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Healthcare waste disposal location selection by a multi-criteria decision-making method with intuitionistic fuzzy sets

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Abstract *– Healthcare industries create hazardous waste (HCW), which can become a danger to the health of society. HCW disposal management is one of the main challenges for urban organizations and healthcare systems. Meanwhile, the HCW disposal location is a wrapped flow due to the contention of different alternatives, criteria, and government principles related to the HCW disposal. In this regard, a new multi-criteria decision-making (MCDM) approach is introduced under the intuitionistic fuzzy (IF) conditions to evaluate the importance degrees of criteria and decision-makers (DMs) by computing their weights and coping with uncertain situations. A new integrated weighting criteria method is provided based on aggregating the subjective and objective criterion weight. The subjective weight is gathered from an expert person and objective weight is computed from ordered weight averaging (OWA) method. Afterward, the DM weights are computed based on similarity measure approach. Also, a new ranking approach is introduced with an ideal and anti-ideal distance-based method. These methods are utilized under IF condition. Finally, a case study from the recent literature is applied to validate the proposed approach. This case determines that the proposed method has a high performance to take the appropriate decision.*

Keywords– *Healthcare waste disposal location, Multi-criteria decision-making, Intuitionistic fuzzy sets, Ordered weight averaging method, Similarity measure, Ideal solutions method, Ranking method.*

I. INTRODUCTION

Nowadays, one of the most critical challenges in recent years is related to the rapid growth of the population. Furthermore, the rapid development of society in developing countries is caused to increase in the severe effects on humans' and animals’ wellbeing. The disposal of the healthcare industries creates hazardous waste (HCW), such as hospitals, laboratories, and medical centers, that is one of the main concerns of health organizations. According to World Health Organization (WHO), the HCW includes the wastes created by the healthcare operations containing a wide confine of materials, used syringes, blooded cotton, bandages, scalpels, body parts, chemicals, cytotoxic, and radioactive ingredients. Hence, the HCW consists of two types non-hazardous and hazardous waste. Also, non-hazardous waste is approximately 85%, and hazardous is 15% of the healthcare system wastes (Chauhan & Singh, 2016a,b).

Developing a compatible environmental and appropriate HCW management system is one of the significant concerns for health care systems (Rabbani et al., 2018). The management of HCW systems offers the approach to evaluate the healthcare waste transportation to treatment factories and assist in selecting the appropriate treatment

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alternative and disposal location. Nevertheless, with the growth of the population and increasing healthcare services, the value of HCW for treatment and disposal is growing rapidly (Chauhan & Singh, 2016b)

One of the major strategic problems of the governments and municipalities is the contact with the location of the HCW disposal facilities. In the related works, the supply chain facility location problems have been considered, which introduces the concerning evaluation of production place, storage, and distribution center location (Ertuğrul & Karakaşoğlu, 2008; Melo et al., 2009). Also, other problems include the decisions relevant to the storage bins of waste in medical centers, location of medical centers, and others (Andrinopoulos et al., 2006). For this reason, Ertugrul and Karakasoglu (2008) introduced the multi-criteria facility location problem with labor availability as certain criteria. A notable point in the HCW disposal location problem is the wide range of this issue that considers all segments of sustainability, i.e., social, economic, and environmental segments. Therefore, the appropriate location selection of HCW disposal location among a set of potential locations is a wrapped multi-criteria decision-making (MCDM) process, which considers the presence of diverse qualitative and quantitative sustainable criteria landscapes (Yazdani et al., 2020).

MCDM approach is a practical material for presenting the best solution among possible alternatives against different indicators with various effects. As a matter of fact, the decision makers (DMs) with incrementing the complexity rate of the decision support systems (DSS) take into mind the experts' groups and use their opinions in solving the complex problem. The reliability of the solution in the MCDM problem is one of the main issues in recent years that the researchers have been focusing on. This problem is solved by considering the evaluation of groups of opinions instead of one DM regard (Vahdani et al., 2010). Another subject in the MCDM method is related to the subjective judgment of the DMs that is caused the uncertainty conditions occurred in this problem (Mousavi et al., 2013). For this reason, the linguistic variables are used to present the opinion of the expert persons. In the MCDM approach, the weights of criteria and DMs opinions are the essential factors, which are assisted to make the suitable decisions. Also, the ranking of the main alternatives has an important role in this regard.

On the other hand, uncertainty often occurs in the HCW disposal location flow that causes the attendance of various constraints, lack of knowledge, the empirical human mentality, and incompatibility of the problem. In this regard, the fuzzy sets (FSs) theory has been impressively implemented in different real-life MCDM problems and illustrated the prevailing capability to control vague and uncertain information (Zadeh, 1978). The intuitionisitc fuzzy sets (IFSs) are a good method to model the uncertain condition to improve the FSs. Also, vague information arises from real-life applications. According to advantages, this paper focuses on the IFs status. This paper is used the MCDM procedure to compute the weights of the criteria and DMs, and to rank alternatives of the decision-making process in the HCW disposal location problem under IF conditions, respectively. Commonly, the weights are classified into two kinds that consist of subjective and objective weights, respectively. Subjective weights based on experts' opinions are used to present comparative weights among indexes. Furthermore, Ye (2009) proposed an entropy method to develop subjective weights with the performance matrix. Liu et al. (2015) introduced both subjective and objective weights to create the FMEA more feasible and reasonable. Adar and Delice (2019) proposed a combination approach with MC-HFLTS for healthcare treatment technique selection.

In addition, the location of the HCW disposal facility is an important issue that is existed in the literature. Rani et al. (2020) evaluated the healthcare waste treatment problem under new Paythagorean fuzzy approach. Furthermore, Narayanamoorthy et al. (2020) evaluated the disposal waste of the medical centers with hesitant MOOSRA requirement. Ranjbari et al. (2021) generated a review paper that extensively analyzed the diverse point of waste management in the healthcare industry. Torkayesh et al. (2021) proposed the selection of the landfill location in the urban area with the hybrid BWM-grey MARCOS model. Chen et al. (2021) introduced a method to select a best healthcare waste disposal method during and after COVID-19 pandemic. This case occurred with Z-number conditions. Mishra and Rani (2021) proposed a selection method in waste healthcare disposal problem that was considered based on WASPAS method in Fermatean fuzzy conditions. Moreover, the main motivation of this paper is to utilize the MCDM model based on a new ranking method that is introduced with computing the ideal and anti-ideal decision matrix, positive, and negative ideal solutions' distances under IF environment. However, this study extended a new weighting method based on integrating the subjective and objective weights of criteria. This approach is a robust method to handle various conditions and can help persons to make suitable decisions in various conditions.

This paper calculates integrated criteria weights in the MCDM model that consists of the subjective and objective weights. Also, the weights of DMs are computed with the applied method. On the other hand, this approach is implemented under the IF environment to keep and handle the uncertain nature of real-life applications. Likewise, this paper introduces vagueness in experts' opinions and decreases the possibility of computing two ranking orders with an identical amount. In this regard, according to the compromise solution issue, the alternatives are ranked with a new collective index. Therefore, the aim and motivation of this paper are to show the subjective and objective criteria weights, display the weights of DMs, and propose the new ranking method under the IF situation, respectively. In addition, this approach is implemented in the evaluation of the HCW disposal location chosen problem. Eventually, the innovations of the paper are defined as:

- Developing the subjective and objective methods to compute the weights of criteria. In this approach, the subjective weight is gathered from an expert opinion and the objective weights are computed from the ordered weight averaging method. Eventually, the final weight is computed based on an aggregation method.
- Applying the DMs weight computational method. In this respect, the DM's weight is obtained based on a similarity measure approach that is provided from a distance-based method.
- Proposing the new method to rank the alternatives. This method is considered based on ideal and anti-ideal decision matrixes that are provided from positive and negative ideal solutions.
- Developing the real case study from the recent literature to validate the proposed methodology in the HCW disposal location problem.

The rest of this paper is organized as follows: Section 2 presents IF preliminaries and section 3 proposes the proposed IF-decision method. Section 4 shows the real case study from the recent literature to determine the performance of the new approach, and eventually, the conclusions are generated in section 5.

II. PRELIMINARIES

This section is relevant to the basic definition of the IF condition and formulation. These are explained as follows:

Definition 1. (Atanassov, 1986). Let X be a universe discourse. The IFS A from X is a goal presented in Eq. (1).

$$P = \{\langle x, \mu_A(x), v_A(x), \pi_A(x)\rangle | x \in X\} \tag{1}$$

The value of the membership function $\mu_A: X \to [0,1]$ is the value of membership function and $v_A: X \to [0,1]$ is the value of non-membership function. Also, π_A is relevant to the hesitance degree. Hence, for each $x \in X$ exists $0 \leq \mu_A(x) + v_A(x) \leq 1$. $\pi_A = 1 - \mu_A - v_A$.

Definition 2. (Atanassov, 1994; Xu & Yager, 2006) Let A and B are two IFSs from set of X; Although the crucial operators are explained in Eqs. (2)-(8).

$$A \cup B = \left\{\langle x. max\big(\mu_A(x). \mu_B(x)\big). min(v_A(x). v_B(x))\ \rangle | x \in A\right\} \tag{2}$$

$$A \cap B = \left\{\langle x. min\big(\mu_A(x). \mu_B(x)\big). max(v_A(x). v_B(x))\rangle | x \in A\right\} \tag{3}$$

$$\bar{A} = \{\langle x. v_A(x). \mu_B(x)\rangle | x \in A\} \tag{4}$$

$$\begin{aligned} A \oplus B = \{\langle x. \mu_A(x) + \mu_B(x) - \mu_A(x). \mu_B(x), v_A(x), v_B(x). 1 - \mu_A(x) - \mu_B(x) + \mu_A(x)\mu_B(x) \\ - v_A(x)v_B(x)\rangle\} \end{aligned} \tag{5}$$

$$\begin{aligned} A \otimes B = \{\langle x. \mu_A(x). \mu_A(x), v_A(x) + v_A(x) - v_B(x). v_B(x). 1 - \mu_A(x)\mu_B(x) - v_A(x) - \mu_B(x) \\ + v_A(x)v_B(x)\rangle\} \end{aligned} \tag{6}$$

$$A^{\lambda} = \left\{\langle x. \mu_A(x)^{\lambda}. 1 - (1 - v_A(x)^{\lambda}) | x \in A\rangle\right\}. \lambda > 0; \tag{7}$$

$$\lambda A = \left\{\langle x. 1 - (1 - \mu_A(x))^{\lambda}, v_A(x) | x \in A\rangle\right\}. \lambda > 0; \tag{8}$$

Definition 3. (Szmidt & Kacprzyk, 2000). The hamming distance and Euclidean distance are obtained with Eqs. (9) and (10) for $X = \{x_1. x_2. \dots. x_m\}$.

$$d_H(A.B) = \sum_{i=1}^{m} \frac{1}{2n} (|\mu_A(x_i) - \mu_B(x_i)| + |v_A(x_i) - v_B(x_i)| + |\pi_A(x_i) - \pi_B(x_i)|) \tag{9}$$

$$d(A.B) = \sqrt{\frac{1}{2n} \sum_{i=1}^{m} ((\mu_A(x_i) - \mu_B(x_i))^2 + (v_A(x_i) - v_B(x_i))^2 + (\pi_A(x_i) - \pi_B(x_i))^2)} \tag{10}$$

Definition 4. (Xu, 2007; Wang et al., 2013). Let $A_j = \left(\mu_{A_j}. v_{A_j}\right), (j = 1.2, \dots. n)$ be an IFS; The IF weighted averaging (IFWA) operator of extent *n* is determined in Eq. (11). In this formulation $w = (w_1.,,, w_n)^T$ is the weights' vector of A_j $\left(\sum_{j=}^{n} w_j = 1. w_j \in [0.1]\right)$.

$$IFWA_w(A_1. A_2. \dots. A_n) = \left[1 - \prod_{j=1}^{n} \left(1 - \mu_{A_j}\right)^{w_j}. \prod_{j=1}^{n} \left(v_{A_j}\right)^{w_j}\right] \tag{11}$$

Definition 5. (Xu & Yager, 2006). The IF weighted geometric averaging (IFWGA) operator is shown in Eq. (12). Also, $w = (w_1.,,, w_n)^T$ is the weights' vector of A_j $\left(\sum_{j=}^{n} w_j = 1. w_j \in [0.1]\right)$. In this equation $\sigma(j)$ is the permuation degree of the *jth* and the $A_{\sigma(n)}$is the largest IF value among all IF values.

$$IFWGA_w(A_1. A_2. \dots. A_n) = \left[1 - \prod_{j=1}^{n} (1 - \mu_{\sigma(j)})^{w_j}. \prod_{j=1}^{n} (1 - \mu_{\sigma(j)})^{w_j} - \prod_{j=1}^{n} (1 - \mu_{\sigma(j)} - v_{\sigma(j)})^{w_j}\right] \tag{12}$$

Definition 6. (Liu et al., 2013).The ordered weighted averaging (OWA) operator is presented in Eq. (13). In this equation, θ_j is related to the *jth* largest value of the A_j.

$$OWA(A_1.A_2.\dots.A_n) = \sum_{j=1}^{n} w_j \theta_j \tag{13}$$

Yager (1988) proposed the normal distribution-based approach to handle the partial judgment of the DMs. This point is shown in Eq. (14).

$$w_j = \frac{1}{\sqrt{2\pi\psi_n}} e^{-((j-\xi_n)^2/2\psi_n{}^2)} = \frac{e^{-((j-\xi_n)^2/2\psi_n{}^2)}}{\sum_{j=1}^{n} e^{-((j-\xi_n)^2/2\psi_n{}^2)}} \qquad \forall\, j = 1.,,,.n \tag{14}$$

where, $w = (w_1.,,,w_n)^T$ is the weight vector, ψ_n is standard deviation, and ξ_n is the mean. The standard deviation and mean values are obtained from Eqs. (15) and (16), respectively.

$$\psi_n = \left(\frac{1}{n}\sum_{j=1}^{n}(j-\xi_n)^2\right)^{\frac{1}{2}} \tag{15}$$

$$\xi_n = \frac{1+n}{2} \tag{16}$$

Definition 7. The matrix of positive and negative normalized IF l_{ij} are introduced in Eq. (17) ($\forall\, i = 1,2,\dots,m; j = 1,2,\dots,n$).

$$l_{ij} = \begin{cases} \{[\mu_{ij}, v_{ij}]\} & for\ positive\ criteria \\ \{[1-\mu_{ij}, 1-v_{ij}]\} & for\ negetive\ criteria \end{cases} \tag{17}$$

III. PROPOSED MODEL

This section evaluates the proposed method that is structured based on the calculation criteria' weights, DMs' weights, and ranking of the alternatives. The steps of the proposed method are described as follows:

Step 1. In this step, the data is gathered from groups of experts $(DM_k = DM_1, \dots DM_k; K = 1, \dots, k)$ for the indicators $\left(C_j = C_1, \dots, C_n; j = 1, \dots, n\right)$ and the main alternatives $(A_i = A_1, \dots, A_n; i = 1, \dots, m)$. In this paper, the criteria are assumed interdependent. Afterward, the decision matrix (F_k) is presented for *kth* DMs in Eq. (18).

$$F_k = \left(\tilde{F}_{ij}^k\right)_{m\times n} = \begin{pmatrix} \tilde{F}_{11}^k & \cdots & \tilde{F}_{1n}^k \\ \vdots & \ddots & \vdots \\ \tilde{F}_{m1}^k & \cdots & \tilde{F}_{mn}^k \end{pmatrix}_{m\times n} \tag{18}$$

Moreover, the weights of criteria are suggested from DMs with linguistic terms is $w_j = [w_{\mu j}^k, w_{vj}^k]$. Also, the importance measure of the DMs is $\lambda\tilde{T}_k = [\lambda_\mu^k, \lambda_v^k]$.

Step 2. (Xu, 2007; Wang et al., 2013). The expert opinion is aggregated with IFWA operator in Eqs. (19) and (20).

$$\tilde{F}_{ij} = IFWA_w(\tilde{F}_{ij}^1.\tilde{F}_{ij}^2.\ldots.\tilde{F}_{ij}^k) = \left[1 - \prod_{k=1}^{K}(1-\mu_{ij}^k)^{\lambda_k}.\prod_{k=1}^{K}(v_{ij}^k)^{\lambda_k}\right] \tag{19}$$

$$\widetilde{w}_j = IFWA_w(\widetilde{w}_j^1.\widetilde{w}_j^2.\ldots.\widetilde{w}_j^k) = \left[1 - \prod_{k=1}^{K}(1-w_{\mu j}^k)^{\lambda_k}.\prod_{k=1}^{K}(w_{vj}^k)^{\lambda_k}\right] \tag{20}$$

where $\tilde{E}_{ij}$is aggregated IF evaluation of *ith* alternative A_i with regard to criteria C_j. Also, $\widetilde{w}_j$ is the subjective weights aggregation of criteria C_j.

Step 3. (Hajighasemi and Mousavi, 2018). Obtaining the weight of criteria.

Step 3.1. The normalized subjective weight of the criterion $(\overline{w}_j)$ is calculated with Eq. (21).

$$\overline{w}_j = \frac{\widetilde{w}_j}{\sum_{j=1}^{n}\widetilde{w}_j} \tag{21}$$

Step 3.2. (Liu et al., 2013). According to definition 6, the objective weight $(\acute{w}_j)$ is obtained from Eqs. (13)-(16).

For this reason, if the n=5, the $\xi_5 = 3$, and the $\psi_5 = \sqrt{2}$. Hence, the weight of criteria is obtained from Eq. (14) that is presented $\acute{w}_5 = (0.10415, 0.22049, 0.28312, 0.22049, 0.17172)$.

Step 3.3. (Zhao et al., 2017). The aggregation of the criteria weight is obtained from Eq. (22).

$$\omega_j = \varphi\overline{w}_j + (1-\varphi)\acute{w}_j \tag{22}$$

where, φ is the relative importance between the subjective and objective weights of the criteria. This measure has an interval value between 0 to 1, but in this paper, this scale has the 0.5 value.

Step 4. (Yue, 2011). Computing the DMs' weights

Step 4.1. The normalized decision-making matrix is computed with Eqs. (23)-(25).

$$\hat{\mu}_{ij}^k = \frac{\mu_{ij}^k - \min_j \mu_{ij}^k}{\max_j \mu_{ij}^k - \min_j \mu_{ij}^k} \tag{23}$$

$$\hat{v}_{ij}^{k} = \frac{\max_{j} v_{ij}^{k} - v_{ij}^{k}}{\max_{j} v_{ij}^{k} - \min_{j} v_{ij}^{k}} \tag{24}$$

$$\hat{P}_{ij}^{k} = \left(\mu_{ij}^{k}. v_{ij}^{k}\right) = \left(\hat{\mu}_{ij}^{k}. 1 - \hat{v}_{ij}^{k}\right) \tag{25}$$

Step 4.2. The ideal decision-making matrix is calculated with Eqs. (26)-(28).

$$\mu_{ij}^{*} = 1 - \prod_{k=1}^{K} \left(1 - \mu_{ij}^{k}\right)^{\frac{1}{k}} \qquad \forall i, j \tag{26}$$

$$v_{ij}^{*} = \prod_{k=1}^{K} \left(v_{ij}^{k}\right)^{\frac{1}{k}} \qquad \forall i, j \tag{27}$$

$$P_{ij}^{*} = \left(\mu_{ij}^{*}, v_{ij}^{*}\right) \qquad \forall i, j \tag{28}$$

Step 4.3. (Xu and Chen, 2008). The similarity measure (ς_m) is obtained with Eq. (29).

$$\varsigma_m(P_k, P^*) = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} d\left(\tilde{P}_{ij}^{k}, \tilde{P}_{ij}^{*c}\right)}{\sum_{i=1}^{m} \sum_{j=1}^{n} \left(d\left(\tilde{P}_{ij}^{k}, \tilde{P}_{ij}^{*}\right) + d\left(\tilde{P}_{ij}^{k}, \tilde{P}_{ij}^{*c}\right)\right)} \tag{29}$$

where $\tilde{P}_{ij}^{*c}$ and $d\left(\tilde{P}_{ij}^{k}, \tilde{P}_{ij}^{*c}\right)$ are computed with Eqs. (30) and (31), respectively.

$$\tilde{P}_{ij}^{*c} = \left(v_{ij}^{*}, \mu_{ij}^{*}\right) \tag{30}$$

$$d\left(\tilde{P}_{ij}^{k}, \tilde{P}_{ij}^{*c}\right) = \frac{1}{2mn} \sum_{i=1}^{m} \sum_{j=1}^{n} \left(\left|\mu_{ij}^{k} - \mu_{ij}^{*}\right| + \left|v_{ij}^{k} - v_{ij}^{*}\right|\right) \tag{31}$$

Step 4.4. (Yue, 2011). The DMs' weights are calculated with Eq. (32).

$$W_k = \frac{\varsigma_m(P_k, P^*)}{\sum_{k=1}^{K} \varsigma_m(P_k, P^*)} \qquad \forall k \tag{32}$$

Step 5. Computing the alternatives ranking with the new proposed method.

Step 5.1. The aggregation ideal decision matrix is computed based on step 4.2.

Step 5.2. The positive and negative ideal solutions are obtained from Eqs. (33)-(36).

$$I^{*\mu} = \left\{\left(\max_i \mu^*_{ij} \mid j \in J\right), \left(\min_i \mu^*_{ij} \mid j \in \acute{J}\right) \mid i = 1, \dots, m\right\} \tag{33}$$

$$I^{*v} = \left\{\left(\min_i v^*_{ij} \mid j \in J\right), \left(\max_i v^*_{ij} \mid j \in \acute{J}\right) \mid i = 1, \dots, m\right\} \tag{34}$$

$$I^{-\mu} = \left\{\left(\min_i \mu^-_{ij} \mid j \in J\right), \left(\max_i \mu^-_{ij} \mid j \in \acute{J}\right) \mid i = 1, \dots, m\right\} \tag{35}$$

$$I^{-v} = \left\{\left(\max_i v^-_{ij} \mid j \in J\right), \left(\min_i v^-_{ij} \mid j \in \acute{J}\right) \mid i = 1, \dots, m\right\} \tag{36}$$

where, J and $\acute{J}$ are the benefit and cost atrributes, respectively.

Step 5.3. The ideal and anti-ideal decision matrixes $(D^*. D^-)$ with Euclidean distance formulation are obtained in Eqs. (37)-(40).

$$D^{*\mu} = \left[D^{*\mu}_{ij}\right] = \begin{pmatrix} D\left(\tilde{I}^{\mu}_{11}.\tilde{I}^{*\mu}_{1}\right) & \cdots & D\left(\tilde{I}^{\mu}_{1n}.\tilde{I}^{*\mu}_{n}\right) \\ \vdots & \ddots & \vdots \\ D\left(\tilde{I}^{\mu}_{m1}.\tilde{I}^{*\mu}_{1}\right) & \cdots & D\left(\tilde{I}^{\mu}_{mn}.\tilde{I}^{*\mu}_{n}\right) \end{pmatrix}_{m\times n} \tag{37}$$

$$D^{*v} = \left[D^{*v}_{ij}\right] = \begin{pmatrix} D(\tilde{I}^{v}_{11}.\tilde{I}^{*v}_{1}) & \cdots & D(\tilde{I}^{v}_{1n}.\tilde{I}^{*v}_{n}) \\ \vdots & \ddots & \vdots \\ D(\tilde{I}^{v}_{m1}.\tilde{I}^{*v}_{1}) & \cdots & D(\tilde{I}^{v}_{mn}.\tilde{I}^{*v}_{n}) \end{pmatrix}_{m\times n} \tag{38}$$

$$D^{-\mu} = \left[D^{-\mu}_{ij}\right] = \begin{pmatrix} D\left(\tilde{I}^{\mu}_{11}.\tilde{I}^{-\mu}_{1}\right) & \cdots & D\left(\tilde{I}^{\mu}_{1n}.\tilde{I}^{-\mu}_{n}\right) \\ \vdots & \ddots & \vdots \\ D\left(\tilde{I}^{\mu}_{m1}.\tilde{I}^{-\mu}_{1}\right) & \cdots & D\left(\tilde{I}^{\mu}_{mn}.\tilde{I}^{-\mu}_{n}\right) \end{pmatrix}_{m\times n} \tag{39}$$

$$D^{-v} = \left[D^{-v}_{ij}\right] = \begin{pmatrix} D(\tilde{I}^{v}_{11}.\tilde{I}^{-v}_{1}) & \cdots & D(\tilde{I}^{v}_{1n}.\tilde{I}^{-v}_{n}) \\ \vdots & \ddots & \vdots \\ D(\tilde{I}^{v}_{m1}.\tilde{I}^{-v}_{1}) & \cdots & D(\tilde{I}^{v}_{mn}.\tilde{I}^{-v}_{n}) \end{pmatrix}_{m\times n} \tag{40}$$

Step 5.4. The values of $\varphi^{\mu}_{i}.\varphi^{v}_{i}.\phi^{\mu}_{i}.\phi^{v}_{i}.\varrho^{\mu}_{i}.\varrho^{v}_{i}.\chi^{\mu}_{i}.$ and χ^{v}_{i} for $j = 1.,,,.n$ are obtained with Eqs. (41)-(48).

$$\varphi^{\mu}_{i} = \sum_{j=1}^{m} \omega_j D^{*\mu}_{ij} \tag{41}$$

$$\varphi_i^v = \sum_{j=1}^{m} \omega_j D_{ij}^{*v} \tag{42}$$

$$\phi_i^\mu = \max_j \omega_j D_{ij}^{*\mu} \tag{43}$$

$$\phi_i^v = \max_j \omega_j D_{ij}^{*v} \tag{44}$$

$$\varrho_i^\mu = \sum_{j=1}^{m} \omega_j D_{ij}^{-\mu} \tag{45}$$

$$\varrho_i^v = \sum_{j=1}^{m} \omega_j D_{ij}^{-v} \tag{46}$$

$$\chi_i^\mu = \max_j \omega_j D_{ij}^{-\mu} \tag{47}$$

$$\chi_i^v = \max_j \omega_j D_{ij}^{-v} \tag{48}$$

Step 5.5. The values of $\psi_i^\mu . \varepsilon_i^\mu . \tau_i^v .$ and γ_i^v are calculated with Eqs. (49)-(52)

$$\psi_i^\mu = \begin{cases} \dfrac{\phi_i^\mu - \phi^{+\mu}}{\phi^{-\mu} - \phi^{+\mu}} & if\ \varphi^{+\mu} = \varphi^{-\mu} \\ \dfrac{\varphi_i^\mu - \varphi^{+\mu}}{\varphi^{-\mu} - \varphi^{+\mu}} & if\ \phi^{\mu+} = \phi^{\mu-} \\ \Gamma\left(\dfrac{\varphi_i^\mu - \varphi^{+\mu}}{\varphi^{-\mu} - \varphi^{+\mu}}\right) + (1-\Gamma)\left(\dfrac{\phi_i^\mu - \phi^{+\mu}}{\phi^{-\mu} - \phi^{+\mu}}\right) & Otherwise \end{cases} \tag{49}$$

$$\tau_i^v = \begin{cases} \dfrac{\phi_i^v - \phi^{+v}}{\phi^{-v} - \phi^{+v}} & if\ \varphi^{+v} = \varphi^{-v} \\ \dfrac{\varphi_i^v - \varphi^{+v}}{\varphi^{-v} - \varphi^{+v}} & if\ \phi^{+v} = \phi^{-v} \\ \Gamma\left(\dfrac{\varphi_i^v - \varphi^{+v}}{\varphi^{-v} - \varphi^{+v}}\right) + (1-\Gamma)\left(\dfrac{\phi_i^v - \phi^{+v}}{\phi^{-v} - \phi^{+v}}\right) & Otherwise \end{cases} \tag{50}$$

$$\varepsilon_i^\mu = \begin{cases} \dfrac{\varrho_i^\mu - \varrho^{-\mu}}{\varrho^{+\mu} - \varrho^{-\mu}} & if\ \chi^{+\mu} = \chi^{-\mu} \\ \dfrac{\chi_i^\mu - \chi^{-\mu}}{\chi^{+\mu} - \chi^{-\mu}} & if\ \varrho^{+\mu} = \varrho^{-\mu} \\ \rho\left(\dfrac{\varrho_i^\mu - \varrho^{-\mu}}{\varrho^{+\mu} - \varrho^{-\mu}}\right) + (1-\rho)\left(\dfrac{\chi_i^\mu - \chi^{-\mu}}{\chi^{+\mu} - \chi^{-\mu}}\right) & Otherwise \end{cases} \tag{51}$$

$$\gamma_i^v = \begin{cases} \dfrac{\varrho_i^v - \varrho^{-v}}{\varrho^{+v} - \varrho^{-v}} & if\ \chi^{+v} = \chi^{-v} \\ \dfrac{\chi_i^v - \chi^{-v}}{\chi^{+v} - \chi^{-v}} & if\ \varrho^{+v} = \varrho^{-v} \\ \rho\left(\dfrac{\varrho_i^v - \varrho^{-v}}{\varrho^{+v} - \varrho^{-v}}\right) + (1-\rho)\left(\dfrac{\chi_i^v - \chi^{-v}}{\chi^{+v} - \chi^{-v}}\right) & Otherwise \end{cases} \tag{52}$$

where $\begin{cases}\phi^{+\mu} = min\phi_i^{\mu} \\ \phi^{-\mu} = max\phi_i^{\mu}\end{cases}$, $\begin{cases}\phi^{+v} = min\phi_i^{v} \\ \phi^{-v} = max\phi_i^{v}\end{cases}$, $\begin{cases}\varphi^{+\mu} = min\varphi_i^{\mu} \\ \varphi^{-\mu} = max\varphi_i^{\mu}\end{cases}$. $\begin{cases}\varphi^{+v} = min\varphi_i^{v} \\ \varphi^{-v} = max\varphi_i^{c}\end{cases}$, $\begin{cases}\varrho^{+\mu} = max\varrho_i^{\mu} \\ \varrho^{-\mu} = min\varrho_i^{\mu}\end{cases}$. $\begin{cases}\varrho^{+v} = max\varrho_i^{v} \\ \varrho^{-v} = min\varrho_i^{v}\end{cases}$, $\begin{cases}\chi^{+\mu} = max\chi_i^{\mu} \\ \chi^{-\mu} = min\chi_i^{\mu}\end{cases}$, and $\begin{cases}\chi^{+v} = max\chi_i^{v} \\ \chi^{-v} = min\chi_i^{v}\end{cases}$. Also, Γ and ρ are regarded to the weight of majority indicators, and (1- Γ) and (1- ρ) are the individual regret. The strategic range of two factors can be compromised with 0.5 degrees.

Step 5.6. The collective index is computed with Eqs. (53)-(55).

$$CO^{\mu} = \psi_i^{\mu} + \varepsilon_i^{\mu} \tag{53}$$

$$CO^{v} = \tau_i^{v} + \gamma_i^{v} \tag{54}$$

$$CO = CO^{\mu} + \frac{1}{CO^{v}} + \emptyset_i \tag{55}$$

When the CO^vtakes the zero value, $\emptyset_i$ is added to the equation. This value is computed with Eq. (56).

$$\emptyset_i = \left(\min_i CO^v\right)^{\min_j \omega_j} \tag{56}$$

IV. CASE STUDY

This section describes a major challenge of the real-case study from the recent literature of healthcare management in the Indian healthcare organization (Mishra and Rani, 2021). Especially, Uttarakhand state is the main issue of this section. The healthcare service system is separated into private and public parts that are similar to many of the countries. With growing the private section, HCW disposal in healthcare industries has become the principal problem of the governments and related organizations. Also, the HCW can be created pollution, which is hazardous and pestiferous for society; so the proper disposal of this waste becomes a required work for waste disposal organizations. Hence, the HCW disposal location is an essential issue in the healthcare system (Yazdani et al., 2020). Nevertheless, this case study is presented according to the literature Mishra and Rani (2021). This paper uses the proposed method for HCW disposal suitable location problem of three hospitals Rishikesh AIIMS, Government Nirmal Ashram Hospital. In this regard, all information about the management, separation, accumulation, storage, and disposal of HCWs was gained. This paper can assure the healthcare managers with the new proposed MCDM method under IF uncertain environment in selecting the HCW disposal appropriate location problem.

Hence, this problem has the ten main criteria in the fields of economic, social, and environmental. The list of the criteria and their nature is presented in Table I. Also, the five-potential locations, ESI dispensary Jaspur (A_1), Bharat Oil and Waste Management Ltd (BOWML) Roorkee (A_2), District Hospital Bageshwar (A_3), Waste Warriors

Swachhata Kendra (WWSK) Dehradun (A_4), Globe Hospital & Pharmaceutical Research Center (GHPRC) Rudrapur (A_5) are considered the alternatives of the problem. Moreover, this paper used three types of DMs (DM_1, DM_2, DM_3) to evaluate the HCW disposal location problem. Furthermore, Table II presents the linguistic variables to assess the decision matrix with DMs in the HCW disposal problem (Hashemi et al., 2013). The introduced criterion is provided based on three main sustainable categories. The environmental factor consists of five criteria that have an impact on the environmental emission and geographic state. Furthermore, the economic and social sides are considered based on two and three criteria, respectively.

Table I. list of the criteria

Factors	*Criteria*	*Description*	*Types*
Environmental	C_1	The potential risk of interference and emission	Cost
	C_2	Distance to the urban foundation and society	Benefit
	C_3	Distance from the storing waste	Cost
	C_4	Geographic and geologic status	Benefit
	C_5	The dominant environmental amicable services	Benefit
Economic	C_6	Costs of the system consist of land cost	Cost
	C_7	Future development possibility	Benefit
Social	C_8	Employee's availability	Benefit
	C_9	Sensitivity to the environment, native and regional rules or protocols	Benefit
	C_{10}	Satisfaction level among residents to the place chosen	Benefit

Table II. Linguistic value

Linguistic variables	*Intuitionistic fuzzy values*
Extremely high (EH)	$[0.95, 0.05]$
Very very high (VVH)	$[0.90, 0.10]$
Very high (VH)	$[0.80, 0.10]$
High (H)	$[0.70, 0.20]$
Medium high (MH)	$[0.60, 0.30]$
Medium (M)	$[0.50, 0.40]$
Medium low (ML)	$[0.40, 0.50]$
Low (L)	$[0.25, 0.60]$
Very low (VL)	$[0.10, 0.75]$
Very very low (VVL)	$[0.10, 0.90]$

Table III is related to the comparison decision matrix among alternatives and criteria with the various DMs' opinion linguistic terms.

Table III. The comparison decision matrix

Alternatives	*DMs*	*Criteria*									
		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A_1	DM_1	VVH	H	M	MH	VVH	H	H	M	MH	VVH
	DM_2	MH	ML	MH	H	MH	ML	ML	MH	H	MH
	DM_3	H	L	H	ML	H	L	L	H	ML	H
A_2	DM_1	ML	ML	VVL	VH	ML	ML	ML	VVL	VH	ML
	DM_2	VVL	H	L	MH	VVL	H	H	L	MH	VVL
	DM_3	VL	VL	VL	M	VL	VL	VL	VL	M	VL
A_3	DM_1	H	VVL	VH	M	H	VVL	VVL	VH	M	H
	DM_2	H	EH	M	ML	H	EH	EH	M	ML	H
	DM_3	ML	VH	H	L	ML	VH	VH	H	L	ML
A_4	DM_1	MH	M	ML	H	MH	M	M	ML	H	MH
	DM_2	L	VH	ML	M	L	VH	VH	ML	M	L
	DM_3	M	H	VL	MH	M	H	H	VL	MH	M

A. Computational results

This section provides obtaining results from the proposed approach. In this regard, the subjective weights, and the objective weights of criteria are calculated with Eqs. (20) and (21) and step 3.2. The final results are determined in Table IV. The ninth index with the most weight has an essential position in comparison to other criteria.

Table IV. The weight of criteria

Criteria	*Subjective weight*	*Objective weight*	*Aggregated weight*
C_1	0.09954	0.10961	0.10458
C_2	0.07874	0.10299	0.09087
C_3	0.07296	0.09830	0.08563
C_4	0.14443	0.09529	0.11986
C_5	0.07169	0.09381	0.08275
C_6	0.10134	0.09381	0.09758
C_7	0.14290	0.09529	0.11909
C_8	0.04434	0.09830	0.07132
C_9	0.16850	0.10299	0.13575
C_{10}	0.07554	0.10961	0.09258

Afterward, the weights of the DMs are computed with Eq. (32). For this reason, the similarity measure is computed with Eq. (29), and the distance among $\tilde{P}_{ij}^{k}$, $\tilde{P}_{ij}^{*}$, and $\tilde{P}_{ij}^{*c}$ are obtained from Eq. (31). The final results are shown in Table V. The second DM has the most priority than other DMs.

Table V. The DMs' weights

DMs	$d(\tilde{P}_{ij}^{k}, \tilde{P}_{ij}^{*})$	$d(\tilde{P}_{ij}^{k}, \tilde{P}_{ij}^{*c})$	ς_m	W_k
DM_1	28.62524	25.85393	0.47457	0.29842
DM_2	23.01803	29.65206	0.56298	0.35402
DM_3	22.84962	28.23538	0.55271	0.34756

Moreover, the rankings of the alternatives are the essential issue that is obtained from Eq. (55). For this point, the distance matrixes $D^{*\mu}.D^{*v}.D^{-\mu}$, and D^{-v} are computed with Eqs. (37)- (40), which are determined in Table (Ⅵ)- (Ⅸ). After that, the values $\varphi_i^{\mu}.\varphi_i^{v}.\phi_i^{\mu}.\phi_i^{v}.\varrho_i^{\mu}.\varrho_i^{v}.\chi_i^{\mu}$. and χ_i^{v} are obtained from Eqs. (41)- (48), which are shown in Table Ⅹ. Furthermore, the values of $\varphi^{+\mu}$, $\varphi^{-\mu}$, φ^{+v}, φ^{-v}, $\phi^{+\mu}$, $\phi^{-\mu}$, ϕ^{+v}, ϕ^{-v}, $\varrho^{+\mu}$, $\varrho^{-\mu}$, ϱ^{+v}, ϱ^{-v}, $\chi^{+\mu}$, $\chi^{-\mu}$, χ^{+v}, and χ^{v} are determined in Table ⅰ. Eventually, the amounts of CO^{μ}, CO^{v}, CO, and final ranking are obtained from Eqs. (49)- (52) and are presented in Table ⅱ.

Table VI. The values of $D^{*\mu}$ matrix

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A_1	0.19118	0.12056	0.10086	0.08131	0.00000	0.00806	0.12056	0.05805	0.08131	0.00000
A_2	0.00000	0.12862	0.00000	0.00000	0.19118	0.00000	0.12862	0.20634	0.00000	0.19118
A_3	0.11531	0.00000	0.20634	0.16430	0.07587	0.12862	0.00000	0.00000	0.16430	0.07587
A_4	0.07176	0.06748	0.05236	0.07388	0.15374	0.06114	0.06748	0.15398	0.07388	0.11942

Table VII. The values of D^{*v} matrix

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A_1	0.00000	0.02377	0.00000	0.00000	0.10158	0.00000	0.02377	0.16614	0.00000	0.19432
A_2	0.04009	0.00416	0.08685	0.01901	0.08062	0.01961	0.00416	0.00000	0.01901	0.15423
A_3	0.19432	0.02377	0.08685	0.00791	0.00000	0.00000	0.02377	0.00000	0.00791	0.00000
A_4	0.19432	0.00000	0.08685	0.03657	0.00000	0.02377	0.00000	0.00000	0.03657	0.00000

Table VIII. The values of $D^{-\mu}$ matrix

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A_1	0.00000	0.00806	0.10548	0.08299	0.19118	0.12056	0.00806	0.14829	0.08299	0.19118
A_2	0.19118	0.00000	0.20634	0.16430	0.00000	0.12862	0.00000	0.00000	0.16430	0.00000
A_3	0.07587	0.12862	0.00000	0.00000	0.11531	0.00000	0.12862	0.20634	0.00000	0.11531
A_4	0.11942	0.06114	0.15398	0.09042	0.03744	0.06748	0.06114	0.05236	0.09042	0.07176

Table IX. The values of D^{-v} matrix

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A_1	0.19432	0.00000	0.08685	0.03657	0.00000	0.02377	0.00000	0.00000	0.03657	0.00000
A_2	0.15423	0.01961	0.00000	0.01757	0.02096	0.00416	0.01961	0.16614	0.01757	0.04009
A_3	0.00000	0.00000	0.00000	0.02867	0.10158	0.02377	0.00000	0.16614	0.02867	0.19432
A_4	0.00000	0.02377	0.00000	0.00000	0.10158	0.00000	0.02377	0.16614	0.00000	0.19432

Table X. The amounts of $\varphi_i^\mu . \varphi_i^v . \phi_i^\mu . \phi_i^v . \varrho_i^\mu . \varrho_i^v . \chi_i^\mu$. and χ_i^v

Alternatives	φ_i^μ	φ_i^v	ϕ_i^μ	ϕ_i^v	ϱ_i^μ	ϱ_i^v	χ_i^μ	χ_i^v
A_1	0.07131	0.03726	0.07065	0.04244	0.02553	0.01714	0.01530	0.02595
A_2	0.05988	0.03277	0.08208	0.04693	0.02129	0.00896	0.02553	0.02059
A_3	0.08070	0.03926	0.06126	0.04044	0.02129	0.02595	0.02129	0.01714
A_4	0.07137	0.04244	0.07059	0.03726	0.01589	0.02595	0.01595	0.01714

Table i . The values of ranking elements

The ranking elements	*Values*
$\varphi^{+\mu}$	0.05988
$\varphi^{-\mu}$	0.08070
φ^{+v}	0.03277
φ^{-v}	0.04244
$\phi^{+\mu}$	0.06126
$\phi^{-\mu}$	0.08208
ϕ^{+v}	0.03726
ϕ^{-v}	0.04693
$\varrho^{+\mu}$	0.02553
$\varrho^{-\mu}$	0.01589
ϱ^{+v}	0.02595
ϱ^{-v}	0.00896
$\varrho^{+\mu}$	0.02553
$\varrho^{-\mu}$	0.01530
ϱ^{+v}	0.02595
ϱ^{-v}	0.01714

Table ii . The amount of CO^{μ}, CO^{ν}, CO, and final RANKING

Alternatives	CO^{μ}	CO^{ν}	CO	*Final ranking*
A_1	1.09001	1.24078	1.89595	4
A_2	0.47027	0.69608	1.90688	3
A_3	1.30056	1.00000	2.30056	1
A_4	1.02046	1.00000	2.02046	2

This table illustrates that the third alternative that is relevant to the District Hospital Bageshwar has a higher priority than other options. Moreover, the sensitivity analysis is presented to validate the proposed method.

B. Sensitivity analysis

In this part, the sensitivity analysis is done on the impact of the weight of criteria on the final ranking results. For this reason, weights of the first and fourth criteria, third and seventh criteria, and fifth and tenth attributes change with each other, respectively. The final changing of the ranking is depicted in Fig. 1. This figure shows that the alternatives' ranking changes with shifted the value of criteria' weights, but the third alternative has the high priority than other options. This point is an emphasis on the importance of the third alternative in the decision-making process.

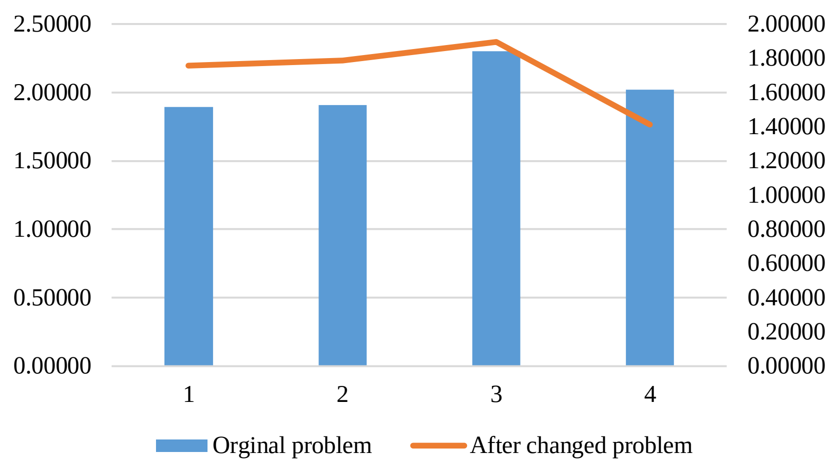

Fig. 1. Comparison of the alternatives' ranking

C. Comparative analysis

This section considers a comparative analysis of the proposed approach. In this respect, the introduced ranking model is compared with the IF-TOPSIS approach (Memari et al., 2019). The final results determine that the proposed approach and the literature method have similar results, and this point confirms that the proposed approach has a good performance in computing the ranking of the alternatives. This issue is shown in Table iii.

TABLE iii. COMPARISON BETWEEN TWO METHODS

Alternatives	*IF-TOPSIS values*	*IF-TOPSIS ranking*	*Proposed model values*	*Proposed method ranking*
A_1	0.47643	4	1.89595	4
A_2	0.48477	3	1.90688	3
A_3	0.52929	1	2.30056	1
A_4	0.48831	2	2.02046	2

V. CONCLUSION

One of the critical problems in urban management is relevant to the healthcare industries creating hazardous waste (HCW) disposal location selection. This problem can be exposed the population to diseases. The HCW disposal location selection needs the appropriate management decisions with suitable planning and process. This paper introduced one efficient multi-criteria decision-making (MCDM) procedure to determine the proper decisions with obtaining the weight of the criteria and the ranking of the alternatives. For this reason, it used the experts ' opinions and identified the importance of each expert by applying the calculation method of the decision makers' (DMs') weights. Also, this paper proposed a new method to rank and analyze the significance of the various alternatives in the decision-making process. Furthermore, one of the strong points of the paper is about the uncertainty condition that was handled with the intuitionistic fuzzy (IF) requirement. Finally, the real case study from the recent literature was applied to validate the proposed method, and the sensitivity analysis was generated to measure the efficiency of the introduced approach. In this respect, the research gap is related to the use of IFS in decision-making problems. The IF is the new approach that was fewer existed in the literature, and this point helps to take decisions in a real-world application. Also, the distance-based ranking method is one of the strongest points of this paper that does not exist in previous works. This method was introduced based on the ideal and anti-ideal solutions. The new method has a good performance with changing the environment condition and has well-positioned to help the manager to take an appropriate decision. Hence, the proposed model was compared to the IF-TOPSIS approach, and the final results have shown that the introduced model has a good performance to obtain the ranking of the alternatives. This comparison determined that the proposed method was validated to compute the ranking of the alternatives. However, the main findings of this paper are related to using a new ranking approach that is utilized to take an appropriate decision in the healthcare waste problem. This paper aids in taking a decision to determine the priority of the DM and criterion, respectively, to give a suitable policy with various opinions by different weights. Furthermore, the limitation of the paper is related to (1) all criteria were assumed to be interdependent, and (2) the evaluation indicator system can contain more sustainable dimensions of the criteria.

For future suggestions, the introduced method can be used in the different types of industries. Also, various kinds of new fuzzy uncertainty approaches in the literature (e.g., Mohagheghi & Mousavi, 2021; Foroozesh et al., 2021; Davoudabadi et al., 2021; Dorfeshan et al., 2021; Aramesh et al., 2021) can be used to handle the vagueness environment and to compare with this decision method.

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