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ASSESSMENT OF SUSTAINABLE WASTEWATER TREATMENT TECHNOLOGIES USING INTERVAL-VALUED INTUITIONISTIC FUZZY DISTANCE MEASURE-BASED MAIRCA METHOD

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Abstract. *Effective wastewater treatment has significant effects on saving water and preventing unnecessary water scarcity. An appropriate wastewater treatment technology (WWTT) brings economic benefits through reuse in different sectors and benefits the society and environment. This study aims to develop a decision-making framework for evaluating the sustainable WWTTs under interval-valued intuitionistic fuzzy set (IVIFS) environment. The proposed MCDM framework is divided into two stages. First, a new Hellinger distance measure is developed to determine the degree of difference between IVIFSs and also discussed its desirable characteristics. Second, an interval-valued intuitionistic fuzzy extension of multi-attribute ideal-real comparative analysis (MAIRCA) model is developed using the proposed Hellinger distance measure-based weighting tool. Further, the proposed model is implemented on an empirical study of sustainable WWTTs evaluation problem. Sensitivity and comparative studies are made. The results indicate that odor impacts, sludge production, maintenance and operation are the most effective sustainable factors and Microbial fuel cell (MFC) technology is the best WWTT followed by natural treatment methods.*

Key words: *Interval-valued intuitionistic fuzzy sets, Distance measure, Sustainability, MAIRCA, Rank sum model, Wastewater treatment*

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1. INTRODUCTION

Most of the water that is not used as an ingredient finally appears in the wastewater stream. Wastewater treatment (WWT) is the elimination of impurities from wastewater before it reaches aquifers or natural bodies of water such as lakes, rivers and oceans. It is one of the most imperative necessities of the current scenario that can provide wider environmental and societal benefits including improved ambient water quality, protect wildlife, reduced greenhouse gas emissions and so on [1-3]. Treated wastewater also brings economic benefits through reuse in different sectors like agriculture, groundwater recharge, vehicle washing, golf course irrigation, toilet flushes, cooling purposes in thermal power plants and building construction activities. The quality of treated wastewater used in agriculture has a great influence on the operation and performance of the wastewater-soil-plant or aquaculture system. WWT solutions can recover valuable resources from wastewater such as biodiesel, electricity, recycled water and nutrients and serve as the components of fertilizer [4]. Thus, it is significant for maintaining the health of human beings and ecosystems.

The process of WWT consists of using suitable technology to improve or upgrade the quality of a wastewater. Usually, WWT will involve collecting the wastewater in a central, segregated location and subjecting the wastewater to various treatment processes. WWT process needs to be a technology type that will be suitable for a particular development and not necessarily the best available technology. Selection of suitable WWT technologies that is highly correlated with sustainable development, presents a challenge to the local, regional, national and global policy makers. In developing countries, there is a need for a decision-making tool to evaluate the wastewater treatment technology (WWTT) selection. Many researchers have presented their works on the development new technologies and also reviewed the current systems for wastewater treatment. For instance, Choudhury et al. [5] highlighted the working strategies of Microbial fuel cell (MFC) technology for WWT and reuse of wastewater for power generation. In a study, Tarpani and Azapagic [6] assessed the life cycle environmental impacts of advanced WWT methods for removal of pharmaceuticals and personal care products. Arroyo and Molinos-Senante [7] presented a choosing-by-advantages approach to evaluate seven WWT alternatives. Based on different aspects of sustainability, they selected the most suitable WWT alternative. A systematic review has presented to explain the advantages and disadvantages of different membrane technologies for water treatment [8]. Munoz-Cupa et al. [9] highlighted the benefits and technical barriers of current MFC systems for WWT. Moreover, they have presented the effects of different reaction conditions on chemical oxygen demand removal and electricity generation from MFCs. Zhang et al. [10] stated the current trends of WWT plants in China. Their study provided some useful implications to the authorities and policy makers by analyzing the industries' current status in the WWT process. Saravanan et al. [11] reviewed several WWT technologies and presented their remarkable power for toxic pollutants removal from wastewater. In addition, they discussed the difficulties related to commercial development of WWT technologies and suggested the future research directions. Saravanan et al. [12] presented sustainable strategy on MFC technology to treat the wastewater for the green energy production. For this purpose, the authors have reviewed diverse MFC technologies and their core performance in the direction of waste management and energy conversion. As per the existing studies, several technologies, ranging from conventional to advanced treatment processes, are available to treat the wastewater.

Finding the most suitable wastewater treatment technology (WWTT) is a complex issue due to involvement of multiple sustainability aspects of criteria. An alternative WWTT is considered "most suitable" to the degree that it is consistent with the economic, environment, social, technical, cultural and political aspects of the society. Thus, the multi-criteria decision-making (MCDM) approaches are more appropriate to systematically solve this problem. Ullah et al. [13] established a decision-making agenda for the selection of WWTT. For this purpose, they firstly provided the comprehensive review of the state-of-the-art in WWT. Srivastava and Singh [14] established a decision support model for the selection of most suitable WWTT from multiple criteria perspective in which the criteria weights are determined through Full consistency method. Salamirad et al. [15] proposed an integrated decision support system using the best worst method and the behavioral Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). In that study, the authors have evaluated seven WWTTs with respect to economic, environmental and social dimensions of sustainability. Pennelilini et al. [16] presented a novel utility interval-based evidential reasoning approach to evaluate and prioritize the WWTT alternatives for agricultural reuse. With the use of analytic hierarchy process, Ćetković et al. [17] reviewed the current situation and problems related to WWTTs and evaluated the optimal variant of WWTTs.

In the process of multi-criteria WWTT selection, ambiguity arises in some form due to the genuine limits on the human mind and imprecise information. The notion of fuzzy set (FS) has widely been used in practice to handle such types of uncertain decision-making problems [18-20]. In order to choose the WWTT, Dursun [21] developed a hybrid method by incorporating the Decision making trial and evaluation laboratory (DEMATEL) and TOPSIS methods with 2-tuple fuzzy linguistic set and applied to evaluate the WWTT candidates. Attri et al. [22] presented the combined use of three MCDM methods such as the Multi-Objective Optimization by Ratio Analysis (MOORA), the Stepwise Weight Assessment Ratio Analysis (SWARA) and the TOPSIS under fuzzy environment. In this study, fuzzy SWARA method has applied to evaluate the significance values of the considered criteria, while the fuzzy MOORA and TOPSIS approaches have used to determine the rank of six WWTTs. A hybrid decision support system has developed based on the Pivot pairwise relative criteria importance assessment and an interactive MCDM approach with linear diophantine fuzzy information to handle the multi-criteria WWTT selection problem [23].

As the FS only contains a membership grade (MG), therefore, Atanassov [24] extended the classical FS and investigated the notion of intuitionistic fuzzy set (IFS), which assigns a MG, a non-membership grade (NG) and an indeterminacy grade (IG) to each element with sum of the MG and NG is bounded to 1. After the pioneering innovation by Atanassov [24], various significant results have been achieved based on IFS theory [25-28]. In the intuitionistic fuzzy set theory, the degrees of membership and non-membership are exact numbers, which is hard for the experts to define their exact value in several decision-making problems. To conquer this issue, Atanassov and Gargov [29] gave the idea of interval-valued intuitionistic fuzzy set (IVIFS), which deals with uncertainty in practical decision-making problems. Its basic feature is that both membership and non-membership functions of an element to a given set are considered and taken as interval values rather than exact numbers. Due to the broad range of information coverage, the theory of IVIFS is used in our proposed work. In the context of IVIFS, some relations and basic operations score and accuracy functions have been presented [30]. As an extended version of IFS, the IVIFS theory provides a more effective and reasonable way to cope with imprecise and uncertain information. Due to its higher flexibility in dealing with uncertain data, the IVIFS doctrine has been broadly explored from different perspectives [31-33].

To deal with MADM problems, several novel methods have been developed in the recent past [34-39]. The Multi-Attribute Ideal-Real Comparative Analysis (MAIRCA) [40] method is a newly developed MCDM method, which determines the gap between the ideal and empirical ratings during the assessment of alternatives [41]. For each alternative, summation of the gaps for all the criteria determines the total gap and option with the least total distance is considered as the best choice. This ranking technique uses different linear normalization method, which is characterized by easy mathematical computations and solution stability [42]. In a study, the classical MAIRCA method has integrated with the well-known DEMATEL model and applied to evaluate the sites for multimodal logistics centre development from sustainability perspectives. Kaya [43] analyzed the consequence of COVID-19 pandemic in the countries' sustainable development level through MAIRCA method. The classical MAIRCA method has been combined with LBWA model and interval rough numbers to develop a hybrid MCDM model [44]. In the context of uncertainty, Boral et al. [41] incorporated the standard MAIRCA approach with analytic hierarchy process, failure mode and effects analysis and fuzzy numbers, and developed a hybrid decision support system for solving complicated MCDM problem. Further, Ecer [45] proposed a hybrid intuitionistic fuzzy MAIRCA method with an application in the assessment of COVID-19 vaccines. In the recent past, Hezam et al. [46] discussed an approach based on symmetry point of criterion-based MAIRCA method and applied to select the most suitable biomass resources for biofuel production under intuitionistic fuzzy environment. The classical MAIRCA approach has been extended from interval-valued neutrosophic perspective and applied to select the multi-criteria sustainable materials [47]. Rani et al. [48] proposed a Pythagorean fuzzy information-based MAIRCA model, in which the criteria weights are determined through standard deviation-based method. In addition, they presented the drawbacks of existing studies in the context of Pythagorean fuzzy set.

Based on the literature review, this paper identifies some research gaps in the existing studies, given as

- Existing distance measures (Zhang et al. [49], Düğenci [50], Baccour and Alimi [51], Mishra et al. [52]) present some counter-intuitive cases in order to measure the degree of difference between two IVIFSs.
- Few authors (Kaya [43], Božanić et al. [44], Boral et al. [42], Ecer [45], Haq et al. [47], Hezam et al. [46], Rani et al. [48]) have developed the extensions of classical MAIRCA method from fuzzy, intuitionistic fuzzy, interval-valued neutrosophic, Pythagorean fuzzy perspectives, but the these methods cannot deal with IVIF information in which the alternatives' information is represented in terms of intervals rather than the crisp numbers.
- In the literature, some authors (Ullah et al. [13], Srivastava and Singh [14], Salamirad et al. [15], Pennelilini et al. [16], Ćetković et al. [17]) have proposed different MCDM methods for solving WWTTs assessment problem. As an extension of IFS, the theory of IVIFS has the advantage that both membership and non-membership degrees are interval values and can used to characterize the uncertain information more flexibly

due to its constraint condition. Unfortunately, existing decision support models are unable to deal with the interval-valued membership and non-membership degrees.

Inspired by the limitations of existing studies, this study develops an interval-valued intuitionistic fuzzy MADM framework to evaluate and prioritize the WWTT alternatives. The developed methodology does not only evaluate the considered options through IVIF-distance measure-MAIRCA model, but also consider the weights of considered criteria and decision makers. The proposed model can assist the decision makers (DMEs) to get more confident for ranking the blockchain platforms.

The key contributions of this paper are presented as follows:

- New Hellinger distance measure is proposed to overcome the limitations of existing IVIF-distance measures. Comparative study is presented to prove the effectiveness of the proposed measure.
- A novel extension of MAIRCA method is developed in the context of interval-valued intuitionistic fuzzy information perspective in which the information about the criteria and decision makers is completely unknown.
- In the proposed method, the proposed distance measure and total support degree-based model is presented to compute the criteria weights.
- The presented MAIRCA method is implemented on a case study of WWTTs assessment, which proves its applicability and powerfulness.

The leading question of the WWTT alternative selection problem is “which one is the most appropriate WWTT alternative among a set of alternatives from sustainability perspective?” To solve this problem, the following questions need to be answered: (i) What are the main criteria to evaluate the most appropriate WWTT alternatives with interval-valued intuitionistic fuzzy information? (ii) Which is the most significant criterion for WWTTs assessment? (iii) Which is the most suitable MCDM technique to select and prioritize the WWTT alternatives based on the economic, social, environmental and technical aspects of sustainability? The key objectives of this study are as follows: (i) Identify the main criteria to choose the most suitable WWTT alternative through literature survey and DE opinions. (ii) Find the importance weights of each criterion under the context of uncertain information. Introduce a model to compute the weights of considered evaluation criteria. (iii) Determine a hybrid MCDM methodology to prioritize the WWTT alternatives under interval-valued intuitionistic fuzzy environment.

The rest part of this study is organized as follows: Section 2 firstly presents the basic concepts and then proposes a new distance measure for IVIFSs. Section 3 develops a hybrid MAIRCA method for assessing the MCDM problems under IVIFS context. Section 4 implements the proposed method on a case study of WWTTs assessment. Section 5 presents the comparative analysis, discussion on the results and implications. Section 6 concludes the whole study and recommends for future researches.

2. Proposed Distance Measure for IVIFSs

This section firstly discusses the fundamental notions related to an IVIFS and then proposes a new measure to describe the degree of difference between two IVIFSs.

2.1. Basic Concepts

Definition 2.1. Consider $\Phi = \{\phi_1, \phi_2, ..., \phi_t\}$ be a finite universal set. In the following way, Atanassov and Gargov [29] mathematically defined the IVIFS Q on Φ:

$Q=\{<\phi_i,([\mu_Q^-(\phi_i),\mu_Q^+(\phi_i)],[\nu_Q^-(\phi_i),\nu_Q^+(\phi_i)])>:\phi_i\in\Phi\}$, where $0\le\mu_Q^-(\phi_i)\le\mu_Q^+(\phi_i)\le 1$, $0\le\nu_Q^-(\phi_i)\le\nu_Q^+(\phi_i)\le 1$ and $0\le\mu_Q^+(\phi_i)+\nu_Q^+(\phi_i)\le 1$. Here, $\mu_Q(\phi_i)=[\mu_Q^-(\phi_i),\mu_Q^+(\phi_i)]$ and $\nu_Q(\phi_i)=[\nu_Q^-(\phi_i),\nu_Q^+(\phi_i)]$ define the degrees of interval-valued membership and non-membership of an object ϕ_i in Q, respectively.

The function $\pi_Q(\phi_i)=[\pi_Q^-(\phi_i),\pi_Q^+(\phi_i)]$ represents the indeterminacy degree of ϕ_i to Q, where $\pi_Q^-(\phi_i)=1-\mu_Q^+(\phi_i)-\nu_Q^+(\phi_i)$ and $\pi_Q^+(\phi_i)=1-\mu_Q^-(\phi_i)-\nu_Q^-(\phi_i)$. For the simplicity, the term $([\mu_Q^-(\phi_i),\mu_Q^+(\phi_i)],[\nu_Q^-(\phi_i),\nu_Q^+(\phi_i)])$ is defined as the "interval-valued intuitionistic fuzzy value/number (IVIFV/IVIFN)" and denoted by $\omega=([\mu_\omega^-,\mu_\omega^+],[\nu_\omega^-,\nu_\omega^+])$ which fulfills $0\le(\mu_\omega^+)+(\nu_\omega^+)\le 1$.

Definition 2.2. Xu and Gou [30] defined some operational laws on IVIFVs $\omega_1=([\mu_1^-,\mu_1^+],[\nu_1^-,\nu_1^+])$ and $\omega_2=([\mu_2^-,\mu_2^+],[\nu_2^-,\nu_2^+])$, presented as

(a) $\omega_1\subseteq\omega_2$ if and only if $\mu_1^-(\phi_i)\le\mu_2^-(\phi_i)$, $\mu_1^+(\phi_i)\le\mu_2^+(\phi_i)$, $\nu_1^-(\phi_i)\ge\nu_2^-(\phi_i)$ and $\nu_1^+(\phi_i)\ge\nu_2^+(\phi_i)$, $\forall\phi_i\in\Phi$,

(b) $\omega_1=\omega_2$ if and only if $\omega_1\subseteq\omega_2$ and $\omega_1\supseteq\omega_2$,

(c) $\omega_1^c=\{(\phi_i,[\nu_1^-(\phi_i),\nu_1^+(\phi_i)],[\mu_1^-(\phi_i),\mu_1^+(\phi_i)])|\phi_i\in\Phi\}$,

Definition 2.3. For any IVIFN $\omega=([\mu_\omega^-,\mu_\omega^+],[\nu_\omega^-,\nu_\omega^+])$, Xu and Gou [30] studied the normalized score function and accuracy function, given by Eq. (1) and Eq. (2), respectively.

$$\mathbb{S}(\omega)=\frac{1}{2}\left(\frac{1}{2}(\mu_\omega^-+\mu_\omega^+-\nu_\omega^--\nu_\omega^+)+1\right), \tag{1}$$

$$\mathbb{H}(\omega)=\frac{1}{2}(\mu_\omega^-+\mu_\omega^++\nu_\omega^-+\nu_\omega^+). \tag{2}$$

Definition 2.4. For a set of IVIFNs $\omega = \{\omega_1, \omega_2, ..., \omega_t\}$, Xu and Gou [30] defined the interval-valued intuitionistic fuzzy weighted averaging (IVIFWA) and interval-valued intuitionistic fuzzy weighted geometric (IVIFWG) operators as

$$\overset{t}{\underset{k=1}{\oplus}}\alpha_k\,\omega_k=\left(\left[1-\prod_{k=1}^{t}(1-\mu_k^-)^{\omega_k},1-\prod_{k=1}^{t}(1-\mu_k^+)^{\omega_k}\right],\left[\prod_{k=1}^{t}(\nu_k^-)^{\omega_k},\prod_{k=1}^{t}(\nu_k^+)^{\omega_k}\right]\right), \tag{3}$$

$$\overset{\ell}{\underset{k=1}{\otimes}}\alpha_k\,\omega_k=\left(\left[\prod_{k=1}^{t}(\mu_k^-)^{\omega_k},\prod_{k=1}^{t}(\mu_k^+)^{\omega_k}\right],\left[1-\prod_{k=1}^{t}(1-\nu_k^-)^{\omega_k},1-\prod_{k=1}^{t}(1-\nu_k^+)^{\omega_k}\right]\right). \tag{4}$$

Definition 2.5 [30]. Assume that Q, R, $S\in IVIFSs$ (Φ), A real-valued function D: $IVIFSs$ (Φ)×$IVIFSs$ (Φ) → [0,1] is said to be IVIF-distance measure if it holds the following axioms:

(a1). $0\le D(Q,R)\le 1$,

(a2). $D\,(Q, R)$ if and only if $Q = R$,
(a3). $D\,(Q, R) = D\,(R, Q)$,
(a4). If $Q \subseteq R \subseteq S$, then $D\,(Q, R) \le D\,(Q, S)$ and $D\,(R, S) \le D\,(Q, S)$.

2.2. Hellinger Distance Measure on IVIFSs

Hellinger [54] originated the idea of Hellinger distance to quantify the degree of difference between two discrete probability distributions. Based on the concept of Hellinger distance, this section proposes a Hellinger distance measure on IVIFSs. Moreover, the important characteristics of this measure are discussed in this section.

Definition 2.6 Suppose that $Q, R \in IVIFSs(\Phi)$, then the distance measure on IVIFSs is presented as

$$D(Q,R)=\frac{1}{2t}\sum_{i=1}^{t}\sqrt{\left[\begin{array}{l}\left(\sqrt{\mu_Q^-(\phi_i)}-\sqrt{\mu_R^-(\phi_i)}\right)^2+\left(\sqrt{\mu_Q^+(\phi_i)}-\sqrt{\mu_R^+(\phi_i)}\right)^2\\ +\left(\sqrt{\nu_Q^-(\phi_i)}-\sqrt{\nu_R(\phi_i)}\right)^2+\left(\sqrt{\nu_Q^+(\phi_i)}-\sqrt{\nu_R^+(\phi_i)}\right)^2\\ +\left(\sqrt{\pi_Q^-(\phi_i)}-\sqrt{\pi_R^-(\phi_i)}\right)^2+\left(\sqrt{\pi_Q^+(\phi_i)}-\sqrt{\pi_R^+(\phi_i)}\right)^2\end{array}\right]}\,. \tag{5}$$

Remark 2.1. The bigger value of $D\,(Q, R)$ signifies the larger difference between two IVIFSs Q and R. In a similar way, the lesser value of $D\,(Q, R)$ signifies the smaller difference between two IVIFSs Q and R.

The properties of $D\,(Q, R)$ are deduced as follows:

Property 2.1: For $Q, R \in IVIFSs(\Phi)$, $0 \le D\,(Q, R) \le 1$.

Proof: In IVIFS, we have $\mu_Q^-(\phi_i)+\nu_Q^-(\phi_i)+\pi_Q^-(\phi_i)=1,$ $\mu_Q^+(\phi_i)+\nu_Q^+(\phi_i)+\pi_Q^+(\phi_i)=1,$ $\mu_R^-(\phi_i)+\nu_R^-(\phi_i)+\pi_R^-(\phi_i)=1$ and $\mu_R^+(\phi_i)+\nu_R^+(\phi_i)+\pi_R^+(\phi_i)=1.$ Thus, we deduce that

$$D(Q,R)=\frac{1}{2t}\sum_{i=1}^{t}\sqrt{\left[\begin{array}{l}\mu_Q^-(\phi_i)-2\sqrt{\mu_Q^-(\phi_i)\,\mu_R^-(\phi_i)}+\mu_R^-(\phi_i)+\mu_Q^+(\phi_i)\\ -2\sqrt{\mu_Q^+(\phi_i)\,\mu_R^+(\phi_i)}+\mu_R^+(\phi_i)+\nu_Q^-(\phi_i)-2\sqrt{\nu_Q^-(\phi_i)\,\nu_R^-(\phi_i)}\\ +\nu_R^-(\phi_i)+\nu_Q^+(\phi_i)-2\sqrt{\nu_Q^+(\phi_i)\,\nu_R^+(\phi_i)}+\nu_R^+(\phi_i)+\pi_Q^-(\phi_i)\\ -2\sqrt{\pi_Q^-(\phi_i)\,\pi_R^-(\phi_i)}+\pi_R^-(\phi_i)+\pi_Q^+(\phi_i)-2\sqrt{\pi_Q^+(\phi_i)\,\pi_R^+(\phi_i)}+\pi_R^+(\phi_i)\end{array}\right]}$$

$$=\frac{1}{2t}\sum_{i=1}^{t}\sqrt{\left[\begin{array}{l}\mu_Q^-(\phi_i)-2\sqrt{\mu_Q^-(\phi_i)\,\mu_R^-(\phi_i)}+\mu_R^-(\phi_i)+\mu_Q^+(\phi_i)\\ -2\sqrt{\mu_Q^+(\phi_i)\,\mu_R^+(\phi_i)}+\mu_R^+(\phi_i)+\nu_Q^-(\phi_i)-2\sqrt{\nu_Q^-(\phi_i)\,\nu_R^-(\phi_i)}\\ +\nu_R^-(\phi_i)+\nu_Q^+(\phi_i)-2\sqrt{\nu_Q^+(\phi_i)\,\nu_R^+(\phi_i)}+\nu_R(\phi_i)+\pi_Q^-(\phi_i)\\ -2\sqrt{\pi_Q^-(\phi_i)\,\pi_R^-(\phi_i)}+\pi_R^-(\phi_i)+\pi_Q^+(\phi_i)-2\sqrt{\pi_Q^+(\phi_i)\,\pi_R^+(\phi_i)}+\pi_R^+(\phi_i)\end{array}\right]}$$

$$= \frac{1}{2t}\sum_{i=1}^{t}\sqrt{\left[\begin{array}{l}4-2\left(\sqrt{\mu_Q^-(\phi_i)\,\mu_R^-(\phi_i)}\right)+\sqrt{\mu_Q^+(\phi_i)\,\mu_R^+(\phi_i)}+\sqrt{\nu_Q^-(\phi_i)\,\nu_R^-(\phi_i)}\\ \qquad +\sqrt{\nu_Q^+(\phi_i)\,\nu_R^+(\phi_i)}+\sqrt{\pi_Q^-(\phi_i)\,\pi_R^-(\phi_i)}+\sqrt{\pi_Q^+(\phi_i)\,\pi_R^+(\phi_i)}\Big)\end{array}\right]}$$

$$= \frac{1}{t}\sum_{i=1}^{t}\sqrt{\left[\begin{array}{l}1-\frac{1}{2}\left(\sqrt{\mu_Q^-(\phi_i)\,\mu_R^-(\phi_i)}\right)+\sqrt{\mu_Q^+(\phi_i)\,\mu_R^+(\phi_i)}+\sqrt{\nu_Q^-(\phi_i)\,\nu_R^-(\phi_i)}\\ \qquad +\sqrt{\nu_Q^+(\phi_i)\,\nu_R^+(\phi_i)}+\sqrt{\pi_Q^-(\phi_i)\,\pi_R^-(z_i)}+\sqrt{\pi_Q^+(\phi_i)\,\pi_R^+(\phi_i)}\Big)\end{array}\right]} \le 1.$$

Therefore, we can prove that $0 \le D\,(Q, R) \le 1$.

Property 2.2: $D\,(Q, R) = 0$, if and only if $Q = R$.

Proof: For given two IVIFSs Q and R, we have $\mu_Q^-(\phi_i)=\mu_R^-(\phi_i)$, $\mu_Q^+(\phi_i)=\mu_R^+(\phi_i)$, $\nu_Q^-(\phi_i)=\nu_R^-(\phi_i)$, $\nu_Q^+(\phi_i)=\nu_R^+(\phi_i)$, $\pi_Q^-(\phi_i)=\pi_R^-(\phi_i)$ and $\pi_Q^+(\phi_i)=\pi_R^+(\phi_i)$.

Then we find that

$$D(Q,R)=\frac{1}{2t}\sum_{i=1}^{t}\sqrt{\left[\begin{array}{l}\left(\sqrt{\mu_Q^-(\phi_i)}-\sqrt{\mu_R^-(\phi_i)}\right)^2+\left(\sqrt{\mu_Q^+(\phi_i)}-\sqrt{\mu_R^+(\phi_i)}\right)^2\\ +\left(\sqrt{\nu_Q^-(\phi_i)}-\sqrt{\nu_R(\phi_i)}\right)^2+\left(\sqrt{\nu_Q^+(\phi_i)}-\sqrt{\nu_R^+(\phi_i)}\right)^2\\ +\left(\sqrt{\pi_Q^-(\phi_i)}-\sqrt{\pi_R^-(\phi_i)}\right)^2+\left(\sqrt{\pi_Q^+(\phi_i)}-\sqrt{\pi_R^+(\phi_i)}\right)^2\end{array}\right]}=0$$

For any $\phi_i \in \Phi$, if $D\,(Q, R) = 0$, then we have

$$\frac{1}{2t}\sum_{i=1}^{t}\sqrt{\left[\begin{array}{l}\left(\sqrt{\mu_Q^-(\phi_i)}-\sqrt{\mu_R^-(\phi_i)}\right)^2+\left(\sqrt{\mu_Q^+(\phi_i)}-\sqrt{\mu_R^+(\phi_i)}\right)^2+\left(\sqrt{\nu_Q^-(\phi_i)}-\sqrt{\nu_R^-(\phi_i)}\right)^2\\ +\left(\sqrt{\nu_Q^+(\phi_i)}-\sqrt{\nu_R^+(\phi_i)}\right)^2+\left(\sqrt{\pi_Q^-(\phi_i)}-\sqrt{\pi_R^-(\phi_i)}\right)^2+\left(\sqrt{\pi_Q^+(\phi_i)}-\sqrt{\pi_R^+(\phi_i)}\right)^2\end{array}\right]}=0.$$

It implies

$\left(\sqrt{\mu_Q^-(\phi_i)}-\sqrt{\mu_R^-(\phi_i)}\right)^2=0$, $\left(\sqrt{\mu_Q^+(\phi_i)}-\sqrt{\mu_R^+(\phi_i)}\right)^2=0$, $\left(\sqrt{\mu_Q^-(\phi_i)}-\sqrt{\mu_R^-(\phi_i)}\right)^2=0$, $\left(\sqrt{\nu_Q^-(\phi_i)}-\sqrt{\nu_R(\phi_i)}\right)^2=0$, $\left(\sqrt{\nu_Q^+(\phi_i)}-\sqrt{\nu_R^+(\phi_i)}\right)^2=0$, $\left(\sqrt{\pi_Q^-(\phi_i)}-\sqrt{\pi_R^-(\phi_i)}\right)^2=0$ and $\left(\sqrt{\pi_Q^+(\phi_i)}-\sqrt{\pi_R^+(\phi_i)}\right)^2=0$. Hence, $D(Q,R)=0$ if and only if $Q=R$.

Property 2.3: $D\,(Q, R) = D\,(R, Q)$.

Proof: For given two IVIFSs Q and R, we have

$$D(Q,R)=\frac{1}{2t}\sum_{i=1}^{t}\sqrt{\begin{bmatrix}\left(\sqrt{\mu_Q^-(\phi_i)}-\sqrt{\mu_R^-(\phi_i)}\right)^2+\left(\sqrt{\mu_Q^+(\phi_i)}-\sqrt{\mu_R^+(\phi_i)}\right)^2\\+\left(\sqrt{\nu_Q^-(\phi_i)}-\sqrt{\nu_R^-(\phi_i)}\right)^2+\left(\sqrt{\nu_Q^+(\phi_i)}-\sqrt{\nu_R^+(\phi_i)}\right)^2\\+\left(\sqrt{\pi_R^-(\phi_i)}-\sqrt{\pi_R^-(\phi_i)}\right)^2+\left(\sqrt{\pi_Q^+(\phi_i)}-\sqrt{\pi_R^+(\phi_i)}\right)^2\end{bmatrix}}$$

$$=\frac{1}{2t}\sum_{i=1}^{t}\sqrt{\begin{bmatrix}\left(\sqrt{\mu_R^-(\phi_i)}-\sqrt{\mu_Q^-(\phi_i)}\right)^2+\left(\sqrt{\mu_R^+(\phi_i)}-\sqrt{\mu_Q^+(\phi_i)}\right)^2\\+\left(\sqrt{\nu_R^-(\phi_i)}-\sqrt{\nu_Q^-(\phi_i)}\right)^2+\left(\sqrt{\nu_R^+(\phi_i)}-\sqrt{\nu_Q^+(\phi_i)}\right)^2\\+\left(\sqrt{\pi_R^-(\phi_i)}-\sqrt{\pi_Q^-(\phi_i)}\right)^2+\left(\sqrt{\pi_R^+(\phi_i)}-\sqrt{\pi_Q^+(\phi_i)}\right)^2\end{bmatrix}}=D(R,Q).$$

Hence, $D(Q, R) = D(R, Q)$.

Property 2.4: If $Q \subseteq R \subseteq S,$ then $D(Q, R) \le D(Q, S)$ and $D(R, S) \le D(Q, S)$.

Proof: For given three IVIFSs Q, R and S, if $Q \subseteq R \subseteq S,$ then $\mu_Q^-(\phi_i)\le\mu_R^-(\phi_i)\le\mu_S^-(\phi_i),$ $\mu_Q^+(\phi_i)\le\mu_R^+(\phi_i)\le\mu_S^+(\phi_i),$ $\nu_Q^-(\phi_i)\ge\nu_R^-(\phi_i)\ge\nu_S^-(\phi_i),$ $\nu_Q^+(\phi_i)\ge\nu_R^+(\phi_i)\ge\nu_S^+(\phi_i),$ $\pi_Q^-(\phi_i)\ge\pi_R^-(\phi_i)\ge\pi_S^-(\phi_i)$ and $\pi_Q^+(\phi_i)\ge\pi_R^+(\phi_i)\ge\pi_S^+(\phi_i)$.

$$D(Q,S)=\frac{1}{2t}\sum_{i=1}^{t}\sqrt{\begin{bmatrix}\left(\sqrt{\mu_Q^-(\phi_i)}-\sqrt{\mu_S^-(\phi_i)}\right)^2+\left(\sqrt{\mu_Q^+(\phi_i)}-\sqrt{\mu_S^+(\phi_i)}\right)^2\\+\left(\sqrt{\nu_Q^-(\phi_i)}-\sqrt{\nu_s^-(\phi_i)}\right)^2+\left(\sqrt{\nu_Q^+(\phi_i)}-\sqrt{\nu_S^+(\phi_i)}\right)^2\\+\left(\sqrt{\pi_Q^-(\phi_i)}-\sqrt{\pi_S^-(\phi_i)}\right)^2+\left(\sqrt{\pi_Q^+(\phi_i)}-\sqrt{\pi_S^+(\phi_i)}\right)^2\end{bmatrix}}$$

$$\ge\frac{1}{2t}\sum_{i=1}^{t}\sqrt{\begin{bmatrix}\left(\sqrt{\mu_Q^-(\phi_i)}-\sqrt{\mu_R^-(\phi_i)}\right)^2+\left(\sqrt{\mu_Q^+(\phi_i)}-\sqrt{\mu_R^+(\phi_i)}\right)^2\\+\left(\sqrt{\nu_Q^-(\phi_i)}-\sqrt{\nu_R(\phi_i)}\right)^2+\left(\sqrt{\nu_Q^+(\phi_i)}-\sqrt{\nu_R^+(\phi_i)}\right)^2\\+\left(\sqrt{\pi_Q^-(\phi_i)}-\sqrt{\pi_R^-(\phi_i)}\right)^2+\left(\sqrt{\pi_Q^+(\phi_i)}-\sqrt{\pi_R^+(\phi_i)}\right)^2\end{bmatrix}},=D(Q,R).$$

Similarly, we can prove that when $Q \subseteq R \subseteq S,$ then $D(Q, R) \le D(Q, S)$ and $0 \le D(R, S) \le D(Q, S)$.

Proposition 2.1: From the Properties 2.1-2.4, Eq. (5) holds all the necessary conditions of Definition 2.5. Hence, Eq. (5) is valid IVIF-distance measure on *IVIFSs* (Φ).

Definition 2.7. Suppose that Q, R, $S \in IVIFSs(\Phi)$, then the weighted Hellinger distance measure D_α: $IVIFSs(\Phi) \times IVIFSs(\Phi) \to [0,1]$ is given by

$$D_\alpha(Q,R) = \frac{1}{2}\sum_{i=1}^{t}\alpha_i \sqrt{\begin{bmatrix} \left(\sqrt{\mu_Q^-(\phi_i)} - \sqrt{\mu_R^-(\phi_i)}\right)^2 + \left(\sqrt{\mu_Q^+(\phi_i)} - \sqrt{\mu_R^+(\phi_i)}\right)^2 \\ + \left(\sqrt{\nu_Q^-(\phi_i)} - \sqrt{\nu_R(\phi_i)}\right)^2 + \left(\sqrt{\nu_Q^+(\phi_i)} - \sqrt{\nu_R^+(\phi_i)}\right)^2 \\ + \left(\sqrt{\pi_Q^-(\phi_i)} - \sqrt{\pi_R^-(\phi_i)}\right)^2 + \left(\sqrt{\pi_Q^+(\phi_i)} - \sqrt{\pi_R^+(\phi_i)}\right)^2 \end{bmatrix}}, \tag{6}$$

where α_i is the weight of ϕ_i on Φ satisfying $\alpha_i \in [0, 1]$ and $\sum_{i=1}^{t}\alpha_i = 1$.

2.3. Comparative Study

In this section, we firstly recall some of the previously developed distance measures in the context of IVIFS (Zhang et al. [49], Düğenci [50], Baccour and Alimi [51], Mishra et al. [52]). Further, we apply the proposed and existing IVIF-distance measures on some common data sets and obtain some useful results.

$$D_H(Q,R) = \frac{1}{4t}\sum_{i=1}^{t}\begin{bmatrix} \left|\mu_Q^-(\phi_i) - \mu_R^-(\phi_i)\right| + \left|\mu_Q^+(\phi_i) - \mu_R^+(\phi_i)\right| \\ + \left|\nu_Q^-(\phi_i) - \nu_R^-(\phi_i)\right| + \left|\nu_Q^+(\phi_i) - \nu_R^+(\phi_i)\right| \end{bmatrix}, \tag{7}$$

$$D_E(Q,R) = \sqrt{\frac{1}{4t}\sum_{i=1}^{t}\begin{bmatrix} (\mu_Q^-(\phi_i) - \mu_R^-(\phi_i))^2 + (\mu_Q^+(\phi_i) - \mu_R^+(\phi_i))^2 \\ + (\nu_Q^-(\phi_i) - \nu_R^-(\phi_i))^2 + (\mu_Q^+(\phi_i) - \nu_R^+(\phi_i))^2 \end{bmatrix}}, \tag{8}$$

$$D_{HH}(Q,R) = \frac{1}{4t}\sum_{i=1}^{t}\max\begin{bmatrix} \left|\mu_Q^-(\phi_i) - \mu_R^-(\phi_i)\right|, \left|\mu_Q^+(\phi_i) - \mu_R^+(\phi_i)\right|, \\ \left|\nu_Q^-(\phi_i) - \nu_R^-(\phi_i)\right|, \left|\nu_Q^+(\phi_i) - \nu_R^+(\phi_i)\right| \end{bmatrix}, \tag{9}$$

$$D_{HE}(Q,R) = \sqrt{\frac{1}{4t}\sum_{i=1}^{t}\max\begin{bmatrix} (\mu_Q^-(\phi_i) - \mu_R^-(\phi_i))^2, (\mu_Q^+(\phi_i) - \mu_R^+(\phi_i))^2, \\ (\nu_Q^-(\phi_i) - \nu_R^-(\phi_i))^2, (\nu_Q^+(\phi_i) - \nu_R^+(\phi_i))^2 \end{bmatrix}}, \tag{10}$$

$$D_Z(Q,R) = \frac{1}{t}\sum_{i=1}^{t}\max\begin{bmatrix} \dfrac{\left|\mu_Q^-(\phi_i) - \mu_R^-(\phi_i)\right| + \left|\mu_Q^+(\phi_i) - \mu_R^+(\phi_i)\right|}{2}, \\ \dfrac{\left|\nu_Q^-(\phi_i) - \nu_R^-(\phi_i)\right| + \left|\nu_Q^+(\phi_i) - \nu_R^+(\phi_i)\right|}{2} \end{bmatrix}, \tag{11}$$

$$D_D(Q,R)=\left(\frac{1}{4t(\alpha+1)^p}\sum_{i=1}^{t}\left[\begin{array}{l}\left|\begin{array}{l}\alpha(\mu_Q^-(\phi_i)-\mu_R^-(\phi_i))\\-(\nu_Q^-(\phi_i)-\nu_R^-(\phi_i))\end{array}\right|^p+\left|\begin{array}{l}\alpha(\nu_Q^-(\phi_i)-\nu_R^-(\phi_i))\\-(\mu_Q^-(\phi_i)-\mu_Q^-(\phi_i))\end{array}\right|^p\\ \left|\begin{array}{l}\alpha(\mu_Q^+(\phi_i)-\mu_R^+(\phi_i))\\-(\nu_Q^+(\phi_i)-\nu_R^+(\phi_i))\end{array}\right|^p+\left|\begin{array}{l}\alpha(\nu_Q^+(\phi_i)-\nu_R^+(\phi_i))\\-(\mu_Q^+(\phi_i)-\mu_R^+(\phi_i))\end{array}\right|^p\end{array}\right]\right)^{\frac{1}{p}}, \quad (12)$$

where α = 2, 3, 4, . . . and p = 1, 2, 3, . . .

$$D_{B1}(Q,R)=\frac{1}{4t}\sum_{i=1}^{t}\left(\begin{array}{l}\left(\sqrt{\mu_Q^-(\phi_i)}-\sqrt{\mu_R^-(\phi_i)}\right)^2\\+\left(\sqrt{\nu_Q^-(\phi_i)}-\sqrt{\nu_R(\phi_i)}\right)^2\end{array}\right)+\frac{1}{4t}\sum_{i=1}^{t}\left(\begin{array}{l}\left(\sqrt{\mu_Q^+(\phi_i)}-\sqrt{\mu_R^+(\phi_i)}\right)^2\\+\left(\sqrt{\nu_Q^+(\phi_i)}-\sqrt{\nu_R^+(\phi_i)}\right)^2\end{array}\right), \quad (13)$$

$$D_{B2}(Q,R)=\frac{1}{8t}\sum_{i=1}^{t}\left(\begin{array}{l}\sqrt{\left|\mu_Q^-(\phi_i)-\mu_R^-(\phi)\right|}\\+\sqrt{\left|\nu_Q^-(\phi_i)-\nu_R^-(\phi_i)\right|}\end{array}\right)^2+\frac{1}{8t}\sum_{i=1}^{t}\left(\begin{array}{l}\sqrt{\left|\mu_Q^+(\phi_i)-\mu_R^+(\phi_i)\right|}\\+\sqrt{\left|\nu_Q^+(\phi_i)-\nu_R^+(\phi_i)\right|}\end{array}\right)^2, \quad (14)$$

$$D_M(Q,R)=\frac{1-\exp\left[-\frac{1}{2t}\left(\sum_{i=1}^{t}\left(\begin{array}{l}\left|\mu_Q^-(\phi_i)-\mu_R^-(\phi_i)\right|^\gamma+\left|\mu_Q^+(\phi_i)-\mu_R^+(\phi_i)\right|^\gamma\\+\left|\nu_Q^-(\phi_i)-\nu_R^-(\phi_i)\right|^\gamma+\left|\nu_Q^+(\phi_i)-\nu_R^+(\phi_i)\right|^\gamma\\+\left|\pi_Q^-(\phi_i)-\pi_R^-(\phi_i)\right|^\gamma+\left|\pi_Q^+(\phi_i)-\pi_R^+(\phi_i)\right|^\gamma\end{array}\right)\right)^{1/\gamma}\right]}{1-\exp(-(1))}, \quad (15)$$

where $\gamma > 0$, $\gamma \neq 1$.

Table 1 Comparisons of diverse IVIF-distance measures (Bold shows the counter-intuitive cases)

Q_i	([0.25, 0.35], [0.25, 0.35])	[0.25, 0.35], [0.35, 0.45])	([1, 1], [0, 0])	([0.5, 0.5], [0.5, 0.5])	([0.35, 0.45], [0.15, 0.25])	([0.35, 0.45], [0.15, 0.25])
R_i	([0.35, 0.45], [0.35, 0.45])	[0.35, 0.45], [0.25, 0.35])	([0, 0], [0, 0])	([0, 0], [0,0])	([0.45, 0.55], [0.25, 0.35])	([0.45, 0.55], [0.15, 0.25])
$D_H(Q_i, R_i)$	**0.1**	**0.1**	**0.5**	**0.5**	**0.1**	0.05
$D_E(Q_i, R_i)$	**0.1**	**0.1**	0.707	0.5	**0.1**	0.071
$D_{HH}(Q_i, R_i)$	**0.025**	**0.025**	0.25	0.125	**0.025**	**0.025**
$D_{HE}(Q_i, R_i)$	**0.05**	**0.05**	0.5	0.25	**0.05**	**0.05**
$D_Z(Q_i, R_i)$	**0.100**	**0.100**	1.000	0.500	**0.100**	**0.100**
$D_D(Q_i, R_i)$	**0.033**	0.100	0.500	0.208	**0.033**	0.050
$D_{B1}(Q_i, R_i)$	**0.007**	**0.007**	0.500	0.375	0.008	0.003
$D_{B2}(Q_i, R_i)$	**0.100**	**0.100**	0.250	0.313	**0.100**	0.025
$D_M(Q_i, R_i)$	**0.252**	**0.151**	1.000	0.802	**0.252**	**0.151**
$D(Q_i, R_i)$	0.165	0.086	1.000	0.804	0.167	0.082

Table 1 presents the computational results obtained by the proposed and previously developed IVIF-distance measures (Zhang et al. [49], Düğenci [50], Baccour and Alimi [51], Mishra et al. [52]). The distance measures D_H, D_E, D_{HH}, D_{HE}, D_{B1}, D_{B2}, D_Z, D_D and D_M present the counter-intuitive results for some examples. For instance, D_H (Q_1, R_1) = 0.1 and D_H (Q_2, R_2) = 0.1, D_E (Q_1, R_1) = 0.1 and D_E (Q_2, R_2) = 0.1, D_{HH} (Q_1, R_1) = 0.025 and D_{HH} (Q_2, R_2) = 0.025, D_{HE} (Q_1, R_1) = 0.05 and D_{HE} (Q_2, R_2) = 0.05, D_Z (Q_1, R_1) = 0.1 and D_Z (Q_2, R_2) = 0.1, D_{B1} (Q_1, R_1) = 0.007 and D_{B1} (Q_2, R_2) = 0.007, D_{B2} (Q_1, R_1) = 0.1 and D_{B2} (Q_2, R_2) = 0.1, when Q_1 = [(0.25, 0.35), (0.25,0.35)], R_1 = [(0.35, 0.45), (0.35, 0.45)], Q_2 = [(0.25, 0.35), (0.35, 0.45)] and R_2 = [(0.35, 0.45), (0.25, 0.35)]. Also, D_{HH} (Q_5, R_5) = 0.025 and D_{HH} (Q_6, R_6) = 0.025, D_{HE} (Q_5, R_5) = 0.05 and D_{HE} (Q_6, R_6) = 0.05, D_Z (Q_5, R_5) = 0.1 and D_Z (Q_6, R_6) = 0.1, when Q_5 = [(0.35, 0.45), (0.15,0.25)], R_5 = [(0.45, 0.55), (0.25, 0.35)], Q_6 = [(0.35, 0.45), (0.15, 0.25)] and R_6 = [(0.45, 0.55), (0.15, 0.25)]. For the above discussed sets, the Hellinger distance measure proposed in this study can successfully discriminate the given IVIFSs and the results are as follows: D (Q_1, R_1) = 0.165 and D (Q_2, R_2) = 0.086, D (Q_5, R_5) = 0.167 and D (Q_6, R_6) = 0.082. For a different pair of IVIFSs Q_3 = [(1, 1), (0, 0)], R_3 = [(0, 0), (0, 0)] and Q_4 = [(0.5, 0.5), (0.5, 0.5)], R_4 = [(0, 0), (0, 0)], we get D_H (Q_3, R_3) = D_H (Q_4, R_4) = 0.5, while other measures provide reasonable results. In addition, the counter-intuitive cases arise for Q_1 = ([0.25, 0.35], [0.25, 0.35]), R_1 = ([0.35, 0.45], [0.35, 0.45]), Q_5 = ([0.35, 0.45], [0.15, 0.25]), R_5 = ([0.45, 0.55], [0.25, 0.35]) and R_2 = [(0.25, 0.35), (0.35, 0.45)] and R_2 = [(0.35, 0.45), (0.25, 0.35)], R_6 = [(0.35, 0.45), (0.15, 0.25)] and R_6 = [(0.45, 0.55), (0.15, 0.25)], respectively. In all the discussed cases, the present measure is free from all the counter-intuitive cases, see Table 1.

3. An Integrated IVIF-Distance Measure-Based MAIRCA Method

The current part of the study develops an extended MAIRCA model for solving MCDM problems in which the information about the criteria and DMs is completely known. This model combines the proposed IVIF-distance measure and the MAIRCA method with IVIF information. The proposed model comprises the following procedure (see Fig.1):

Step 1: Create the decision matrix.

A group of DMEs $H = \{h_1, h_2, ..., h_n\}$ is invited for the assessment of an optimal alternative among a set of options $Y = \{y_1, y_2, ..., y_s\}$ by means of the criteria set $W = \{w_1, w_2, ..., w_t\}$ The DMs present the linguistic assessment rating of each option y_i with respect to criteria w_j, j = 1, 2, ..., t. Let D = $(\delta_{ij}^{(k)})_{s\times t}$ be the linguistic assessment matrix (LAM), where $\delta_{ij}^{(k)}$ denotes the linguistic variable (LV) of each candidate y_i over a criterion w_j presented by k^{th} DME. Based on the given linguistic scale's table, the LAM is switched into IVIF decision matrix (IVIFDM).

Step 2: Compute the DMEs' significance values.

Assume that $h_k = ([\mu_k^-, \mu_k^+],[\nu_k^-, \nu_k^+]), k = 1, 2, ..., n$ be the performance of k^{th} DME. Then the procedure for estimating the numeric significance value of k^{th} DME is presented in the following steps:

Step 2a: Determine the matrix using score function.

Each IVIFN h_k is normalized and computed as Mishra et al. [54]:

$$\bar{h}_k = \frac{(\mu_k^- + \mu_k^+)(2 + \pi_k^- + \pi_k^+)}{\sum_{k=1}^{n}((\mu_k^- + \mu_k^+)(2 + \pi_k^- + \pi_k^+))}, \forall k. \tag{16}$$

Step 2b: Determine the rank of DMEs' performances and compute the DME's significance value n-ρ_k+1, wherein ρ_k denotes the priority of k^{th} expert. The normalization process is used to normalize each significance value (Zhu et al. [55]):

$$\bar{h}_k^r = \frac{n-\rho_k+1}{\sum_{k=1}^{n}(n-\rho_k+1)}, \forall k. \tag{17}$$

Step 2c: Compute the weights.

In accordance with the combination of Eq. (7) and Eq. (8), DME's weighting formula is given as

$$\lambda_k = \frac{1}{2}((\bar{h}_k)+(\bar{h}_k^r)),\ \forall k,\ \text{where}\ \lambda_k \geq 0\ \text{and}\ \sum_{k=1}^{n}\lambda_k = 1. \tag{18}$$

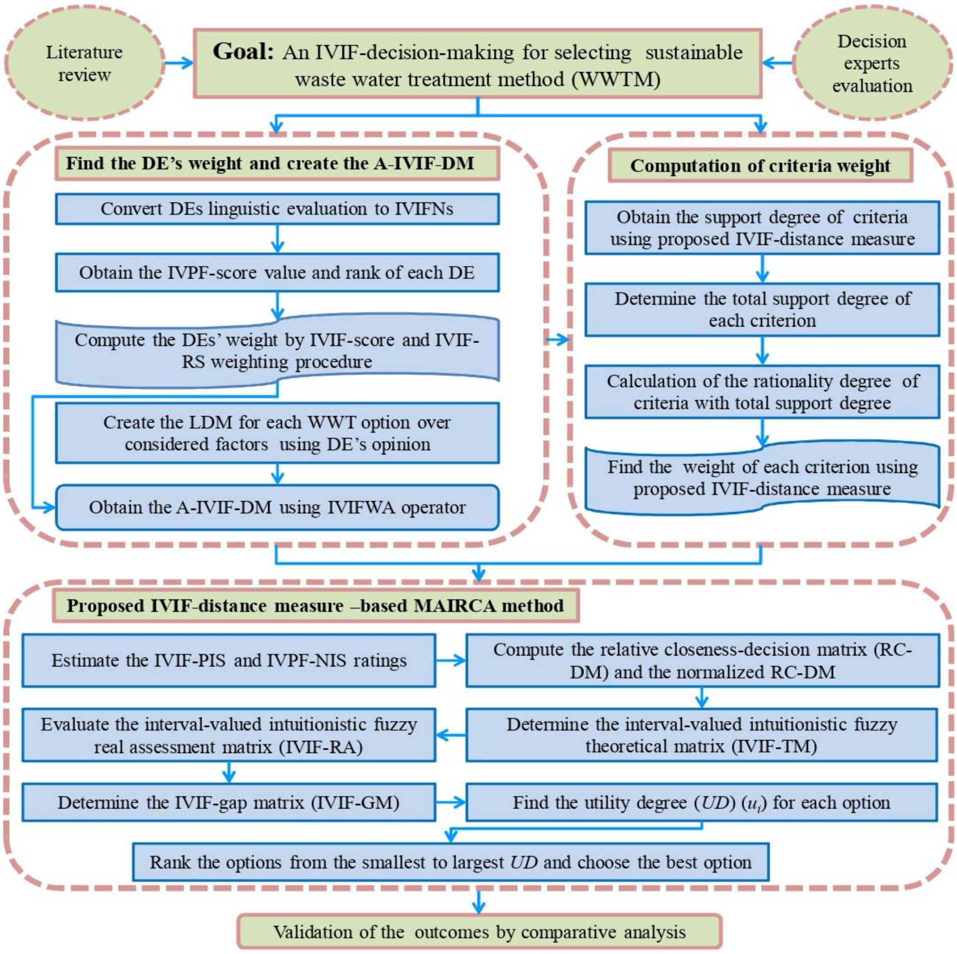

Fig. 1 Graphical structure of the proposed IVIF-distance measure-MAIRCA model

Step 3: Aggregate the individual DME's opinions.

As each decision maker has their own opinion regarding the performance of options with respect to the criteria. To make an optimal decision, there is a need to combine the individual decision opinions and create the aggregated IVIFDM (A-IVIFDM) $A = (\delta_{ij})_{s\times t}$, where δ_{ij} denotes the aggregated IVIFN, computed based on IVIFWA operator.

$$\delta_{ij} = ([\mu_{ij}^-, \mu_{ij}^+],[\nu_{ij}^-, \nu_{ij}^+]) = IVIFWA_\lambda\,(\delta_{ij}^{(1)}, \delta_{ij}^{(2)}, ..., \delta_{ij}^{(n)})\,. \quad (19)$$

Step 4: Compute the criteria weights.

Assume that the significance value of each criterion is different and independent of each other. Let $X = (x_1, x_2, ..., x_t)^T$ be the weight vector of criteria set, satisfying $x_j \in [0, 1]$ and $\sum_{j=1}^{t} x_j = 1.$ Next, we present the procedure to compute the criteria weights as follows:

Step 4.1: Determine the support degree *sup* $(\delta_{ij}, \delta_{il})$ between the considered criteria w_j and w_l using the proposed IVIF-distance measure, which as

$$\sup(\delta_{ij}, \delta_{il}) = 1 - D(\delta_{ij}, \delta_{il}),\ i = 1, 2, ..., s,\ j, l = 1, 2, ..., t,\ j \neq l, \quad (20)$$

where $D\,(\delta_{ij}, \delta_{il})$ denotes the IVIF-distance measure given in Eq. (5).

Step 4.2: Compute the total support degree $T\,(\delta_{ij})$ for each criterion w_j, by means of Eq. (21).

$$T(\delta_{ij}) = \sum_{l=1, l\neq j}^{t} \sup(\delta_{ij}, \delta_{il}). \quad (21)$$

Step 4.3: Compute the rationality degree θ_j of each criterion w_j, given as

$$\theta_j = \frac{1}{s(t-1)} \sum_{i=1}^{s} \sum_{j=1}^{t} T(\delta_{ij}),\ \theta_j \in [0,1]. \quad (22)$$

Step 4.4: Determine the comprehensive index (weight of criteria) x_j, of j^{th} criterion w_j, given as

$$x_j = \frac{\theta_j}{\sum_{j=1}^{t} \theta_j}, \quad (23)$$

where $j = 1, 2, \ldots, t$.

Step 5: Calculate the positive distance grade ps_{ij} and the negative distance grade pn_{ij} between an element δ_{ij} in an A-IVIFDM $A = (\delta_{ij})_{s\times t}$ and the PIS ω^+ and the NIS ω^-, respectively, where $\delta_{ij} = ([\mu_{ij}^-, \mu_{ij}^+],[\nu_{ij}^-, \nu_{ij}^+]),\ \omega^+ = ([\mu_{\omega_j^+}^-, \mu_{\omega_j^+}^+],[\nu_{\omega_j^+}^-, \nu_{\omega_j^+}^+])$ and $\omega^- = ([\mu_{\omega_j^-}^-, \mu_{\omega_j^-}^+],[\nu_{\omega_j^-}^-, \nu_{\omega_j^-}^+]),$ shown as follows:

$$ps_{ij} = \frac{1}{2}\sqrt{\begin{bmatrix} \left(\sqrt{\mu_{ij}^-} - \sqrt{\mu_{\omega_j^+}^-}\right)^2 + \left(\sqrt{\mu_{ij}^+} - \sqrt{\mu_{\omega_j^+}^+}\right)^2 + \left(\sqrt{\nu_{ij}^-} - \sqrt{\nu_{\omega_j^+}^-}\right)^2 \\ + \left(\sqrt{\nu_{ij}^+} - \sqrt{\nu_{\omega_j^+}^+}\right)^2 + \left(\sqrt{\pi_{ij}^-} - \sqrt{\pi_{\omega_j^+}^-}\right)^2 + \left(\sqrt{\pi_{ij}^+} - \sqrt{\pi_{\omega_j^+}^+}\right)^2 \end{bmatrix}}, \quad (24)$$

$$pn_{ij}=\frac{1}{2}\sqrt{\begin{bmatrix}\left(\sqrt{\mu_{ij}^{-}}-\sqrt{\mu_{\omega_j^{-}}^{-}}\right)^2+\left(\sqrt{\mu_{ij}^{+}}-\sqrt{\mu_{\omega_j^{-}}^{+}}\right)^2+\left(\sqrt{\nu_{ij}^{-}}-\sqrt{\nu_{\omega_j^{-}}^{-}}\right)^2\\+\left(\sqrt{\nu_{ij}^{+}}-\sqrt{\nu_{\omega_j^{-}}^{+}}\right)^2+\left(\sqrt{\pi_{ij}^{-}}-\sqrt{\pi_{\omega_j^{-}}^{-}}\right)^2+\left(\sqrt{\pi_{ij}^{+}}-\sqrt{\pi_{\omega_j^{-}}^{+}}\right)^2\end{bmatrix}}. \tag{25}$$

Here, i = 1, 2, …, s and j = 1, 2, …, t. An IVIFN has a positive ideal solution ω^+ and a negative ideal solution ω^-, where $\omega^+ = ([1, 1], [0, 0])$ and $\omega^- = ([0, 0], [1, 1])$ are the IVIFNs.

Step 6: With the use of Eq. (24) and Eq. (25), create the relative closeness decision matrix $R = (rc_{ij})_{s\times t}$, where

$$rc_{ij}=\frac{pn_{ij}}{pn_{ij}+ps_{ij}}. \tag{26}$$

Step 7: Normalize the relative closeness-decision matrix $R = (rc_{ij})_{s\times t}$ into the normalized form $R = (nrc_{ij})_{s\times t}$, where

$$nrc_{ij}=\begin{cases}\dfrac{rc_{ij}-(rc_{ij})_{\min}}{(rc_{ij})_{\max}-(rc_{ij})_{\min}}, & \text{for } w_j \text{ is the benefit criterion,}\\[2ex] \dfrac{(rc_{ij})_{\max}-rc_{ij}}{(rc_{ij})_{\max}-(rc_{ij})_{\min}}, & \text{for } w_j \text{ is the cost criterion.}\end{cases} \tag{27}$$

Step 8: Make the IVIF theoretical matrix $T = (\varepsilon_{ij})_{s\times t}$, where

$$\varepsilon_{ij}=P_{C_i}\,x_j, \tag{28}$$

$$P_{C_i}=1/t, \tag{29}$$

where x_j signifies the j^{th} criterion's weight, where j = 1, 2, …, t.

Step 9: Based on the obtained IVIF theoretical matrix $T = (\varepsilon_{ij})_{s\times t}$ and the obtained normalized relative closeness decision matrix $R = (nrc_{ij})_{s\times t}$, construct the interval-valued intuitionistic fuzzy real assessment matrix $\beta = (\beta_{ij})_{s\times t}$, where

$$\beta_{ij}=\varepsilon_{ij}.nrc_{ij}. \tag{30}$$

Step 10: Based on the obtained IVIF-TM $T = (\varepsilon_{ij})_{s\times t}$ and the obtained real assessment matrix $\beta = (\beta_{ij})_{s\times t}$, construct the interval-valued intuitionistic fuzzy gap matrix $G = (g_{ij})_{s\times t}$, where

$$g_{ij}=\varepsilon_{ij}-\beta_{ij}. \tag{31}$$

Step 11: Calculate the utility degree C_i of alternative y_i, shown as follows:

$$C_i=\sum_{j=1}^{t}g_{ij},\ i=1,2,...,s. \tag{32}$$

Prioritize the options as per the obtained utility degrees C_1, C_1, ..., and C_s of the alternatives y_1, y_1, ..., and y_s, respectively. The lesser the utility degree of an option y_i, the better the ranking order of option y_i, where i = 1, 2, …, s.

4. CASE STUDY: WWTT SELECTION PROBLEM

Environmental challenges related to the chemical and biological pollution of water have become important for the industrial sector, society and public agencies. Most of the domestic and industrial activities generate wastewater that contains harmful and undesirable pollutants, thus, it requires a proper management and treatment. The wastewater management and treatment aim to the sustainable development of natural resources together with the protection of environment and public health. In this section, the present MAIRCA model is firstly executed on a case study of the WWTTs assessment problem with respect to several factors. Further, the sensitivity analysis and comparative study by means of existing methods are discussed under IVIFS environment, which shows the stability and robustness of the presented methodology.

With the increasing complexity, time boundedness and lack of precise knowledge/ information, it is quite hard to evaluate the candidates with regard to given criteria in realistic situations. In this section, a group of three DMs is formed to identify the criteria and evaluate the WWTTs based on considered criteria. These DEs are having more than 15 years of experience in their respective fields. Two of them are from the environmental engineering department and the other one is from sustainable planning and management. Based on the literature review and online questionnaire, we have considered five WWTT alternatives and nine criteria. The presented case study is for the demonstration purposes to prove the practicality of the proposed method. Readers may reduce some criteria or add more criteria as per their requirements. Description of the alternatives is presented as follows:

- **Microbial fuel cell (MFC) (y_1):** MFC is relatively a new promising technology for producing renewable energy while treating wastewater. This technology is a chemical reactor system that generates electricity from the biodegradation of organic materials with the help of suitable microbial substrate. It is used to acquire a higher energy density and pollutants removal.
- **Membrane Filtration (y_2):** It is physiochemical process for the treatment of water from different wastewater streams and makes it possible to reuse. This process of treatment is defined on the size of the material that needs to be separated from the liquid.
- **Automatic Variable Filtration (AVF) (y_3):** It is a simple water filtration technology used for wastewater treatment where the upward flow of influent is purified or cleaned by the downward flow of filter media. It can effectively remove the bacterial contamination and micro-organisms while treating wastewater.
- **Natural treatment methods (y_4):** It is a biological treatment method to treat the wastewater naturally by removing contaminants from wastewater. These methods are eco-friendly, cost-effective, and can be jointly driven by public bodies and communities.

- **Advanced Photo-Oxidation Process (APOP) (y_5):** APOP is a type of chemical treatment that oxidizes organic molecules in wastewater that are hard to manage biologically.

Table 2 Criteria used for WWTT selection extracted from the literature

Dimensions	Criteria	Meanings	References
Economic (EC)	Maintenance and operation cost (EC1)	Repair, personnel, chemical and energy costs to manage WWT	Curiel-Esparza et al. [56], Molinos-Senante et al. [57], Saghafi et al. [58], Obaideen et al. [59]
	Land requirement (EC2)	Enough space for WWT plant/future expansion	Kalbar et al. [60], Mahjouri et al. [61], Saghafi et al. [58], Obaideen et al. [59]
Environmental (EN)	Energy consumption (EN1)	Energy consumption amount during WWT activities	Molinos-Senante et al. [57], Piadeh et al. [62], Srdjevic et al. [63], Salamirad et al. [15], Narayanamoorthy et al. [23]
	Sludge production (EN2)	Sludge generation of the system	Molinos-Senante et al. [57], Saghafi et al. [58], Salamirad et al. [15]
	Odor impacts (EN3)	Undesired smell potential of the system	Plakas et al. [64], Eseoglu et al. [65], Salamirad et al. [15]
Social (S)	Public acceptance (S1)	Public awareness	Molinos-Senante et al. [57], Plakas et al. [64], Obaideen et al. [59], Salamirad et al. [15]
	Aesthetic (S2)	Acceptability of plant conditions and appearance	Eseoglu et al. [65], Salamirad et al. [15]
Technical (T)	COD removal capacity (T1)	The removal capacity of amount of oxygen consumed to oxidize all organic material by chemical oxidants	Zhang et al. [10], Eseoglu et al. [65], Srivastava and Singh [14]
	BOD removal capacity (T2)	The removal capacity of amount of oxygen consumed by microorganisms while decomposing organic matter	Zhang et al. [10], Eseoglu et al. [65], Srivastava and Singh [14]

Further, an online survey has been prepared with the purpose of determining the significance of criteria to assess the WWTT alternatives. In addition, the criteria that may have an effect on the WWTT alternatives' evaluation are assembled through literature survey. Table 2 presents the source and type of each considered criterion. Fig. 2 presents the hierarchical structure of the considered criteria and alternatives.

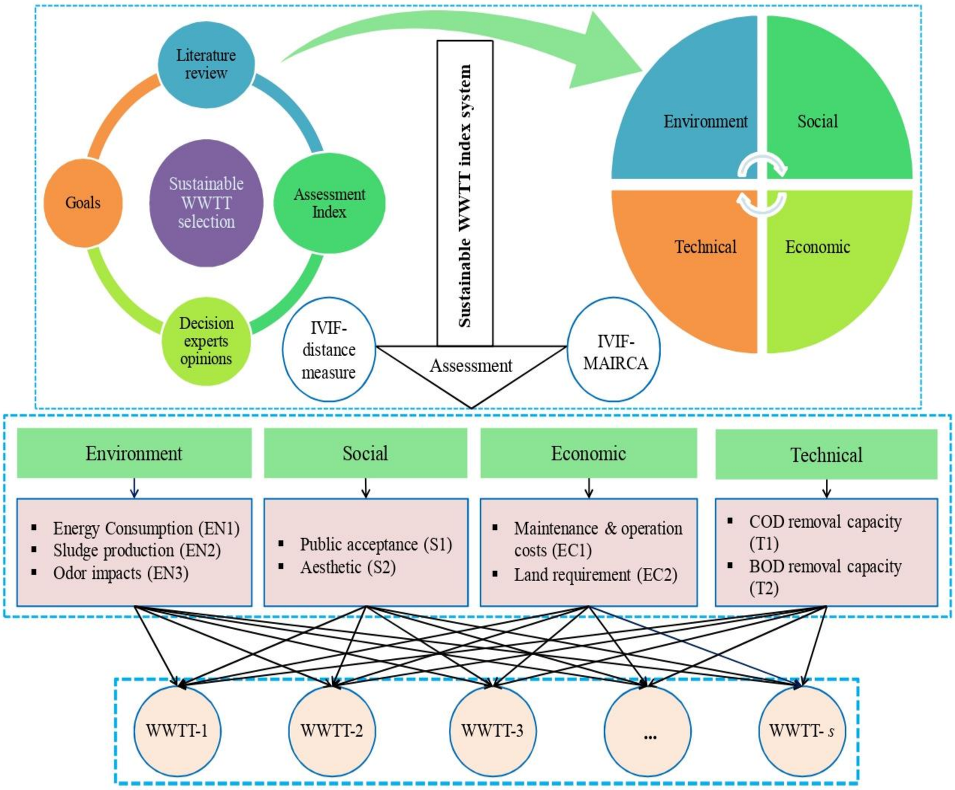

Fig. 2 Hierarchical structure for sustainable WWTT selection

Step 1: Table 3 presents the linguistic variables and their corresponding IVIFNs (Alrasheedi et al. [32] and Mishra et al. [52]). Based on the DMs' opinions, the assessment rating of each WWTT alternative with respect to each criterion and form a linguistic assessment matrix in Table 4.

Table 3 LVs for sustainable WWTTs assessment

LVs	IVIFNs
Absolutely significant (AS)	([0.90,0.95],[0.01,0.05])
Very significant (VS)	([0.80,0.90],[0.05,0.10])
Significant (S)	([0.70,0.80],[0.10,0.15])
Quite significant (QS)	([0.65,0.70],[0.15,0.25])
Moderate (M)	([0.55,0.65],[0.20,0.35])
Quite insignificant (QI)	([0.40,0.50],[0.40,0.45])
Insignificant (I)	([0.25,0.40],[0.45,0.50])
Very insignificant (VI)	([0.15,0.20],[0.60,0.75])
Absolutely insignificant (AI)	([0.05,0.10],[0.80,0.90])

Table 4 The LAM for sustainable WWTT selection problem

Criteria	y_1	y_2	y_3	y_4	y_5
w_1	(VI,VI,QI)	(AI,I,QI)	(I,VI,VI)	(VI,AI,M)	(VI,QI,QI)
w_2	(S,S,VS)	(S,VS,M)	(M,S,VS)	(QS,QS,S)	(M,QS,S)
w_3	(VI,SI,M)	(QI,I,M)	(QI,I,I)	(VI,I,VI)	(VI,M,VI)
w_4	(M,I,VI)	(I,VI,AI)	(I,VI,M)	(I,QI,I)	(VI,QI,AI)
w_5	(VI,I,VI)	(QI,I,VI)	(VI,VI,M)	(I,I,AI)	(QI,I,AI)
w_6	(S,QS,VS)	(VS,QS,S)	(S,S,QS)	(M,VS,S)	(VS,VS,S)
w_7	(VS,QS,QI)	(S,QS,QS)	(VS,VS,QI)	(S,VS,S)	(AS,M,QS)
w_8	(QS,AS,S)	(S,S,QS)	(QS,M,S)	(VS,S,QI)	(VS,M,QI)
w_9	(M,M,VS)	(QS,VS,S)	(S,S,S)	(M,VS,M)	(QI,VS,M)

Step 2: With the use of linguistic scales of Table 3 and Eqs. (16-18), the significance values of DMs are derived and shown in Table 5 for sustainable WWTT selection problem.

Table 5 DMEs' weights for sustainable WWTT selection

DMEs	h_1	h_2	h_3
LVs	H	VH	EH
IVIFNs	([0.70,0.80],[0.10,0.15])	([0.80,0.90],[0.05,0.10])	([0.90,0.95],[0.01,0.05])
n-ρ_k+1	1	2	3
Weights	0.2382	0.3343	0.4274

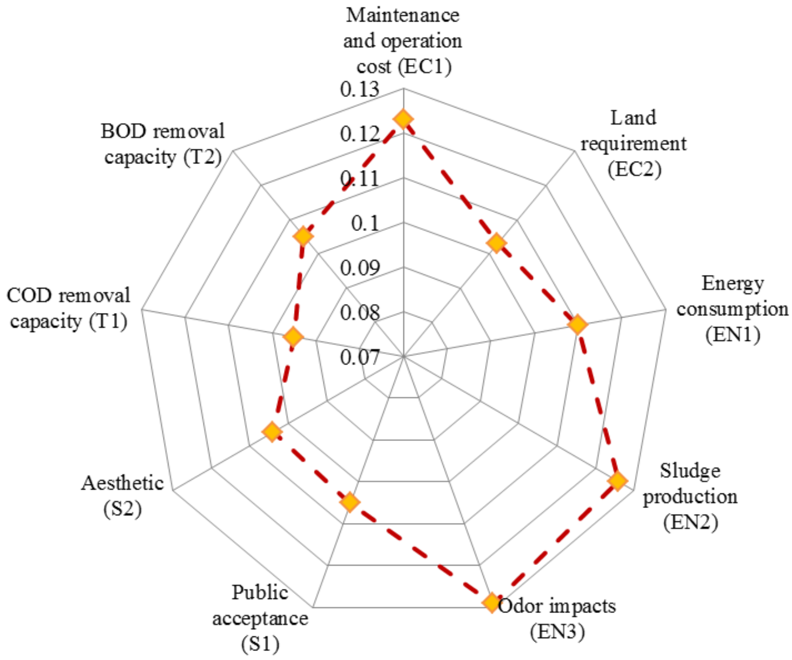

Fig. 3 Representation of the criteria weights using IVIF-distance measure-based tool

Table 6 Aggregated decision matrix for sustainable WWTT selection

Criteria	y_1	y_2	y_3	y_4	y_5
w_1	([0.268, 0.346], [0.505, 0.603])	([0.279, 0.389], [0.491, 0.550])	([0.175, 0.253], [0.560, 0.681])	([0.328, 0.416], [0.413, 0.576])	([0.348, 0.441], [0.441, 0.508])
w_2	([0.748, 0.851], [0.074, 0.126])	([0.688, 0.798], [0.107, 0.188])	([0.722, 0.830], [0.088, 0.154])	([0.672, 0.748], [0.126, 0.177])	([0.652, 0.738], [0.135, 0.202])
w_3	([0.423, 0.520], [0.328, 0.457])	([0.428, 0.544], [0.309, 0.419])	([0.289, 0.425], [0.438, 0.488])	([0.185, 0.273], [0.545, 0.655])	([0.313, 0.393], [0.416, 0.581])
w_4	([0.299, 0.403], [0.420, 0.546])	([0.135, 0.214], [0.634, 0.736])	([0.371, 0.475], [0.350, 0.492])	([0.304, 0.435], [0.433, 0.483])	([0.207, 0.281], [0.593, 0.684])
w_5	([0.185, 0.273], [0.545, 0.655])	([0.250, 0.350], [0.495, 0.580])	([0.352, 0.438], [0.375, 0.542])	([0.170, 0.286], [0.575, 0.643])	([0.229, 0.317], [0.560, 0.627])
w_6	([0.734, 0.830], [0.085, 0.139])	([0.657, 0.770], [0.135, 0.197])	([0.680, 0.762], [0.119, 0.170])	([0.711, 0.819], [0.094, 0.160])	([0.762, 0.865], [0.067, 0.119])
w_7	([0.614, 0.713], [0.176, 0.240])	([0.663, 0.728], [0.136, 0.184])	([0.680, 0.801], [0.122, 0.207])	([0.738, 0.841], [0.079, 0.131])	([0.718, 0.794], [0.087, 0.173])
w_8	([0.784, 0.861], [0.051, 0.111])	([0.596, 0.672], [0.177, 0.276])	([0.644, 0.734], [0.139, 0.213])	([0.634, 0.749], [0.153, 0.218])	([0.580, 0.698], [0.193, 0.289])
w_9	([0.682, 0.795], [0.111, 0.205])	([0.728, 0.825], [0.087, 0.140])	([0.700, 0.800], [0.100, 0.150])	([0.657, 0.770], [0.126, 0.230])	([0.632, 0.749], [0.148, 0.244])

Step 3: By means of Table 3, Table 4 and Eq. (19), the aggregated decision matrix is created to combine the individual opinions of three DMEs and presented in Table 6.

Step 4: To determine criteria weights, the total support degree using the proposed IVIF-distance measure and rationality degree of the aggregated decision matrix are calculated using Eqs. (20-22) and depicted in Table 7. Based on the rationality degree of each criterion, we determine the weights of criteria for sustainable WWTT selection using Eq. (23) and portrayed in Table 7.

Here, Fig. 3 presents the significance degrees or weights of considered evaluation criteria in HSWPP locations assessment. Based on the obtained results, Odor impacts (EN3) is the most important criterion among a set of twelve criteria for assessing the WWTT. Sludge production (EN2) is the second most important criterion for WWTT evaluation. Maintenance and operation cost (EC1) has third with significance value 0.123, Energy consumption (EN1) with weight value 0.11 has fourth most important criterion for WWTT evaluation and others are considered crucial sub-criteria for the taken case study.

Table 7 Rationality and comprehensive degree of option for sustainable WWTT selection

Criteria	y_1	y_2	y_3	y_4	y_5	δ_j	x_j
w_1	2.058	1.789	2.492	1.846	1.592	0.244	0.123
w_2	1.723	1.608	1.621	1.672	1.571	0.205	0.103
w_3	1.604	1.441	1.769	2.245	1.677	0.218	0.110
w_4	1.848	2.660	1.517	1.777	2.170	0.249	0.126
w_5	2.443	1.894	1.630	2.275	1.995	0.256	0.129
w_6	1.661	1.438	1.473	1.715	2.027	0.208	0.105
w_7	1.489	1.525	1.669	1.858	1.720	0.207	0.104
w_8	1.896	1.335	1.363	1.513	1.409	0.188	0.095
w_9	1.730	1.746	1.533	1.773	1.512	0.207	0.105

Table 8 Normalized relative closeness-decision matrix for sustainable WWTT selection

Criteria	y_1	y_2	y_3	y_4	y_5
w_1	0.509	0.325	1.000	0.120	0.000
w_2	1.000	0.403	0.738	0.157	0.000
w_3	0.082	0.000	0.460	1.000	0.534
w_4	0.248	1.000	0.000	0.173	0.769
w_5	0.956	0.541	0.000	1.000	0.816
w_6	0.676	0.000	0.128	0.497	1.000
w_7	0.000	0.298	0.532	1.000	0.726
w_8	1.000	0.017	0.286	0.273	0.000
w_9	0.513	1.000	0.729	0.241	0.000

Steps 5-6: Based on Eqs (24-26), we obtain the positive distance grade ps_{ij} and the negative distance grade pn_{ij} and relative closeness matrix, where ω^+ = ([1,1], [0, 0]) and ω^- = ([0,0], [1,1]) are positive and negative ideal solutions, respectively for sustainable WWTT selection as rc_{11} = 0.431, rc_{12} = 0.718, rc_{13} = 0.522, and others.

Table 9 IVIF-Theoretical matrix for sustainable WWTT selection

Criteria	y_1	y_2	y_3	y_4	y_5
w_1	0.025	0.025	0.025	0.025	0.025
w_2	0.021	0.021	0.021	0.021	0.021
w_3	0.022	0.022	0.022	0.022	0.022
w_4	0.025	0.025	0.025	0.025	0.025
w_5	0.026	0.026	0.026	0.026	0.026
w_6	0.021	0.021	0.021	0.021	0.021
w_7	0.021	0.021	0.021	0.021	0.021
w_8	0.019	0.019	0.019	0.019	0.019
w_9	0.021	0.021	0.021	0.021	0.021

Step 7: Using Eq. (27), we obtain the normalized relative closeness decision matrix for sustainable WWTT selection and given in Table 8, where nrc_{11} = 0.509, nrc_{12} = 1.000, nrc_{13} = 0.083, and others.

Step 8: Based on Eq. (28) and Eq. (29), we obtain the interval-valued intuitionistic fuzzy theoretical matrix for sustainable WWTT selection and discussed in Table 9, where ε_{11} = 0.025, ε_{12} = 0.021, ε_{13} = 0.022, and others.

Step 9: Based on Eq. (30), we obtain the interval-valued intuitionistic fuzzy real assessment matrix for sustainable WWTT selection and presented in Table 10, where β_{11} = 0.013, β_{12} = 0.021, β_{13} = 0.002, and others.

Table 10 IVIF-Real assessment matrix for sustainable WWTT selection

Criteria	y_1	y_2	y_3	y_4	y_5
w_1	0.013	0.008	0.025	0.003	0.000
w_2	0.021	0.008	0.015	0.003	0.000
w_3	0.002	0.000	0.010	0.022	0.012
w_4	0.006	0.025	0.000	0.004	0.019
w_5	0.025	0.014	0.000	0.026	0.021
w_6	0.014	0.000	0.003	0.010	0.021
w_7	0.000	0.006	0.011	0.021	0.015
w_8	0.019	0.000	0.005	0.005	0.000
w_9	0.011	0.021	0.015	0.005	0.000

Step 10: Based on Eq. (31), we obtain the interval-valued intuitionistic fuzzy gap matrix for sustainable WWTT selection and discussed in Table 11, where g_{11} = 0.012, g_{12} = 0.000, g_{13} = 0.020, and others.

Table 11 IVIF-Gap matrix for sustainable WWTT selection

Criteria	y_1	y_2	y_3	y_4	y_5
w_1	0.012	0.017	0.000	0.022	0.025
w_2	0.000	0.012	0.005	0.017	0.021
w_3	0.020	0.022	0.012	0.000	0.010
w_4	0.019	0.000	0.025	0.021	0.006
w_5	0.001	0.012	0.026	0.000	0.005
w_6	0.007	0.021	0.018	0.011	0.000
w_7	0.021	0.015	0.010	0.000	0.006
w_8	0.000	0.019	0.014	0.014	0.019
w_9	0.010	0.000	0.006	0.016	0.021

Step 11: Based on Eq. (32), we obtain the utility score C_i of alternative y_i, where i = 1, 2, 3, 4, 5, C_1 = 0.0902, C_2 = 0.1171, C_3 = 0.1155, C_4 = 0.1001 and C_5 = 0.1118. Because $C_1 > C_4 > C_5 > C_3 > C_2$, therefore ranking order of the WWTT alternatives y_1, y_2, y_3, y_4 and y_5 is: $y_1 \succ y_4 \succ y_5 \succ y_3 \succ y_2$. Thus, the alternative y_1 is the best alternative for sustainable WWTT selection.

5. Comparative Analysis and Discussion

In this part of the study, we compare the results obtained by the proposed and some of the extant MADM methods including IVIF-weighted aggregated sum product assessment (IVIF-WASPAS) [66] model, IVIF-complex proportional assessment (IVIF-COPRAS) [67] model and IVIF-combined compromise solution (IVIF-CoCoSo) [32] model and IVIF-technique for order of preference by similarity to ideal solution (IVIF-TOPSIS) [68] model.

Here, Fig. 4 depicts the obtained ranking results by different MCDM approaches. From Fig. 4, we can observe that the ranking orders are different by all the methods but the optimum alternative is same in case of the obtained results by introduced method, IVIF-WASPAS, IVIF-COPRAS and IVIF-CoCoSo methods, while IVIF-TOPSIS model provides different optimal candidate. The preference orders of WWTT candidate by means of different weighting approaches are shown in Fig. 5. To accomplish better insight from the IVIF-distance measure-based MAIRCA technique in the assessment of sustainable WWTT, we calculate the utility score of each WWTT over considered sustainable aspects and factors, as given in Fig. 5. Since MFC (y_1) has extensively highest score for all extant and proposed models social, economic environmental aspects of attributes' weighting (see Fig. 5), consequently, it is chosen as the best WWTT option. In accordance with the aforementioned analysis, it can be easily noticed that observing the various weighting frameworks will enhance the utility and effectiveness of the developed IVIF-MAIRCA method. Table 12 presents the parameters to compare different approaches including proposed and existing MCDM approaches.

Table 12 Parameters to compare different approaches

Standards	IVIF-WASPAS	IVIF-COPRAS	IVIF-CoCoSo	IVIF-TOPSIS	Proposed method
Interrelationships between the arguments	Not considered	Not considered	Not considered	Not considered	Considered
Criteria weights	Computed	Computed	Computed	Assumed	Computed
MCDM procedure	Group	Group	Group	Group	Group
DMEs' weights	Not considered	Computed	Computed	Not considered	Computed
Does the ranking tool consider type of criteria	No	No	Yes	No	Yes
Preference order	$y_1 \succ y_4 \succ y_2 \succ y_5 \succ y_3$	$y_1 \succ y_4 \succ y_5 \succ y_2 \succ y_3$	$y_1 \succ y_4 \succ y_2 \succ y_5 \succ y_3$	$Y_4 \succ y_5 \succ y_1 \succ y_2 \succ y_3$	$y_1 \succ y_4 \succ y_5 \succ y_3 \succ y_2$
Optimal option	y_1	y_1	y_1	y_4	y_1

The main advantages of the developed IVIF-distance measure-based MAIRCA are listed as

- In this method, the weights of the decision makers are computed through score function-based model. Thus, the proposed approach gives a more accurate decision as compared to existing IVIF MCDM methods.
- The distance measure proposed in this study avoids the limitations of several existing IVIF-distance measures. Thus, the criteria weighting model based on the proposed distance measure provides more efficient result in the assessment of WWTT alternatives.
- The MAIRCA method determines the best solution considering the deviation between the defined theoretical and the real results. The key benefits of the MAIRCA approach are presented as follows: (i) it can solve the MCDM problems with mixed qualitative and quantitative assessment criteria; (ii) this method considers the concept of the positive and negative ideal solutions and (iii) the MAIRCA has a distinctive linear normalization algorithm which can obtain highly reliable discrepancies and generate consistent results.

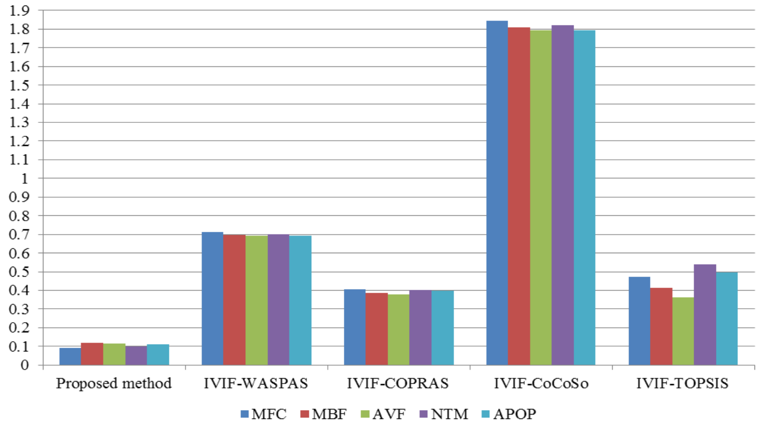

Fig. 4 Comparison of proposed with extant methods for sustainable WWTT selection

5.1. Discussion and Implications

The weighting outcomes revealed that the Odor impacts (EN3), Sludge production (EN2) and Maintenance and operation cost (EC1) had become the most significant factors for sustainable WWTT assessment (see Fig. 3). As a result, these criteria should be taken sincerely, while energy consumption (EN1), public acceptance (S1), BOD removal capacity (T2), aesthetic (S2), land requirement (EC2) and COD removal capacity (T1) should be also emphasized with small weights. Moreover, assessment outcomes of sustainable aspects of WWTT assessments are prioritized as: Environmental (0.365) $\succ$ Economic (0.226) $\succ$ Social (0.209) $\succ$ Technical (0.2), which means Environmental dimension have highest impact on prioritization order of sustainable WWTT selection followed by economic, social, technical aspects. The utility scores of WWTT option are 0.0902, 0.1171, 0.1155, 0.1001 and 0.1118, the prioritization order of alternatives y_1, y_2, y_3, y_4 and y_5 is: $y_1 \succ y_4 \succ y_5 \succ y_3 \succ y_2$. By means of the concept of IVIF-distance measure-based MAIRCA methodology, we have combined the weight-determining models based on IVIF-distance measure and MAIRCA tool, which reduces information loss during the process of making decision.

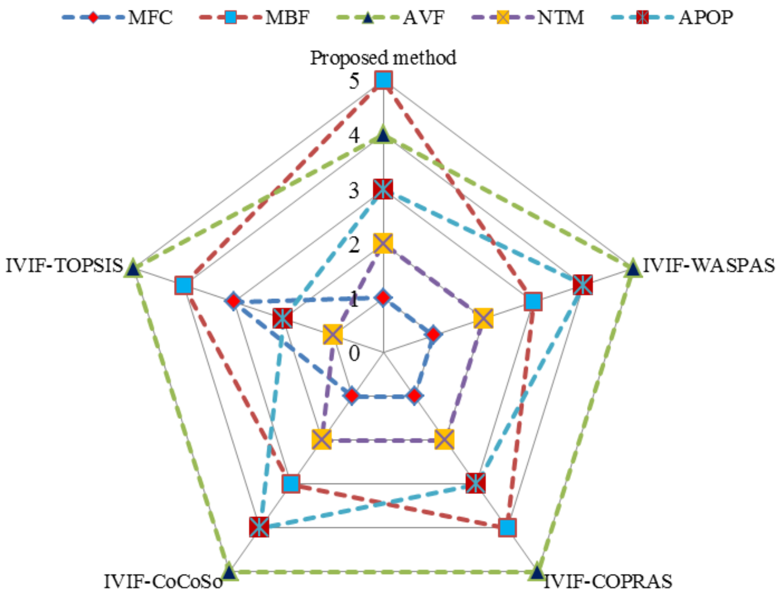

Fig. 5 Ranking results obtained by extant methods for WWTTs assessment

This study suggests the policymakers to understand the performance of WWTT alternatives using different aspects of sustainability from uncertain perspective. The proposed work has the following implications for practitioners and scholars:

- The most suitable WWTT alternative performs better with respect to economic, environmental social and technical dimensions of sustainability with minimum cost and higher efficiency in order to remove the effluents from the wastewater.

- Managers and policymakers can use the information presented in this study to support their decision for assessing the WWTT alternative.
- The proposed model not only evaluates the significant degrees of considered criteria but also tackles the ambiguity and fuzziness arisen during the process of WWTT alternatives assessment process.

6. CONCLUSIONS

To select the best sustainable WWTT for agricultural purposes, we develop a hybrid MCDM methodology that incorporates the sustainability concept. The methodology presented in this study combines the IVIF-distance measure, criteria weighting tool and MAIRCA model, and also considers the uncertainty level of the decision makers. Here, we have firstly proposed a new Hellinger IVIF-distance measure and analyzed the causes of counter-intuitive results of extant distance measures. Further, we have proposed a new criteria weight determining model based on the proposed Hellinger IVIF-distance measure and total support degree-based model. Further, we have proposed an integrated MAIRCA approach for dealing with the MCDM problems in which the information about the criteria and decision makers is completely unknown. The proposed MAIRCA method integrates the normalization process and ideal solutions, and then determines the option with the smallest total distance (gap) is the best option, which is the main advantage of the proposed work. Comparative assessments have been presented to reveal the outcomes obtained by the hybrid approach. As per the comparative study, it can be observed that the proposed MAIRCA model is very robust and appropriate for the decision support problems under IVIFS environment.

This study does not consider the geographical and cultural aspects of the criteria, which is one of the main limitations of this research. In addition, we consider only the independent characteristics of the criteria. In future, we can develop a model to evade the drawbacks of present work. In addition, future works should be deliberated towards utilizing a wider number of global DMs who will assess the factors affecting the healthcare blockchain platforms evaluation process. In addition, we can extend the MAIRCA model under different environments such as "interval-valued hesitant q-rung orthopair fuzzy sets (IVHq-ROFSs)", "q-rung orthopair soft rough sets (q-ROFSRSs)" and "interval-valued picture fuzzy sets (IVPiFSs)".

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