i=1,$ SWAM is defined as;

$$SWAM_w(\tilde{A}_{S_1},\tilde{A}_{S_2},...,\tilde{A}_{S_n})=w_1\tilde{A}_{S_1}+w_2\tilde{A}_{S_2}+.....+w_n\tilde{A}_{S_n}$$
$$=\left\{\left[1-\prod_{i=1}^{n}(1-\mu_{\tilde{A}_S}^2)^{w_i}\right]^{1/2},\right.$$
$$\prod_{i=1}^{n}\upsilon_{\tilde{A}_S}^{w_i},\left[\prod_{i=1}^{n}(1-\mu_{\tilde{A}_S}^2)^{w_i}-\prod_{i=1}^{n}(1-\mu_{\tilde{A}_S}^2-\pi_{\tilde{A}_S}^2)^{w_i}\right]^{1/2}$$
(15)

Definition 5. Spherical Weighted Geometric Mean (SWGM) with respect to, $w=(w_1,w_2,..,w_n);\quad w_i\in[0,1];\ \sum_{i=1}^{n}w_i=1,$ SWGM is defined as;

$$SWGM_w(\tilde{A}_{S_1},\tilde{A}_{S_2},...,\tilde{A}_{S_n})=\tilde{A}_{S_1}^{w_1}+\tilde{A}_{S_1}^{w_2}+.....+\tilde{A}_{S_n}^{w_n}$$
$$=\left\{\prod_{i=1}^{n}\mu_{\tilde{A}_{S_i}}^{w_i},\left[1-\prod_{i=1}^{n}(1-\upsilon_{\tilde{A}_{S_i}}^2)^{w_i}\right]^{1/2},\right.$$
$$\left.\left[\prod_{i=1}^{n}(1-\upsilon_{\tilde{A}_{S_i}}^2)^{w_i}-\prod_{i=1}^{n}(1-\upsilon_{\tilde{A}_{S_i}}^2-\pi_{\tilde{A}_{S_i}}^2)^{w_i}\right]^{1/2}\right\}$$
(16)

3.2. Spherical Fuzzy QUALIFLEX

The qualitative flexible multiple (QUALIFLEX) ranking method is the generalization of Jacquet-Lagreze's permutation approach and is beneficial in decision analysis due to its flexibility regarding cardinal and ordinal information [39]. The approach was firstly introduced by Paelinck in 1975 [40]. It analyzes all possible permutations of the alternatives based on the results of the whole criteria [41]. As decision-making environments often involve uncertainty, one of the most frequently used approaches to address uncertainty in the process is to use fuzzy logic. In particular, the solution of almost all MCDM problems has been expanded with fuzzy logic to provide more realistic results recently. At this point, the QUALIFLEX method has found application with ordinary fuzzy sets and extended fuzzy sets in MCDM problems in different areas. For example, interval-valued intuitionistic fuzzy QUALIFLEX approach with a likelihood-based comparison method is suggested to select most appropriate bridge construction [42], interval type-2 fuzzy sets for QUALIFLEX method applied in a medical decision-making problem [39], a Fine - Kinney occupational risk assessment approach with type-2 fuzzy QUALIFLEX approach is implemented in the chrome plating unit [46], type-2 QUALIFLEX method is used to estimate carbon emissions [48], regret theory and QUALIFLEX under a 2-dimensional vague linguistic variable is suggested for sustainable supplier selection [49], the Gray Group QUALIFLEX method is applied in the project management case [53], the multiple criteria hierarchy process and QUALIFLEX methodology is combined to be suitable for interaction modeling between criteria using the concept of the bipolar Choquet integral [54], QUALIFLEX method is integrated with the ORESTE model to evaluate the performance of green mines in uncertain hesitant conditions [55], probabilistic linguistic QUALIFLEX method is suggested for group decision-making problems in which the evaluation information of alternatives is expressed in hesitant fuzzy sets and the weights are partly known [56], QUALIFLEX is adopted in determining the performance efficiency of existing ballast water treatment system used on ships under interval type-2 fuzzy environment [57] and QUALIFLEX is employed in handling multiple evaluation criteria with heterogeneity [58]. Unlike all these studies, we have extended the QUALIFLEX outranking method with spherical fuzzy sets for the first time in this study.

The QUALIFLEX method based on spherical fuzzy numbers has been presented as follows [39-40], [43], [57], [59]:

Step 1: Formulate the decision-making problem in which the evaluation criteria $X=\{x_1,x_2,....x_n\}$ and feasible alternatives $A=\{A_1,A_2,...A_m\}$.

Step 2. Select appropriate linguistic variables and translation standards for conversion into spherical fuzzy numbers for the importance weights of criteria and the linguistic ratings for the alternatives with respect to each criterion. The linguistic scale that we apply to spherical fuzzy QUALIFLEX method is in Table 1 [30].

Table 1
Spherical fuzzy numbers for linguistic terms

Linguistic Terms	(μ, Ʋ, π)
Absolutely More Importance (AMI)	(0.9,0.1,0.1)
Very High Importance (VHI)	(0.8,0.2,0.2)
High Importance (HI)	(0.7,0.3,0.3)
Slightly More Importance (SMI)	(0.6,0.4,0.4)
Equally Importance (EI)	(0.5,0.5,0.5)
Slightly Low Importance (SLI)	(0.4,0.6,0.4)
Low Importance (LI)	(0.3,0.7,0.3)
Very Low Importance (VLI)	(0.2,0.8,0.2)
Absolutely Low Importance (ALI)	(0.1,0.9,0.1)

Step 3. The linguistic evaluation of criteria and alternatives with respect to each criterion that best represents the importance of the criteria and the alternative evaluation, respectively, is provided by experts.

Step 4. The linguistic evaluation is converted to the spherical fuzzy numbers to obtain the rating A_{ij} of the alternative A_i on the criterion x_j and the importance weight w_j of the criterion x_j which satisfies $0 \le w_j \le 1$ and $\sum_{j=1}^{n} w_j = 1$ for each expert. Denote the evaluation values of alternatives A_i $(i = 1,2,....m)$ with respect to the criterion x_j $(j = 1,2,...n)$ by $x_j(\tilde{A}_i) = (\mu_{ij}, \upsilon_{ij}, \pi_{ij})$ and $\tilde{D} = (x_j(\tilde{A}_i)_{mxn}$ is a spherical fuzzy decision matrix. For an MCDM problem with spherical fuzzy sets, the decision matrix $\tilde{D} = (x_j(\tilde{A}_i)_{mxn}$ should be constructed as in Equation (Eq.) (17) and the importance of criteria vector W as in Eq (18).

$$\tilde{D} = (x_j(\tilde{A}_i)_{mxn} = \begin{pmatrix} (\mu_{11},\upsilon_{11},\pi_{11}) & (\mu_{11},\upsilon_{11},\pi_{11}) & \cdots & (\mu_{1n},\upsilon_{1n},\pi_{1n}) \\ (\mu_{21},\upsilon_{21},\pi_{21}) & (\mu_{11},\upsilon_{11},\pi_{11}) & \cdots & (\mu_{2n},\upsilon_{2n},\pi_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ (\mu_{m1},\upsilon_{m1},\pi_{m1}) & (\mu_{m2},\upsilon_{m2},\pi_{m2}) & \cdots & (\mu_{mn},\upsilon_{mn},\pi_{mn}) \end{pmatrix}$$

(17)

$$\tilde{W}_j = (\tilde{w}_1, \tilde{w}_2, ...\tilde{w}_n) \tag{18}$$

Step 5. The judgments of each decision-maker/expert for criteria-alternative evaluations and criteria weights are aggregated using Spherical Weighted Arithmetic Mean (SWAM) operators that are given in Definitions (4).

Step 6. Calculate the score index for the aggregated decision matrix and criteria vector as in Eq. (19) and Eq. (20), respectively. Then normalize the criteria weights as in Eq. (21).

$$Score(x_j(\tilde{A}_i)) = (2\mu_{ij} - \pi_{ij})^2 - (\upsilon_{ij} - \pi_{ij})^2 \tag{19}$$

$$Score(\tilde{w}_j) = (2\mu_{ij} - \pi_{ij})^2 - (\upsilon_{ij} - \pi_{ij})^2 \tag{20}$$

$$\bar{w}_j = \frac{Score(\tilde{w}_j)}{\sum_{j=1}^{n} Score(\tilde{w}_j)} \tag{21}$$

Step 7. List all of the possible $m!$ permutations of the m alternatives that must be tested. Let $P_l = (l = 1,2,...,m!)$ denote the lth permutation. Assume that the alternative $\tilde{A}_\alpha$ has a higher score index than or equal to $\tilde{A}_\beta$. Given the alternative set A with m alternatives, $m!$ permutations of the ranking of the alternatives exist. Let Pl denote the lth permutation:

$P_l = (..,\tilde{A}_\alpha,...,\tilde{A}_\beta,...),$ for $l=1,2,…,m!$

The evaluation values of $\tilde{A}_\alpha$ and $\tilde{A}_\beta$ with respect to each criterion $x_j \in X$ are

$$\tilde{A}_{\alpha j} = (\mu_{\tilde{A}_{\alpha j}}, \nu_{\tilde{A}_{\alpha j}}, \pi_{\tilde{A}_{\alpha j}})$$

$$\tilde{A}_{\beta j} = (\mu_{\tilde{A}_{\beta j}}, \nu_{\tilde{A}_{\beta j}}, \pi_{\tilde{A}_{\beta j}})$$

The score index values for $\tilde{A}_{\alpha j}$ and $\tilde{A}_{\beta j}$ is taking into consideration to rank the corresponding alternatives.

Step 8. The score index based approach is used to identify the concordance/discordance index. The concordance/discordance index, $I_j^l(\tilde{A}_\alpha, \tilde{A}_\beta)$, for each pair of alternatives, $(\tilde{A}_\alpha, \tilde{A}_\beta)$, $\tilde{A}_\alpha, \tilde{A}_\beta \in A$, at the level of preorder, according to the criterion $xj \in X$ and the ranking corresponding to the lth permutation, is as follows:

$$I_j^l(\tilde{A}_\alpha, \tilde{A}_\beta) = \begin{cases} 1 & \text{if there is concordance} \\ 0 & \text{if there is aequo} \\ -1 & \text{if there is discordance} \end{cases} \quad (22)$$

There are concordance, ex aequo, and discordance if $I_j^l(\tilde{A}_\alpha, \tilde{A}_\beta) > 0, I_j^l(\tilde{A}_\alpha, \tilde{A}_\beta) = 0,$ and $I_j^l(\tilde{A}_\alpha, \tilde{A}_\beta) < 0,$ respectively. Moreover, the concordance/discordance index I_j^l, between the preorder according to the criterion xj and the ranking corresponding to the lth permutation, is:

$$I_j^l = \sum_{\tilde{A}_\alpha, \tilde{A}_\beta \in \tilde{A}} I_j^l(\tilde{A}_\alpha, \tilde{A}_\beta) \quad (23)$$

Step 9. The weighted concordance and discordance index is calculated for each pair of alternatives in mth permutation as following:

$$I^l(\tilde{A}_\alpha, \tilde{A}_\beta) = \sum_{j=1}^{n} I_j^l(\tilde{A}_\alpha, \tilde{A}_\beta).\bar{w}_j \quad (24)$$

Step 10. The comprehensive concordance and discordance index I^l is calculated using Equation (25).

$$I^l = \sum_{\tilde{A}_\alpha, \tilde{A}_\beta \in \tilde{A}} \sum_{j=1}^{n} I_j^l(\tilde{A}_\alpha, \tilde{A}_\beta).\bar{w}_j \quad (25)$$

The permutation with the maximal I^l value is the optimal ranking order of the alternatives.

4. REAL CASE ANALYSIS

A new fuzzy MCDM approach has been proposed to evaluate the smartness of the municipalities which are Istanbul Metropolitan Municipality, Karaman Municipality, Osmaniye Municipality, Karadeniz Ereğli Municipality and Antalya Metropolitan Municipality. They are the candidate smart cities in Turkey determined by Ministry of Environment and Urbanization and involved in studies on the smart city concept. For this purpose, the relevant literature has been reviewed to determine which criteria can be taken into consideration in the smartness comparison of these municipalities. As a result of this research, it is determined that six main axes which are governance, people, economy, mobility, environment, and living can be used to evaluate the smartness of the cities as the criteria. For this reason, smart city alternatives determined by 2020-2023 National Smart Cities Strategy and Action Plan for Turkey [60] published by the Ministry of Environment and Urbanization were evaluated on governance, people, economy, mobility, environment, and living axes and the smartness levels for the determined municipalities were tried to be ranked. In order to calculate the criteria weights and criteria-alternative scores, assessments were get from three decision makers (experts) who previously worked on smart city concept. Then, the evaluations received from the experts were converted into spherical fuzzy numbers with the linguistic scale in Table 1 and the steps of the proposed method were initiated. In this decision making process, Expert-1's weight is 0.2, Expert-2's weight is 0.35 and finally Expert-3's weight is 0.45 by level of their expertise. Table 2 shows the evaluations for criteria weights while Table 3 shows the criteria – alternatives evaluations for each expert.

Table 2
Evaluations for criteria weights by experts

Criteria / Expert	***Expert-1***	***Expert-2***	***Expert-3***
C1: Governance	SMI	SLI	SMI
C2: People	SLI	LI	EI
C3: Economy	HI	SLI	SMI
C4: Mobility	EI	SMI	HI
C5: Environment	SLI	SLI	EI

C6: Living	SMI	EI	SLI

Table 3
Criteria – alternative evaluations by experts

Expert-1	***Criteria***					
Alternatives	Gover	Pe	Eco	Mo	Enviro	Liv
Istanbul	SLI	HI	SMI	HI	SLI	S
Karaman	SMI	LI	SLI	EI	SLI	SL
Osmaniye	SLI	SL	SMI	SLI	SMI	HI
Karadeniz Ereğli	EI	HI	SLI	SMI	HI	SL
Antalya	HI	V	SMI	SMI	HI	S
Expert-2	***Criteria***					
Alternatives	Gover	Pe	Eco	Mo	Enviro	Liv
Istanbul	SMI	HI	SLI	SMI	SLI	SL
Karaman	SMI	LI	SMI	EI	SMI	S
Osmaniye	SLI	SL	SLI	SLI	SMI	S
Karadeniz Ereğli	EI	HI	SLI	SLI	HI	LI
Antalya	HI	EI	SMI	SMI	EI	S
Expert- 3	***Criteria***					
Alternatives	Gover	Pe	Eco	Mo	Enviro	Liv
Istanbul	EI	HI	SMI	HI	SLI	S
Karaman	SLI	LI	SLI	EI	SLI	SL
Osmaniye	SMI	S	EI	SLI	SMI	HI
Karadeniz Ereğli	EI	HI	SLI	SMI	HI	SL
Antalya	HI	V	SMI	EI	SLI	EI

After obtaining evaluations from the experts regarding the criteria weights and criteria - alternative scores, and converting into spherical fuzzy sets using the linguistic variables in Table 1, evaluations were aggregated using the SWAM operator presented in Definition (4). The aggregated evaluations for weights of criteria and criteria – alternative scores were respectively presented in Table 4 and Table 5.

Table 4
Aggregated criteria weights

Criteria	Weight (μ,υ,π)
Governance	(0.544,0.461,0.402)
People	(0.423,0.583,0.434)
Economy	(0.572,0.435,0.380)
Mobility	(0.635,0.367,0.375)
Environment	(0.449,0.553,0.454)
Living	(0.485,0.519,0.442)

Table 5
Aggregated criteria – alternative scores

Criteria /Alternative	Governance			People		
	μ	Ʋ	π	μ	Ʋ	π
A1: Istanbul Metropolitan Municipality	0.524	0.480	0.449	0.700	0.300	0.300
A2: Karaman Municipality	0.526	0.480	0.402	0.300	0.700	0.300
A3: Osmaniye Municipality	0.507	0.500	0.402	0.507	0.500	0.402
A4: Karadeniz Ereğli Municipality	0.500	0.500	0.500	0.700	0.300	0.300
A5: Antalya Metropolitan Municipality	0.700	0.300	0.300	0.731	0.276	0.302
Criteria /Alternative	**Economy**			**Mobility**		
	μ	Ʋ	π	μ	Ʋ	π
A1: Istanbul Metropolitan Municipality	0.544	0.461	0.402	0.669	0.332	0.335
A2: Karaman Municipality	0.486	0.521	0.402	0.500	0.500	0.500
A3: Osmaniye Municipality	0.494	0.510	0.451	0.400	0.600	0.400
A4: Karadeniz Ereğli Municipality	0.400	0.600	0.400	0.544	0.461	0.402
A5: Antalya Metropolitan Municipality	0.600	0.400	0.400	0.559	0.442	0.445
Criteria /Alternative	**Environment**			**Living**		
	μ	Ʋ	π	μ	Ʋ	π
A1:Istanbul Metropolitan Municipality	0.400	0.600	0.400	0.544	0.461	0.402
A2: Karaman Municipality	0.486	0.521	0.402	0.486	0.521	0.402
A3: Osmaniye Municipality	0.600	0.400	0.400	0.669	0.332	0.335
A4: Karadeniz Ereğli Municipality	0.700	0.300	0.300	0.369	0.633	0.371
A5: Antalya Metropolitan Municipality	0.519	0.490	0.420	0.559	0.442	0.445

After the evaluations from experts are aggregated, the score indexes for both criteria-alternative evaluations and criteria weights are calculated as in Eq. (19) and Eq. (20). Score indexes calculated for weights are normalized as in Eq. (21). All possible permutations of the rankings of the five smart cities are enumerated and discordance and concordance indexes are determined which reflects the concordance and discordance of ranks and evaluation preorder for each couple of alternatives of permutations. In this way, for each permutation, 5! (120) matrices are created with the concordance and discordance index calculated. Then, weighted concordance and discordance index are calculated for each alternative pair in *m.* permutation. Table 6 shows the concordance, ex aequo, and discordance matrix for each pair of alternatives in Permutation -1 (P1).

The detailed concordance and discordance index I^l is calculated using Eq. (25) for all permutations. Table 7 shows the concordance and discordance index values for each permutation.

Table 6
The concordance, ex aequo, and discordance matrix for Permutation-1

P1:	**A1>A2>A3>A4>A5**										
	I(A1,A2)	I(A1,A3)	I(A1,A4)	I(A1,A5)	I(A2,A3)	I(A2,A4)	I(A2,A5)	I(A3,A4)	I(A3,A5)	I(A4,A5)	Total
C1	1	1	0	-1	-1	-1	-1	-1	-1	-1	-5
C2	1	1	1	-1	1	1	-1	1	-1	-1	2
C3	1	1	1	1	1	-1	-1	-1	-1	1	2
C4	1	1	1	1	1	-1	-1	-1	-1	1	2
C5	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-6
C6	1	-1	1	1	-1	1	-1	1	1	-1	2
										I^1 :	0.248219

Table 7
The comprehensive concordance and discordance index for each permutation

Permutation	Index Value	Permutation	Index Value	Permutation	Index Value	Permutation	Index Value
P1:A1>A2>A3>A4>A5	0.248219	**P31: A2>A3>A1>A4>A5**	-2.94171	**P61: A3>A4>A1>A2>A5**	-1.68359	**P91: A4>A5>A3>A1>A2**	2.306055
P2: A1>A2>A3>A5>A4	-0.51912	**P32: A2>A3>A1>A5>A4**	-3.70905	**P62: A3>A4>A1>A5>A2**	0.316411	**P92: A4>A5>A3>A2>A1**	0.519121
P3: A1>A2>A4>A3>A5	1.642034	**P33: A2>A3>A4>A1>A5**	-4.34989	**P63: A3>A4>A2>A1>A5**	-3.47052	**P93: A4>A5>A1>A3>A2**	3.709055
P4: A1>A2>A4>A5>A3	3.176073	**P34: A2>A3>A4>A5>A1**	-5.2881	**P64: A3>A4>A2>A5>A1**	-4.40873	**P94: A4>A5>A1>A2>A3**	4.354541
P5: A1>A2>A5>A4>A3	2.408732	**P35: A2>A3>A5>A4>A1**	-6.05544	**P65: A3>A4>A5>A2>A1**	-2.40873	**P95: A4>A5>A2>A1>A3**	2.567607
P6: A1>A2>A5>A3>A4	0.883878	**P36: A2>A3>A5>A1>A4**	-4.64726	**P66: A3>A4>A5>A1>A2**	-0.6218	**P96: A4>A5>A2>A3>A1**	1.164607
P7: A1>A3>A2>A4>A5	-0.39727	**P37: A2>A5>A4>A3>A1**	-3.12759	**P67: A3>A5>A1>A4>A2**	0.019038	**P97: A5>A2>A3>A4>A1**	-2.65244
P8: A1>A3>A2>A5>A4	-1.16461	**P38: A2>A4>A3>A5>A1**	-3.76325	**P68: A3>A5>A1>A2>A4**	-1.50582	**P98: A5>A2>A3>A1>A4**	-1.24426
P9: A1>A3>A4>A2>A5	1.127588	**P39: A2>A4>A1>A3>A5**	-1.42204	**P69: A3>A5>A4>A1>A2**	-1.38914	**P99: A5>A2>A4>A3>A1**	-1.12759
P10: A1>A3>A4>A5>A2	3.127588	**P40: A2>A4>A1>A5>A3**	-0.01904	**P70: A3>A5>A4>A2>A1**	-3.17607	**P100: A5>A2>A4>A1>A3**	0.275412
P11: A1>A3>A5>A4>A2	2.360247	**P41: A2>A4>A5>A1>A3**	-0.95725	**P71: A3>A5>A2>A4>A1**	-4.70093	**P101: A5>A2>A1>A4>A3**	1.683589
P12: A1>A3>A5>A2>A4	0.835393	**P42: A2>A4>A5>A3>A1**	-2.36025	**P72: A3>A5>A2>A1>A4**	-3.29275	**P102: A5>A2>A1>A3>A4**	0.158735
P13: A1>A4>A3>A2>A5	2.652442	**P43: A2>A5>A3>A4>A1**	-4.65244	**P73: A4>A2>A3>A1>A5**	-1.30018	**P103: A5>A3>A2>A4>A1**	-3.29793
P14: A1>A4>A3>A5>A2	4.652442	**P44: A2>A5>A3>A1>A4**	-3.24426	**P74: A4>A2>A3>A5>A1**	-2.23839	**P104: A5>A3>A2>A1>A4**	-1.88975
P15: A1>A4>A2>A3>A5	3.297928	**P45: A2>A5>A4>A3>A1**	-3.12759	**P75: A4>A2>A1>A3>A5**	0.102816	**P105: A5>A3>A4>A2>A1**	-1.77307
P16: A1>A4>A2>A5>A3	4.700927	**P46: A2>A5>A4>A1>A3**	-1.72459	**P76: A4>A2>A1>A5>A3**	1.505816	**P106: A5>A3>A4>A1>A2**	0.01386
P17: A1>A4>A5>A2>A3	6.700927	**P47: A2>A5>A1>A4>A3**	-0.31641	**P77: A4>A2>A5>A1>A3**	0.567607	**P107: A5>A3>A1>A4>A2**	1.422038
P18: A1>A4>A5>A3>A2	6.055441	**P48: A2>A5>A1>A3>A4**	-1.84127	**P78: A4>A2>A5>A3>A1**	-0.83539	**P108: A5>A3>A1>A2>A4**	-0.10282
P19: A1>A5>A3>A4>A2	3.763246	**P49: A3>A2>A1>A4>A5**	-3.5872	**P79: A4>A3>A2>A1>A5**	-1.94567	**P109: A5>A4>A3>A2>A1**	-0.24822
P20: A1>A5>A3>A2>A4	2.238392	**P50: A3>A2>A1>A5>A4**	-4.35454	**P80: A4>A3>A2>A5>A1**	-2.88388	**P110: A5>A4>A3>A1>A2**	1.538715
P21: A1>A5>A4>A3>A2	5.288101	**P51: A3>A2>A4>A1>A5**	-4.99538	**P81: A4>A3>A1>A2>A5**	-0.15873	**P111: A5>A4>A2>A3>A1**	0.397267
P22: A1>A5>A4>A2>A3	5.933587	**P52: A3>A2>A4>A5>A1**	-5.93359	**P82: A4>A3>A1>A5>A2**	1.841265	**P112: A5>A4>A2>A1>A3**	1.800266
P23: A1>A5>A2>A4>A3	4.408732	**P53: A3>A2>A5>A4>A1**	-6.70093	**P83: A4>A3>A5>A1>A2**	0.903056	**P113: A5>A4>A1>A2>A3**	3.5872
P24: A1>A5>A2>A3>A4	2.883878	**P54: A3>A2>A5>A1>A4**	-5.29275	**P84: A4>A3>A5>A2>A1**	-0.88388	**P114: A5>A4>A1>A3>A2**	2.941714
P25: A2>A1>A3>A4>A5	-1.53871	**P55: A3>A1>A2>A4>A5**	-1.80027	**P85: A4>A1>A3>A2>A5**	1.244265	**P115: A5>A1>A3>A4>A2**	2.825037
P26: A2>A1>A3>A5>A4	-2.30606	**P56: A3>A1>A2>A5>A4**	-2.56761	**P86: A4>A1>A3>A5>A2**	3.244265	**P116: A5>A1>A3>A2>A4**	1.300183
P27: A2>A1>A4>A3>A5	-0.01386	**P57: A3>A1>A4>A2>A5**	-0.27541	**P87: A4>A1>A2>A3>A5**	1.88975	**P117: A5>A1>A4>A3>A2**	4.349891
P28: A2>A1>A4>A5>A3	1.389139	**P58: A3>A1>A4>A5>A2**	1.724588	**P88: A4>A1>A2>A5>A3**	3.29275	**P118: A5>A1>A4>A2>A3**	4.995377
P29: A2>A1>A5>A4>A3	0.621798	**P59: A3>A1>A5>A4>A2**	0.957247	**P89: A4>A1>A5>A2>A3**	5.29275	**P119: A5>A1>A2>A4>A3**	3.470523
P30: A2>A1>A5>A3>A4	-0.90306	**P60: A3>A4>A1>A2>A5**	-0.56761	**P90: A4>A1>A5>A3>A2**	4.647264	**P120: A5>A1>A2>A3>A4**	1.945669

After calculating the detailed indexes for all permutations, the permutation with the highest index value is investigated. When Table 7 is examined, it is seen that the permutation with the highest index value is the 17th permutation, "A1> A4> A5> A2> A3". In other words, Istanbul, which is the first alternative – A1, is placed in the first rank in evaluating the smartness of the cities. The second smartest city was found as "Karadeniz Ereğli". The third alternative is Antalya; Karaman takes fourth place and Osmaniye alternative takes the last place. Istanbul is a pioneer city in smart city applications. Intelligent systems are used in many areas such as water management, disaster and emergency management, health, tourism, or security throughout the city. For this reason, it is not surprising that it appears as the "smartest" city in the country. Under favour of the city's plans and breakthroughs in these mentioned directions, Karadeniz Ereğli Municipality has been identified as the second smartest city. The last alternative ranked is the city of Osmaniye. It is seen that it lags behind other alternatives in the planning and implementation of smart systems in the city. At this point, considering the criteria included in the proposed decision problem, Osmaniye can become competitive with other alternatives as a result of making strides in smart systems and instilling the concept of smart into the city.

5. Sensitivity Analysis

We applied sensitivity analysis to understand the robustness of the results obtained from the proposed approach and to monitor the results that change according to criteria weights. Thus, it has been investigated whether flexible recommendations can be developed to take into account the changing conditions in the decision-making process. For this purpose, different scenarios were created by increasing the weight of one criterion higher than others, respectively, keeping the others small and constant, and thus the effect of the criterion on the decision-making process was examined. Each of the six different criteria weighted 0.8 in one scenario, while the other criteria weights were kept constant at 0.04.

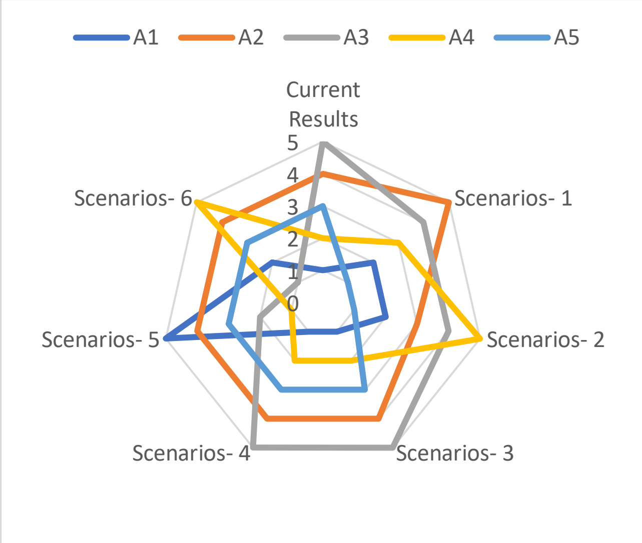

Figure 1: Sensitivity results

According to the sensitivity analysis results, two of the six scenarios (scenarios 3 and 4) gave the same ranking as the current situation. These are scenarios where the weights of the third and fourth criteria are increased. At this point, it can be argued that the third and fourth criteria weights do not have a significant effect on the result of fuzzy MCDM analysis. In scenarios 1 and 2, the A5 alternative was in the first place, in scenario 5 the A4 alternative and in scenario 6, the A3 alternative was found in the first place. Except for the 3rd and 4th scenarios, the Istanbul alternative, which is currently determined in the first place, is determined in the 2nd place in scenarios 1,2 and 6. That is, even if the criteria weights change, the alternative found in the first place in the current situation is taken place near the top. As a result of this sensitivity analysis, it can be said that the proposed approach is affected by different criteria weights parameters, but the results are robust.

6. Conclusions and Future Suggestions

The smart city is a place that effectively uses strategic planning methods and innovative responses to enhance the quality of life, including ecological, social, cultural, institutional and economic factors. A city is considered "smart" if it applies solutions based on information and communication technologies to problems in governance, people, economy, mobility, environment and life. Some scientific approaches have been developed to measure the smartness of a city. Among these approaches, MCDM, which can evaluate many qualitative and quantitative criteria at the same time, becomes prominent. MCDM approaches are generally used in the framework of fuzzy logic when uncertainty is present in decision-making processes. In order to better reflect the uncertainty in the decision-making problem, extended versions instead of ordinary fuzzy sets are adopted. The independent designation of the parameters of membership with broader domains creates a new perspective on the problem of determining the smartness of the cities with using spherical fuzzy sets.

In this paper, the evaluation of smartness of the cities was carried out with the use of spherical fuzzy sets for the first time. In addition, QUALIFLEX, which is an effective MCDM method, was applied for the first time with spherical fuzzy sets and thus an important gap in the literature was also filled with this application. A smartness analysis for the five cities in Turkey which are determined as the smart city candidates by the Ministry of Environment and Urbanization is conducted and İstanbul was found to be the smartest city in Turkey. In addition, as a result of the sensitivity analysis, changes in the results were examined under different criteria weights. In the current situation, the alternative of Istanbul, which was determined in the first place, was also in the first place in different scenarios and the robustness of the proposed approach was revealed. In addition, as a result of the sensitivity analysis, changes in the results were examined according to the different criteria weights. The alternative of Istanbul, which was determined in the first place in the current situation, was also in the first place in some different scenarios in sensitivity analysis and the robustness of the proposed approach was revealed with this analysis. With this paper, the use of spherical fuzzy sets with MCDM approaches has been implemented under a method that has not been used before, and therefore an important contribution has been made to the literature in fuzzy MCDM area.

In future studies that we suggest, different MCDM methods can be employed to make a comparative analysis or different fuzzy sets extensions can be used.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval

The authors declare that this document does not require an ethics committee approval or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the article and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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