A dual hesitant q-rung orthopair enhanced MARCOS methodology under uncertainty to determine a used PPE kit disposal

Daekook Kang¹ · Arumugam Anuja² · Samayan Naraynamoorthy² · Mariangela Gangemi³ · Ali Ahmadian⁴,⁵

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Abstract
Healthcare waste management is regarded as the most critical concern that the entire world is currently and will be confronted with in the near future. During the COVID-19 pandemic, the significant growth in medical waste frightened the globe, prompting it to investigate safe disposal methods. Plastics are developing as a severe environmental issue as a result of their increased use during the COVID-19 pandemic which has triggered a global catastrophe and prompted concerns about plastic waste management. One of the biggest challenges in this circumstance is the disposal of discarded PPE kits. The purpose of this research is to find a viable disposal treatment procedure for enhanced personal protective equipment (PPE) (facemasks, gloves, and other protective equipment) and other single-use plastic medical equipment waste in India during the COVID-19 crises, which will aid in effectively reducing their increasing quantity. To analyse the PPE waste disposal problem in India, we used the fuzzy Measurement Alternatives and Ranking according to the Compromise Solution (MARCOS) technique, which included the dual hesitant q-rung orthopair fuzzy set. The fuzzy Best Worst Method (BWM), which is compatible with the existing MCDM approaches, is used to establish the criteria weights. Sensitivity and comparative analyses are utilised to confirm the stability and validity of the proposed strategy.

Keywords Decision-making in MCDM · PPE disposal · Dual hesitant q-rung orthopair fuzzy set · Enhanced MARCOS · Best Worst Method

Introduction
Corona virus has created a huge impact on all aspects of our ecosystem, including waste management. The classical and fractional variants modeling of the new coronavirus disease transmission are numerically investigated (Zhao et al. 2021). WHO has issued guidelines for waste management during the COVID-19 pandemic. The various waste management techniques used in different countries which are reviewed, and the importance of following proper guidelines in disposing of these waste products has been emphasised (Hantoko et al. 2021). The novel fractional-order discrete-time susceptible-infected-recovered (SIR) epidemic model with vaccination is discussed (He et al. 2022). Prominently, plastic materials play...
an essential role in health sectors, resulting in huge plastic pollution on a global scale which is now widely recognized as a major environmental burden that also has an impact on human health. The importance of implementing dynamic WM strategies described that aims at minimizing environmental pollution caused by plastics generated during the pandemic (Benson et al. 2021). The sources and effects of single use plastic are analyzed and the importance of recycling them (Vanapalli et al. 2021). The long-term systematic assessment of waste management is discussed (Van Fan et al. 2021). The “identify, isolate, disinfect, and safe treatment practises” technique is enough for safer health practices in COVID-19 waste management (Ilyas et al. 2020). Plastic makers must be aware of the usage of macroplastics, as well as the necessity of bio-based plastics, in order to foster sustainable growth and drive both green and blue economies (Silva et al. 2021). Except the health sector authorities and non-authority managements must plan and implement policies which would minimize the use of plastics by developing alternative materials, in India (Zhang et al. 2021). The importance of using innovative methods are discussed for recycling plastics and raising awareness in society about the importance of maintaining a green environment (Parashar and Hait 2021). Following this, the requirement of PPE kits and its impact while the control of COVID-19 is discussed and the importance of using recycled PPE is analyzed. PPEs and other plastic-based healthcare equipment have started to emerge as a lifesaver for ensuring the health and safety of healthcare professionals and ordinary people. The used PPE kits are not disposed of according to typical standards in emerging regions, which has resulted in an increase in the quantity of contaminated surface waste, necessitating increased proper processing and treatment methods for PPE kits in BMW management. The BMW management in India during the COVID-19 pandemic is analyzed with the significance of the investments required in these projects in order to provide a safe and environmentally friendly method of disposing these waste products (Goswami et al. 2021). In India, the various methods for disposing BMWs are examined, as well as the innovations that can be implemented in these processes (Kudli et al. 2021). A three-layered surgical mask that protects against COVID-19, which has become a main cause of micro pollution (Aragaw 2020). The disposal of personal protective equipment (PPE) and its side effects are analyzed in Bangladesh (Shammi and Tareq 2021). Various types of gloves worn by individuals, such as latex, vinyl, and nitrile. They highlighted the consequences of inappropriate disposal on the environment (Jedruchniwicz et al. 2021). The PPEs are disinfectable and reusable up to 5 times during its life cycle by applying the developed recycling technologies (Manoj 2020). The recent developments in sustainable face mask alternatives are reviewed, as well as reprocessing and reusing routes, during the COVID-19 pandemic in Peru (Torres and De-la-Torre 2021). An overview of various waste management strategies are proposed which is used for disposing the hazardous healthcare waste, as well as the importance of using an effective disposal method that helps to recycle waste or convert it into valuable products such as energy (Das et al. 2021). The reduction of plastic waste in future relation to COVID-19 (Klimeš et al. 2020). Since there is a possibility of SARS-CoV-2 viruses in biomedical waste collected from various sources, researchers have been frustrated about the importance of disinfecting these wastes before disposal. The polymers which are used in the manufacture of face masks and gloves from TGA/DTA analysis and the results of FTIR are examined, these polymers can be recycled into fuel energy using the pyrolysis method (Aragaw and Mekonnen 2021). The mixed convection is a mechanism of heat transport in a thermodynamic system in which the motion of fluid particles is produced by gravity as well as external forces (Zhao et al. 2021). The discrete fractional calculus (DFC) is significant for neural networks, complex dynamic systems and frequency response analysis approaches (Rashid et al. 2022). The B-spline curve is used for reducing the entropy of video data which consider the color or lumiance variations of a spatial position in a series of frames as input data points in Euclidean space R or R3 (Ebadi and Ebrahimi). The fuzzy stochastic differential equations (FSDEs) in hybrid real-world systems are discussed (Jafari et al. 2021), including randomness, fuzziness and long-range dependence under some assumptions on the coefficients to study the existence and uniqueness of the solutions (Jin et al. 2022). The exact dynamical wave solutions are discussed to the Date–Jimbo–Kashiwara–Miwa equation with conformable derivative by using an efficient and well-established approach (Iqbal et al. 2021). The magnetic, Stefan blowing and bio-convection effects are analyzed to examine the Cattaneo-Christov double diffusions phenomenon (Chu et al. 2021). The thermal profile varies directly with the magnetic parameter (Chu et al. 2021), and the opposite trend is recorded for the Prandtl number. An efficient mesh-less LRBF collocation approach is utilized for solving the two-dimensional (2D) fractional evolution equation for the arbitrary fractional order in complex-shaped domains (Radmanesh and Ebadi 2020). The numerical solution of nonlinear time-fractional Fisher equations via local meshless method is combined by explicit difference scheme (Wang et al. 2022).

Decision-making is the process of choosing the best solution based on a combination of criteria. Several researchers have provided a wide range of methods based on MCDM to solve problems and make decisions easier. The decision-making process is enhanced with proficiency, logic, and clarity when the MCDM methods are used. The system is highly rewarded for increasing proficiency. The process is exonerated from its indecisiveness by employing better...
logic. Some researchers have sought to dispel the problem of choosing the best method for plastic disposal through the MCDM technique and have suggested a method depending on the alternatives. The healthcare waste disposal problem is addressed using the MULTIMOORA method under intuitionistic hesitant fuzzy set (Geetha et al. 2019). An efficient healthcare waste disposal method is presented using the MCDM approach for selecting during and after COVID-19 pandemic (Hantoko et al. 2021). In the method, incineration has been found to be an efficient disposal method during a pandemic situation. The biomedical waste disposal using MOOSRA method under hesitant fuzzy approach is involved in BWM (Narayananmooorthy et al. 2020). From these, to find the best method for used PPE disposal, we have to determine the efficient criteria such as society’s safety, cost, environmental impact, time, heterogeneity, technology, and infrastructure aspects. Furthermore, by improving clarity, the decision-making process becomes more appealing, even to novices in the field. The MARCOS method (Stivic and Brkovic 2020) is the most realistic MCDM models, and it is used to solve complex decision-making problems in various area of research. A novel MARCOS approach (Stivic et al. 2019) is established for sustainable supplier selection in the healthcare industry in Bosnia and Herzegovina. A novel MARCOS model is developed for SSS decision-making (Puška et al. 2021). A fuzzy MARCOS model is proposed for traffic risk assessment (Stankovic et al. 2020). The fuzzy approach was used in response to the linguistic values provided by decision-makers. It is an innovative procedure that allows a high-quality response to stakeholder and societal demands. The four factors for energy storage are resulted that the energy reduction is almost 5% more than the BCDCP method, and the packet loss rate in our proposed method is almost 25% lower than in the BCDCP method (Rahiminasab et al. 2020).

The BWM is hybrid with different type of MCDM methods, thereby, the MARCOS and BWM framework is suggested to fill the gap in the literature on such a crucial issue in this work. In 2015, by the Best-Worst Method (BWM) the criteria weights are find and alternatives with regard to multiple criteria based on pairwise comparisons with less compared data (Rezaei 2015). On the other hand, BWM can proficiently correct inconsistencies exacerbated by pairwise comparisons. In contrast to AHP, the BWM performs pairwise comparisons using a 1–9 scale. This procedure appears to be simpler, extra precise, and much less superfluous, because it does not use supplementary comparisons (Guo and Zhao 2017). However, experts subjective judgments usually have characteristics of uncertainty and complexity, and the information criteria in the adult situation may be unclear. As a result, for some practical problems, BWM comparisons can be executed by using fuzzy numbers rather than crisp values. This will be more relevant to the current situation and can produce quite persuasive ranking results. A fuzzy-based BWM was proposed, with comparisons carried out using fuzzy decisions. In the available literature, BWM has been applied to some decision-making problems also such as sustainable supplier selection (Gupta and Barua 2017; Ecer and Pamucar 2020), neighborhood assessment (Hashemkhani Zolfani et al. 2020), and renewable energy alternative selection (Pamucar et al. 2020).

In researcher perspectives, Fuzzy sets help the deciders to set up their indeterminancy in the matrix format and showed their keen interest in the generalizations of fuzzy sets such as Intuitionistic Fuzzy Sets (IFSs), Hesistant Fuzzy Sets (HFSs), Pythagorean Fuzzy Sets (PFSs), Intuitionistic Hesistant Fuzzy Sets (IHFSs), and Pythagorean Hesistant Fuzzy Sets (PHFSs) due to their strong points of view to tackle the vagueness and uncertainty. In hesitant fuzzy set, the sum of existing members (θ) grade is less than or equal to 1. But we have inconvenience while taking the positive and negative grades. DHF (Dual Hesistant Fuzzy) set, have non-existing (φ) membership and the sum of membership and non-membership is less than or equal to 1. Furthermore, if the experts can express their priority for the element in the form of a discrete set, that is (θ)² + (φ)² > 1. So the ordinary IHFSs and PHFSs failed to handle such situations and is unable to classify the decision-making approaches (Hussain et al. 2020). Therefore, some more comprehensive model is required for such situations. To cope this situation, in this manuscript we introduced the concept of DHq-ROFSs, which is the generalized form of IHFSs and PHFSs. In DHq-ROFSs the sum of qth power of membership grade and qth power of non-membership grade belongs to [0, 1].

The novelty of this research is to determine a suitable method for the disposal of PPE kits, which will help in minimizing the amount of plastic waste during and after the pandemic period. A new fuzzy linguistic scale with the DHq-ROFNs is determined with the accreditation of enhanced MARCOS method to evaluate the disposal technique for PPEs. The following are the advantages of the proposed method: MARCOS method evaluates the fuzzy reference points using fuzzy ideal and anti-ideal solutions which is more accurate while use the utility degree with respect from both. Especially, this method is applicable for the possibility of taking into account a large number of criteria and alternatives. BWM is also proper for group decision-making. Its support reaching consensus in a natural way, is efficient in terms of input data which makes BWM more compatible with many other existing MCDM methods. So, we hybrid the BWM with the MARCOS method, which obtains the criteria weights and the nomenclature with their abbreviations are given in Table 1. The motivation of the research is detailed as:
Due to the pandemic, there is an increase in the use of single-use plastics in the healthcare sector, which could pose an environmental risk.

To obtain the suitable disposal procedure for the used PPEs, the decision-makers must develop an optimal method in the MCDM.

The DHq-ROFS helps to create a matrix for alternatives with respect to criteria for dealing the suitable waste disposal problem.

The matrix formalisation are scaled with linguistic values. MARCOS is appropriate for arranging the matrix based on alternatives and criteria.

The weights of the criterion should be reviewed subjectively because the region dependent on the removal of the PPE, as well as those involved in the removal, may get infected in the future. A decision-maker considers that the BWM is the best method for dealing with this problem.

Furthermore, by filling existing research gaps, this work makes the following contributions: The first contribution of the current study is the completion of a comprehensive study that covers all of the factors involved in the disposal of PPE kit waste. The methodology used in this study is used as a foundation for formulating the used PPE kit disposal problem as an MCDM problem, in which various alternatives should be evaluated using the MARCOS method and the criteria weights determined using the BWM, whereas the suggested methodology can be useful for evaluating the mentioned disposal problem in other countries as well. Third, combining the strengths of BWM with the flexibility of MARCOS improves the reliability and practicability of existing disposal treatment sustainability evaluations. Other contributions to the literature are listed below, in addition to all of these: The contribution of the research is explained as follows.

In this paper, we proposed BWM and the enhanced MARCOS procedure to rank the alternatives for disposing of the PPEs.

To express the decision-makers opinion in terms of DHq-ROF elements, linguistic scale is standardized for proposed application.

BWM is used to estimate the weight, then the obtained weights are combined with the fuzzy MARCOS method, which provides a juridical way in disposing the waste.

To provide the best disposal solution for this problem, we recommend and visualize the efficacy of the BWM and enhanced MARCOS in the proper manner and the research method is shown in Fig. 1.

The paper is arranged as follows. Preliminaries are provided in Section “Preliminaries”. Section “The conventional MARCOS method” describes the conventional MARCOS method. Section “Research methodology” presents the research methodology. This section describes the MARCOS with DHq-ROFNs and the BWM methods. Section “Numerical example” includes a numerical example that demonstrates the effectiveness of the proposed method and how weight values are calculated. Section “Result validation” examines sensitivity and comparison. Section “Conclusion” concludes with a conclusion and future work.

Preliminaries

Definition 1 (Yager 2017)

Assume that \( S \) be a non-empty fix set, then a q-ROFS \( A \) on \( U \) can be described as follows:

\[
A = \{ < s, (\theta_A(s), \phi_A(s)) > | s \in S \} \tag{1}
\]

where \( \theta_A(s) : S \rightarrow [0, 1] \) and \( \phi_A(s) : S \rightarrow [0, 1] \) are represent the degree of membership and non-membership of \( s \) to \( A \), respectively, which satisfies \( 0 \leq (\theta_A(s))^q + (\phi_A(s))^q \leq 1 (q \geq 1) \). The indeterminacy degree is given as \( \lambda_A(s) = \sqrt{(\theta_A(s))^q + (\phi_A(s))^q} - (\theta_A(s))^q - (\phi_A(s))^q \). \( < \theta_A(s), \phi_A(s) > \) is called a q-ROFN, which is represented by \( \Phi = (\theta_A, \phi_A) \).

Definition 2 (Torra 2010)

Assume \( R \) is a reference set, and describe the hesitant fuzzy set \( A \) on \( R \) with function \( h \), when applied to \( R \) returns a subset of \([0, 1]\) which is denoted mathematically as (Xia and Xu 2011):

\[
A = \{ < r, h(r) > | r \in R \} = \{ < r, \cup \gamma \in h(r) \} > | r \in R \} \tag{2}
\]

in which \( h(r) \) is called the hesitant fuzzy element (HFE) and it contains all possible membership degrees of \( r \in R \) to the set \( H \).
Definition 3 (Zhu et al. 2012)
Assume $S$ is a fixed set, and dual hesitant fuzzy set (DHFS) $T$ on $S$ is defined as,

$$T = \{< s, h(s), g(s)> | s \in S \},$$

where $h(s)$ and $g(s) \in [0,1]$, representing the possible grade of membership and non-membership element $s \in S$ to $T$, respectively, with the conditions

$$0 \leq \alpha, \beta \leq 1, \quad 0 \leq \alpha^+ + \beta^+ \leq 1$$

where $\alpha \in h(s)$, $\beta \in g(s)$, $\alpha^+ \in h^+(s) = \cup_{\alpha \in h(s)} \max \{\alpha\}$ and $\beta^+ \in g^+(s) = \cup_{\beta \in g(s)} \max \{\beta\} \ \forall s \in S$. For, the pair $t(s) = (h(s), g(s))$ is called a DHFE denoted by $t = (h, g)$, with $\alpha \in h$, $\beta \in g$, $\alpha^+ \in h^+$, $\beta^+ \in g^+ = \cup_{\beta \in g} \max \{\beta\}$, $0 \leq \alpha, \beta \leq 1$, and $0 \leq \alpha^+ + \beta^+ \leq 1$.

Definition 4 (Xia and Xu 2011; Xu et al. 2018)
Let $S$ is non-empty set. A DHq-ROFS $A$ described on $S$ is

$$A = \{< s, h_A(s), g_A(s)> | s \in S \},$$

in which $h_A(s)$ and $g_A(s) \in [0,1]$ representing the possible grade of membership and non-membership element $s \in S$ to the set $A$, respectively, with

$$\alpha^q + \beta^q \leq 1 (q \geq 1),$$

where $\alpha \in h_A(s)$, $\beta \in g_A(s) \ \forall s \in S$. For, the pair $t_q(s) = (h_A(s), g_A(s))$ is called a DHq-ROF element denoted by $t_q = (h, g)$ with $\alpha \in h$, $\beta \in g$, $0 \leq \alpha, \beta \leq 1$, $\alpha^q + \beta^q \leq 1$. When $q = 2$, then DHq-ROFS is reduced to DHPFS (Wei and Lu 2017), and when $q = 1$, then DHq-ROFS is reduced DHIFS (Zhu et al. 2012).

Definition 5 (Hussain et al. 2020)
For a DHq-ROFN $t_q = (h, g)$ characterized by $h$ and $g$, the score function of $t_q$ is described as

$$S(t_q) = \frac{1}{\#h} \sum_{a \in h} \alpha^q - \frac{1}{\#g} \sum_{\beta \in g} \beta^q$$

(5)

where $\#h$ and $\#g$ represents the cardinality of $h$ and $g$ respectively.
The conventional MARCOS method

Consider \( m \) alternatives \{ \( C_1, C_2, C_3, \ldots, C_m \) \}, \( n \) criteria \{ \( B_1, B_2, \ldots, B_n \) \}, then the steps of the conventional MARCOS method are given below.

Step 1: Construct an initial decision matrix.
Step 2: Develop an extended initial matrix by using the anti-ideal solution (AIS) and ideal solution (IDS).

\[
B_1 \ B_2 \ \ldots \ B_n \ D = \begin{pmatrix}
C_1 \\
C_2 \\
\vdots \\
C_m \\
IDS
\end{pmatrix}
\]

where

\[
\begin{align*}
AIS &= \left[c_{a1}, c_{a2} \ldots c_{an}\right] \\
IDS &= \left[c_{i1}, c_{i2} \ldots c_{in}\right]
\end{align*}
\]

Step 3: Normalize the extended initial matrix (D) and the normalized matrix (NDM) denoted as \( X = \{x_{ij}\}_{m \times n} \) are calculated by Eqs. 9 and 10.

\[
x_{ij} = \frac{c_{ij}}{c_{ai}} \quad \text{if} \quad j \in N
\]

\[
x_{ij} = \frac{c_{ij}}{c_{ai}} \quad \text{if} \quad j \in P
\]

Step 4: Compute the utility function of alternative \( f(U_i) \) described by Eq. 15.

\[
f(U_i) = \frac{U_i^+ + U_i^-}{1 + \frac{n}{\frac{U_i^-}{U_i^+} + \frac{U_i^+}{U_i^-}}}
\]

Step 7: Finally, ranking the alternatives.

The enhanced MARCOS method

Assume \( m \) alternatives \{ \( C_1, C_2, C_3, \ldots, C_m \) \} and \( n \) criteria \{ \( B_1, B_2, \ldots, B_n \) \} to enhance the MARCOS method an account of decision experts. The graphical illustration of the proposed methodology is shown in Fig. 2.

Table 2 Fuzzy linguistic scale

| Linguistic term                  | DHq-ROF membership values | DHq-ROF non-membership values |
|----------------------------------|---------------------------|-------------------------------|
| Certainly low (CL)              | 0.15                      | 0.95                          |
| Very low (VL)                   | 0.25                      | 0.95                          |
| Low (L)                         | 0.35                      | 0.75                          |
| Under average (UA)              | 0.45                      | 0.65                          |
| Average (A)                     | 0.55                      | 0.55                          |
| Above average (AA)              | 0.65                      | 0.45                          |
| High (H)                        | 0.75                      | 0.35                          |
| Very high (VH)                  | 0.85                      | 0.25                          |
| Certainly high (CH)             | 0.95                      | 0.15                          |
Step 2: Construct the extended initial matrix by using the ideal and anti-ideal solutions, as shown in Eq. 20. The anti-ideal solution (AIS) represents the worst alternative whereas an alternative with best characteristic defines an ideal solution (IDS).

\[
\begin{align*}
\text{AIS} & = \left( \begin{array}{cccc}
\theta_{i1} & \theta_{i2} & \cdots & \theta_{in} \\
\phi_{i1} & \phi_{i2} & \cdots & \phi_{in}
\end{array} \right) \\
\text{IDS} & = \left( \begin{array}{cccc}
\bar{\theta}_{i1} & \bar{\theta}_{i2} & \cdots & \bar{\theta}_{in} \\
\bar{\phi}_{i1} & \bar{\phi}_{i2} & \cdots & \bar{\phi}_{in}
\end{array} \right)
\end{align*}
\]

Based on criteria, AIS and IDS are obtained by Eqs. 21 and 22.

\[
\text{AIS} = (\min_{i,j} \theta_{ij}, \min_{i,j} \phi_{ij}) \quad \text{if } j \in P \quad \text{and} \quad (\max_{i,j} \theta_{ij}, \max_{i,j} \phi_{ij}) \quad \text{if } j \in N
\]

\[
\text{IDS} = (\max_{i,j} \theta_{ij}, \max_{i,j} \phi_{ij}) \quad \text{if } j \in P \quad \text{and} \quad (\min_{i,j} \theta_{ij}, \min_{i,j} \phi_{ij}) \quad \text{if } j \in N
\]

where \( P \) denotes the positive criteria and \( N \) denotes the negative criteria.

Step 3: By using Eqs. 23 and 24 normalize the extended initial matrix, which is denoted as \( X = [x_{ij}]_{m \times n} \).
Step 6: Now, compute the WND \( Z = [z_{ij}]_{m \times n} \) using Eq. 25.
\[
z_{ij} = (\theta_{ij} \times w_j, \phi_{ij} \times w_j)
\]

Step 5: Calculate the utility degree of the alternative \( U_i \) based on Eqs. 26 and 27.
\[
U_{i}^{-} = \frac{S_i}{S_{su}} \tag{26}
\]
\[
U_{i}^{+} = \frac{S_i}{S_{so}} \tag{27}
\]

where \( S_i (i = 1, 2, \ldots, m) \) denotes the sum of the elements of the matrix \( Z \), which is given in Eq. 28.
\[
S_i = \sum_{j=1}^{n} z_{ij} \tag{28}
\]

Step 6: Compute the utility function of alternative \( f(U_i) \) as described in Eq. 29.
\[
f(U_i) = \frac{U_{i}^{+}+U_{i}^{-}}{1+\frac{1}{10}U_{i}^{-}+\phi_{i}U_{i}^{-}} \tag{29}
\]

where \( f(U_{i}^{-}) \) denotes the utility function related to (AIS), and \( f(U_{i}^{+}) \) denotes the utility function with respect to (IDS) which are calculated using Eqs. 30 and 31.
\[
f(U_{i}^{-}) = \frac{U_{i}^{-}}{U_{i}^{+}+U_{i}^{-}} \tag{30}
\]
\[
f(U_{i}^{+}) = \frac{U_{i}^{+}}{U_{i}^{+}+U_{i}^{-}} \tag{31}
\]

Step 7: Finally, as per expert’s choice, the alternatives are ordered in the descending order with the help of MAR-COS method.

The fuzzy BWM method

BWM (Ecer and Pamucar 2020; Gupta and Barua 2017; Hashemkhani Zolfani et al. 2020; Pamucar et al. 2020) offers more consistent findings because to its pairwise comparison approach, as well as algorithm resilience, speed of computing, and ease of calculation, all of which are significant advantages. So, in this section, we discuss the BWM processes for determining the criterion weights in the PPE disposal problem. Figure 3 depicts the steps involved.

Step 1: Create a list of decision criteria.

Here, we look at the criteria \((b_{1}, b_{2}, \ldots, b_{n})\) which are used to make a decision. The PPEs disposing criterion are \(B_{1}\)-society’s safety, \(B_{2}\)-cost, \(B_{3}\)-environmental impact, \(B_{4}\)-time, \(B_{5}\)-heterogeneity, and \(B_{6}\)-technology and infrastructure.

Step 2: Identify the best criteria (e.g., most beneficial and valuable) and the worst criteria (e.g., least beneficial and valuable).

Now, the decision-maker determines the overall best and worst criteria. At this point, no comparisons are made. Then, \((b_{1})\)-environmental impact and \(b_{4}\)-time are the best and the worst criteria for the disposal of PPEs problem.

Step 3: Evaluate their preference for the best overall criterion among the other criteria by assigning values between 1 and 9. The Best-to-Others vector result is:
\[
B_{G} = (b_{G_{1}}, b_{G_{2}}, \ldots, b_{G_{n}})
\]

where \(b_{G_{j}}\) denotes a preference for the best criterion \(G\) over criterion \(j\) (i.e) \(b_{GG} = 1\). In our case, the vector demonstrates a preference for \(C_{3}\)-environmental impact over the other criteria.

Step 4: Using a number between 1 and 9, rank all of the criteria in order of preference over the worst criterion. The resulting others-to-worst vector is:
\[
B_{P} = (b_{1P}, b_{2P}, \ldots, b_{nP})
\]

where \(b_{jP}\) denotes a preference for criterion \(j\) over the worst criterion \(P\). It is obvious that \(b_{PP} = 1\). In this case, the vector depicts preferences for all criteria over the criterion time-\(b_{4}\).

Fig. 3 The procedure of BWM method
Step 5: Obtain the optimal weights \((w_1^*, w_2^*, ..., w_n^*)\).

The optimal weight for the criteria is the one where, for each pair of \(\frac{w_G}{w_j}\) and \(\frac{w_j}{w_p}\) and \(\frac{w_G}{w_j} = b_{Gj}\) and \(\frac{w_j}{w_p} = b_{jp}\). To satisfy these conditions for all \(j\), we should find a solution where \(|\frac{w_G}{w_j} - b_{Gj}|\) and \(|\frac{w_j}{w_p} - b_{jp}|\) for all \(j\) is minimized. Consider the non-negativity and sum conditions for the weights as:

\[
\begin{align*}
\min & \quad \max_j \{|\frac{w_G}{w_j} - b_{Gj}| - |\frac{w_j}{w_p} - b_{jp}|\} \\
\text{s.t} & \quad \sum_j w_j = 1, \ w_j \geq 0 \text{ for all } j \\
\end{align*}
\]

Equation 33 can be transferred to the following problem:

\[
\begin{align*}
\min & \quad \chi \\
\text{s.t} & \quad \left|\frac{w_G}{w_j} - b_{Gj}\right| \leq \chi, \forall j \\
& \quad \left|\frac{w_j}{w_p} - b_{jp}\right| \leq \chi, \forall j \\
& \quad \sum_{j=1}^n w_j = 1, \forall j \\
& \quad w_j \geq 0, \forall j \\
\end{align*}
\]

The optimal weights \((w_1^*, w_2^*, ..., w_n^*)\) and \(\chi^*\) are obtained by solving Eq. 33. Then, using \(\chi^*\), we present a consistency ratio (CR). It is larger the \(\chi^*\), the higher the CR and the less reliable the comparisons become.

### Consistency ratio

We propose a consistency ratio for the proposed best-worst method in this section.

A comparison is fully consistent when \(b_{Gj} \times b_{jp} = b_{GP}\) \(\forall j\), where \(b_{Gj}\) is preference of the best criteria over \(j\), \(b_{jp}\) is preference of the worst criteria \(j\), and \(b_{GP}\) is the preference of the best criteria over the worst criteria (Rezaei 2015).

Moreover, some \(j\) may be inconsistent, for this we suggest a CR to demonstrate how consistent a comparison is. To that end, we begin by computing the minimum consistency of a comparison, which is as follows:

As previously stated, where \(b_{ij} \in \{1,2,...,9\}\) the largest possible value of \(b_{GP}\) is 9. Consistency decreases when \(b_{Gj} \times b_{jp}\) is smaller or larger than \(b_{GP}\) or equivalently \(b_{Gj} \times b_{jp} \neq 1\), and the largest inequality occurs when \(b_{Gj}\) and \(b_{jp}\) have the maximum value, which will result in \(\chi\). We also know that \((\frac{w_G}{w_j}) \times (\frac{w_j}{w_p}) = \frac{w_G}{w_p}\), and given the largest in equality as a results by \(b_{Gj}\) and \(b_{jp}\), \(\chi\) is a value that must be subtracted from \(b_{Gj}\) and \(b_{jp}\), then added to \(b_{GP}\), or:

\[
(b_{Gj} - \chi) \times (b_{jp} - \chi) = (b_{GP} + \chi)
\]

As for the minimum consistency \(b_{Gj} = b_{jp} = b_{GP}\) we have

\[
(b_{GP} - \chi) \times (b_{GP} - \chi) = (b_{GP} + \chi) \\
\implies \chi^2 - (1 + 2b_{GP})\chi + (b_{GP}^2 - b_{GP}) = 0
\]

Solving for different values of \(b_{GP} \in \{1,2,...,9\}\), we can find the maximum possible \(\chi (\max \chi)\). These values are used as the consistency index in Table 3.

The CR is then calculated using \(\chi^*\) and the corresponding consistency index, as follows:

\[
\text{Consistency Ratio} = \frac{X^*}{\text{consistency index}}
\]

### Numerical example

Plastic materials have become an indispensable part of daily life, resulting in massive global plastic pollution. Plastic is lightweight, adaptable, efficient, liquid-resistant, tough, and reasonably priced. These are the enticing characteristics that drive our high regard for and excessive consumption of plastic goods. However, because plastic materials are long-lasting and take a more time to degrade, they eventually end up as waste. Our incredible fascination with plastic, combined with an undeniable behavioural proclivity for increasingly over-consuming, disregarding improper waste disposal and thus contaminating, has become a dangerous combination. Plastics are made of synthetic chemicals and are used in a wide range of products, including water cans, clothing, packaging materials, medical equipment, electrical items, and building materials. Plastic was once thought to be harmless and odourless. Plastic pollution is now widely acknowledged as a significant environmental burden that also has an impact on human health. Despite the fact that PW is reusable, recycled products are more harmful to the environment due to added chemicals and skin tones. However, the disposal of plastic into the environment has resulted in a number of related issues.

Natural creatures have a tough time breaking down the man-made chemical bonds in plastic, making the material’s persistence a major concern. Only a small fraction of plastic manufacturing gets recycled; the remainder is disposed of in landfills or incinerated. In landfills, it will be non-degradable for few years. Incineration (Kudli et al. 2021) releases chemicals into the atmosphere, contributing to increased air pollution. A pure plastic can only be reused two to three times because it deteriorates due to thermal pressure, and it
has a shorter life span after each reprocessing. As a result of inadequate collection and segregation methods, single-use plastic (SUP) trash disposal has been highlighted as a serious concern. Before COVID-19, only 60% of plastic was recycled; the remaining 40% of plastic was left unused, causing water, land, and air pollution. Seventy percent of plastic products are converted into plastic waste during this pandemic. The COVID-19 issue has resulted in an increase in the volume of plastic garbage, which has had a detrimental impact on plastic management. SUP, in particular, adds to our planet’s plastic weight, as do a plethora of abandoned PPE kits. The corona virus has resulted in an increase in the use and disposal of plastic-based items for medical and other purposes. During the pandemic, the increased use of SUP and plastic-based materials, together with greater availability to healthcare items and packaging, caused in a significant increase in global plastic waste generation (World Health Organization 2020; Jribi et al. 2020; WEF 2020). Hence, the pandemic has posed a significant environmental challenge in terms of plastic waste management.

In India, the disposal of personal protective equipment (PPE) waste is a major issue. While no technology has been confirmed so far, a little research on the reuse of plastic waste in road construction and co-processing of plastic waste in cement kilns has been conducted, but infected PPE waste is very dangerous to reuse for society, and incineration of used PPE kits damages the environment very badly. We find a suitable solution to the PPE waste disposal problem for these issues. Furthermore, in the aftermath of the COVID-19 pandemic, a few governments are working to establish new waste management procedures and protocols, taking into account the additional facilities and infrastructure required to maintain compliance for proper waste management. Likewise, governments that lack their own laws or instructions have taken steps to conceptualize international regulations and guidelines issued by various organizations such as WHO, United Nations Environment Programme (UNEP), United Nations Human Settlements Programme (UN-Habitat), the World Bank, and other UN agencies, as well as other international organizations such as Asian Development Bank (ADB), and The International Solid Waste Association (ISWA) (Waste Management 2020).

Many cities report a considerable rise in medical waste in the form of hospital-generated personal protection equipment. As a result, it is critical to increase the capacity to handle and treat this healthcare waste as early as possible. In this situation, we must assess the most viable or acceptable waste disposal solutions for the current plastic waste management system that are compatible with the environmental system and human health consequences of waste management. This paper discusses how to properly dispose the infected personal protective equipment (PPE) and single-use plastics. Here, we address several disposal methods for PPEs from which an efficient disposal technique is chosen based on the proposed method. There are no impacts and drawbacks to the alternatives that would minimize single use plastics, used PPE kits and enhance waste disposal in the future. Here, we consider the four alternatives based on six criteria to dispose these wastes. The criteria are explained in Table 4 and the alternatives are explained as follows.

Landfills (Kudli et al. 2021; Manupati et al. 2022) The Landfills are facilities for the final disposal of single-use plastic waste on land that are designed and built with the goal of minimizing environmental impacts. The landfill site is the oldest type of waste treatment. Landfills have been the most prevalent means of storing and disposing of organized trash, and they are still in practice in many parts of the world. Plastic containers can take ten to a hundred years to degrade in landfills. Other plastic items may take the same number of years or longer to decay in such an environment, which lacks sunlight, air, and moisture (three essential components for facilitating bio-degradation). Plastic buried deep in landfills can leach dangerous chemicals into groundwater.

### Table 3 Consistency index (CI)

| Criteria (b<sub>i</sub>) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|------------------------|---|---|---|---|---|---|---|---|---|
| CI                     | 0.0 | 0.52 | 1.00 | 1.72 | 2.19 | 3.01 | 3.97 | 4.81 | 5.50 |

### Table 4 Selected criterion for ranking the alternative

| Criteria                  | Description                                                                 |
|---------------------------|-----------------------------------------------------------------------------|
| Society’s safety (B<sub>1</sub>) | Method must be safe for the public and workers to use, and it must not have a negative effect on society. |
| Cost (B<sub>2</sub>)         | Operating, transportation, technical, and other costs must be low.           |
| Environmental impact (B<sub>3</sub>) | Method adopted must not pollute the environment.                           |
| Time (B<sub>4</sub>)         | The disposal method must be capable of disposing a large amount of waste in a short period of time. |
| Heterogeneity (B<sub>5</sub>) | The disposal method must be appropriate for the disposal of various types of plastic waste. |
| Technology and infrastructure B<sub>6</sub>   | Technology and land requirements for disposing and handling of waste.       |
The most serious environmental problem caused by landfills is groundwater contamination. A modern landfill that addresses these issues is a complex structure outfitted with a variety of environmentally friendly equipment.

**Incineration (Manupati et al. 2022; Waste Management 2020)** Incineration is an extremely high, dry combustion process that converts organic and combustible waste into inorganic, non-flammable material, resulting in a significant reduction in waste volume and weight. Incineration is the rapid oxidation of trash at high temperatures of 870 – 1200 °C. When plastics are burned, toxic gases such as dioxins, fluorinated gases, mercury, and BCPs are released into the air, endangering both plants and people’s lives. Once plastic is combusted, black carbon (soot) is released, which is a greenhouse gas that contributes to climate change and pollution, and a class of flame retardants known as halogens is also formed. Cancer, neurological damage, birth defects, child developmental disorders, asthma, and multiple organ damage are all known to be caused by these harmful chemicals.

**Microwaving (Manupati et al. 2022; Waste Management 2020)** The microwave device is essentially a steam-based technique that uses the action of soaking and heat created by microwave radiation. The contaminated water is reheated by microwave energy at a frequency of approximately 2,450 MHz and a wavelength of 12.24 cm. Microwaving is a technique for treating biomedical waste made of plastic and glass. At the full design capacity of each microwave device, microwave should kill bacteria and other harmful organisms as determined by an approved biological indicator. In the absence of hazardous waste, it has the advantage of producing no liquid effluents and little emissions. The downsides are that they have high initial costs, have odour issues, and are susceptible to energy loss.

**Chemical pyrolysis (Manupati et al. 2022; Ilyas et al. 2020; Dharmaraj et al. 2021)** Pyrolysis is the thermal degradation of polymers into smaller molecules in the presence of a catalyst (such as aluminium oxides, fly ash, red mud, and calcium hydroxide) in an inert atmosphere at temperatures between 300 °C and 400 °C. It is a thermo-chemical plastic disposal method that involves the oxidative decomposition of lengthy polymer structures into simpler, smaller units under high temperature and pressure in the lack of oxygen for a short period of time. The oil produced during the pyrolysis process resembles normal diesel. Chemical pyrolysis products can be refined in the same way that as oil, using conventional refining technologies to produce polymer building blocks. They can also be used directly as a fuel.

In this section, the proposed methodology is used to evaluate the disposal method for used PPEs. To obtain the best disposal method that has a low environmental impact and is useful for all requirements in society, we have chosen six criteria to evaluate the four alternatives. Those criteria are society’s safety ($B_1$), cost ($B_2$), environmental impact ($B_3$), time ($B_4$), heterogeneity ($B_5$), and technology & infrastructure ($B_6$). Here, we consider three decision-makers to evaluate the alternatives based on those selected criteria’s. Then, the alternatives are landfills ($C_1$), incineration ($C_2$), microwaving ($C_3$), and chemical pyrolysis ($C_4$). The selected alternatives and criteria are shown in Fig. 4.

### The fuzzy BWM method

**Step 1:** Create a list of decision criteria.

Here, we look at the criteria ($B_1$, $B_2$, ..., $B_6$) that is used to make a decision. The PPEs disposing criterion are $B_1$-society’s safety, $B_2$-cost, $B_3$-environmental impact, $B_4$-time, $B_5$-heterogeneity, and $B_6$-technology and infrastructure.

**Step 2:** Obtain the best and the worst criteria, ($B_1$)-environmental impact is best and $B_6$-time is the worst criteria.

**Step 3:** Here, $B_1$ is the best criteria and the pairwise comparison vector for the best criterion values are given in Table 5.

**Step 4:** Here, $B_6$ is the worst criteria and the pairwise comparison vector for the best criterion values are given in Table 6.

**Step 5:** From Tables 5 and 6 results in Eq. 33 for this problem, as follows:

$$\min \chi, \\
\begin{align*}
\frac{w_1}{w_2} - b_2 \leq \chi, & \frac{w_1}{w_3} - b_3 \leq \chi, & \frac{w_1}{w_4} - b_4 \leq \chi, & \frac{w_1}{w_5} - b_5 \leq \chi, & \frac{w_1}{w_6} - b_6 \leq \chi, & \forall j, \\
\frac{w_2}{w_4} - b_4 \leq \chi, & \frac{w_2}{w_5} - b_5 \leq \chi, & \frac{w_2}{w_6} - b_6 \leq \chi, & \frac{w_3}{w_4} - b_4 \leq \chi, & \frac{w_3}{w_5} - b_5 \leq \chi, & \frac{w_3}{w_6} - b_6 \leq \chi, & \forall j, \\
\frac{w_4}{w_6} - b_6 \leq \chi, & \frac{w_5}{w_6} - b_6 \leq \chi, & \frac{w_6}{w_6} - b_6 \leq \chi, & \forall j, \\
w_1 + w_2 + w_3 + w_4 + w_5 + w_6 = 1, \\
w_1, w_2, w_3, w_4, w_5, w_6 \geq 0, \forall j
\end{align*}$$

(37)

**Fig. 4** The used PPEs disposal problem
Solving this Eq. 37, we found the optimal weights $(w^*_1, w^*_2, \ldots, w^*_n)$ are $w_1 = 0.0751$, $w_2 = 0.1503$, $w_3 = 0.4154$, $w_4 = 0.0382$, $w_5 = 0.2004$, $w_6 = 0.1202$ which are shown in Fig. 5 and $\chi^* = 0.1858$. For the consistency ratio, as $b_{GP} = b_{34} = 6$, the consistency index is 3.01 (Table 3), and the CR is $\frac{3.01}{0.1858} = 0.0617$, which implies a very good consistency.

The enhanced MARCOS method

In this section, experts evaluate the disposal methods under the selected criteria are represented as a DHq-ROFNs. The linguistic scale (Table 2) helps the experts to assist their opinions in evaluating the alternatives.

Step 1: Create the initial decision matrix using linguistic variables, which is shown in Table 7. Then, aggregating the initial matrix with $q = 3$ and which is given in Table 8.

Step 2: The extended initial matrix is shown in Table 9 by applying the Eqs. 21 and 22.

Step 3: By using Eqs. 23 and 24 to NDM, then multiplied the weight values $w_1 = 0.0751$, $w_2 = 0.1503$, $w_3 = 0.4154$, $w_4 = 0.0382$, $w_5 = 0.2004$, $w_6 = 0.1202$ with NDM, we get the weighted NDM and which is shown in Table 10.

Step 4: Calculate the utility degree of the alternatives using Eqs. 26 and 27, and utility function and final ranking results are obtained using Eqs. 28, 29, 30, 31 are shown in Table 11.

Step 5: The final ranking results are given in Table 11 and graphical representation is shown in Fig. 6.

From Table 11, the best disposal method for used PPE kits is $C_4$-chemical pyrolysis. The manufacturing of liquid fuel from disposal of PPEs could address both the challenges of PPE waste management and rising energy demand. Plastic-derived liquid fuel is environmentally friendly and has similar fuel properties to fossil fuels. In this situation, converting plastic waste into a liquid biofuel is a viable option for protecting environmental resources. The process of converting any material at extremely high temperatures is known as pyrolysis. All PPEs currently disposed of in landfills, oceans, and other places that harm aquatic species can be relocated to a combustor and exposed to high temperatures to decompose the propane bonds and form a liquid. The liquid that results can be used as a biofuel. We need the fuel to power various mechanical devices. This fuel
Table 7 Decision matrix based on linguistic scale for $DM_1, DM_2, DM_3$

|       | $B_1$     | $B_2$     | $B_3$     | $B_4$     | $B_5$     | $B_6$     |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|
| $DM_1$ | (AA,A)    | (H,A)     | (VH,L)    | (VH,VL)   | (H,VL)    | (CH,A)    |
|       | (L,H)     | (A,H)     | (CH,UA)   | (VH,UA)   | (A,L)     | (H,A)     |
|       | (H,VH)    | (H,VH)    | (UA,A)    | (A,VH)    | (VH,A)    | (AA,A)    |
|       | (CH,H)    | (VH,H)    | (CH,A)    | (AA,VL)   | (VH,AA)   | (VH,A)    |
| $DM_2$ | (A,AA)    | (L,AA)    | (H,A)     | (H,L)     | (VH,VL)   | (VH,UA)   |
|       | (L,A)     | (H,A)     | (CH,A)    | (VH,A)    | (UA,H)    | (VH,UA)   |
|       | (L,VL)    | (VH,AA)   | (A,H)     | (AA,H)    | (L,A)     | (A,UA)    |
|       | (VH,VH)   | (VH,AA)   | (CH,UA)   | (VH,VH)   | (H,A)     | (VH,VH)   |
| $DM_3$ | (L,H)     | (A,H)     | (VH,H)    | (VH,VL)   | (H,VL)    | (CH,A)    |
|       | (VH,A)    | (A,AA)    | (H,UA)    | (CH,UA)   | (H,A)     | (VH,VH)   |
|       | (A,AA)    | (H,VH)    | (AA,VH)   | (H,VH)    | (A,H)     | (L,VH)    |
|       | (H,UA)    | (H,AA)    | (VH,AA)   | (AA,VL)   | (H,VH)    | (A,H)     |

Table 8 Aggregate decision matrix

|       | $B_1$     | $B_2$     | $B_3$     | $B_4$     | $B_5$     | $B_6$     |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|
| $C_1$ | 0.0611    | 0.1102    | 0.3397    | 0.0641    | 0.0772    | 0.4208    |
| $C_2$ | 0.108     | 0.1514    | 0.4737    | 0.4567    | 0.0161    | 0.3888    |
| $C_3$ | 0.0222    | 0.4452    | 0.1024    | 0.1275    | 0.1492    | 0.009     |
| $C_4$ | 0.5201    | 0.475     | 0.5989    | 0.311     | 0.3949    | 0.3899    |

Table 9 Extended aggregated matrix

|       | $B_1$     | $B_2$     | $B_3$     | $B_4$     | $B_5$     | $B_6$     |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|
| AAI   | 0.0222    | 0.475     | 0.1024    | 0.0641    | 0.0772    | 0.4208    |
| $C_1$ | 0.0611    | 0.1102    | 0.3397    | 0.0641    | 0.0772    | 0.4208    |
| $C_2$ | 0.108     | 0.1514    | 0.4737    | 0.4567    | 0.0161    | 0.3888    |
| $C_3$ | 0.0222    | 0.4452    | 0.1024    | 0.1275    | 0.1492    | 0.009     |
| $C_4$ | 0.5201    | 0.475     | 0.5989    | 0.311     | 0.3949    | 0.3899    |
| ID    | 0.5201    | 0.1102    | 0.5989    | 0.4567    | 0.3949    | 0.009     |

Table 10 Weighted normalized matrix

|       | $B_1$     | $B_2$     | $B_3$     | $B_4$     | $B_5$     | $B_6$     |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|
| AAI   | 0.0031    | 0.0348    | 0.0709    | 0.0053    | 0.0391    | 0.0025    |
| $C_1$ | 0.0088    | 0.1503    | 0.2356    | 0.0053    | 0.0391    | 0.0025    |
| $C_2$ | 0.0155    | 0.1093    | 0.3285    | 0.0382    | 0.0081    | 0.0027    |
| $C_3$ | 0.0031    | 0.0371    | 0.0709    | 0.0106    | 0.0757    | 0.1202    |
| $C_4$ | 0.0751    | 0.0348    | 0.4154    | 0.0260    | 1.2004    | 0.0027    |
| ID    | 0.0751    | 0.1503    | 0.4154    | 0.0382    | 0.2004    | 0.1202    |

Table 11 The final ranking values for proposed method

|       | $f(U^-)$  | $f(U^+)$  | $U_-$     | $U_+$     | $f(U)$    | Rank     |
|-------|-----------|-----------|-----------|-----------|-----------|----------|
| $C_1$ | 0.1347    | 0.8652    | 2.8362    | 0.4417    | 0.4324    | 3        |
| $C_2$ | 0.1347    | 0.8652    | 3.2260    | 0.5025    | 0.4919    | 2        |
| $C_3$ | 0.1347    | 0.8652    | 2.0398    | 0.3177    | 0.3110    | 4        |
| $C_4$ | 0.1347    | 0.8652    | 4.8452    | 0.7547    | 0.7388    | 1        |
can be reprocessed, which helps to protect the environment. Because of the growing population and their need for energy, this would be a healthy alternative that would also aid in the preservation of our natural environment.

**Result validation**

**Sensitivity analysis**

This section depicts the analysis in sensitivities of the weight which has evaluated by the proposed method with three cases for used PPE kit disposal, is shown in Table 12. The Enhanced MARCOS method is used to find the alternative ranks. The weights are evaluated using the BWM weight finding method, the final ranks are determined by the weights of each criterion. The best alternative can be found an account of criteria, and which can lead to a better compromise option. The results of three cases are compared with the proposed problem, and the pictorial representation is shown in Fig. 7.

Table 12: Weight values for sensitivity analysis

| Criteria | Case 1 | Case 2 | Case 3 |
|----------|--------|--------|--------|
| B₁       | 0.0751 | 0.4120 | 0.1639 |
| B₂       | 0.1503 | 0.1128 | 0.3538 |
| B₃       | 0.4154 | 0.0705 | 0.0431 |
| B₄       | 0.0382 | 0.2265 | 0.0703 |
| B₅       | 0.2004 | 0.0371 | 0.2459 |
| B₆       | 0.1202 | 0.1411 | 0.1230 |

Case 2: Here, B₁-society’s safety is the best criteria and B₂-heterogeneity is the worst criteria. In BWM method, we found the weights of the criteria are $w₁ = 0.4120$, $w₂ = 0.1128$, $w₃ = 0.0705$, $w₄ = 0.2264$, $w₅ = 0.0371$, $w₆ = 0.1411$, and $χ^* = 0.1522$ and consistency ratio is 0.0408. Which implies a good consistency.

The ranking order in this case is as follows:

$C₄ > C₂ > C₃ > C₁$

when $B₁$ is best criterion and $B₃$ is worst criterion.

Case 3: Here, $B₂$-cost is the best criteria and $B₃$-environmental impact is the worst criteria. In BWM method, we found the weights of the criteria are $w₁ = 0.1639$, $w₂ = 0.3538$, $w₃ = 0.0431$, $w₄ = 0.0703$, $w₅ = 0.2459$, $w₆ = 0.1230$, and $χ^* = 0.1381$ and consistency ratio is 0.0600. Which implies a good consistency.

The ranking order in this case is as follows:

$C₄ > C₁ > C₂ > C₃$

when $B₂$ is best criterion and $B₃$ is worst criterion.

Table 13 shows that alternative $C₄$ has the same rank in all three cases (1). In three cases, alternatives $C₁$, $C₂$, and $C₃$ have different rank positions and rank values. The ranking results are shown in Fig. 8. Furthermore, criterion weight determines its significance, and it implied that the ranking sequential keeps changing as the weighting factor of the criteria changes. So, in order to test the effectiveness, we keep hoping that if a weight detection system is available, we can select the best alternative for disposing of used PPE kits depending on the priorities assigned in such cases.
**Fig. 7** Weight values of the criteria for sensitivity analysis

![Weight values of the criteria for sensitivity analysis](image)

**Table 13** Ranking results for sensitivity analysis

| Alternatives | Case 1   | Rank | Case 2   | Rank | Case 3   | Rank |
|--------------|----------|------|----------|------|----------|------|
| $C_1$        | 0.4324   | 3    | 0.2407   | 4    | 0.4479   | 2    |
| $C_2$        | 0.4919   | 2    | 0.4502   | 2    | 0.3997   | 3    |
| $C_3$        | 0.3110   | 4    | 0.2731   | 3    | 0.3299   | 4    |
| $C_4$        | 0.7388   | 1    | 0.6966   | 1    | 0.5729   | 1    |

**Fig. 8** Sensitivity analysis results

![Sensitivity analysis result](image)
Comparison analysis

To investigate the robustness of the method, we compared the results obtained from the proposed method with other relevant MCDM methods like TOPSIS, VIKOR, and, MULTIMOORA. We can observe changes in the ranking values obtained from all the three methods except TOPSIS. TOPSIS is utilized based on ideal and ideal solution and the ranking value ordered in the descending order VIKOR is proposed based on relative closeness index (Chang 2010) and is ranked in the descending order. Hence, the preference order obtained using VIKOR and TOPSIS methods coincides with that of the proposed method, whereas in the MULTIMOORA method. In MULTIMOORA approach, the alternatives C₁ and C₃ have different ranking position when compared to the proposed approach. This analysis shows the stability and consistency of the proposed method in handling real-life MCDM problems. Table 14 shows the obtained results and are represented graphically in the Fig. 9.

Table 14 Comparison analysis results

| Methods     | Ranking values | Ranking order | Rank result |
|-------------|----------------|---------------|-------------|
| TOPSIS      | C₁-0.3980, C₂-0.4902, C₃-0.2467, C₄-0.7476 | C₄ > C₂ > C₁ > C₃ | C₄         |
| VIKOR       | C₁-0.4528, C₂-0.3076, C₃-1.0000, C₄-0.0000  | C₄ < C₂ < C₁ < C₃ | C₄         |
| MULTIMOORA  | C₁-0.1446, C₂-0.3310, C₃-0.1341, C₄-0.3310  | C₄ > C₂ > C₃ > C₁ | C₄         |
| Proposed method | C₁-0.4324, C₂-0.4919, C₃-0.3110, C₄-0.7388 | C₄ > C₂ > C₁ > C₃ | C₄         |

Conclusion

The used PPE kits has contributed to the enormous growth of the amount of plastic waste during the COVID-19 pandemic which has alarmed the world to look into suitable treatment technique for handling them as they would pose a threat to the environment. In this article, we have proposed an efficient treatment method which converts the plastic waste into biofuel. This means that the suggested method can simultaneously address the problem of plastic waste management and energy demand. The hesitancy that arises with the expert’s opinion in evaluating the treatment techniques has been effectively dealt with the DHq-ROFNs. As the fuzzy MARCOS method provides more precise determination of the degree of utility and as it considers the fuzzy reference points through the fuzzy ideal and anti-ideal solution at the beginning of the problem formulation involving this method for obtaining a suitable treatment method provided more realistic and acceptable results when compared to other existing MCDM methods. The incomplete information in determining the criteria weights has been effectively
handled by the fuzzy BWM method. Furthermore, change in the preference criteria has shown a sensible change in obtaining an optimal alternative. This means that the criteria weights have a great impact in obtaining a feasible solution. The integration of both MARCOS-BWM method when compared to the VIKOR, MULTIMOORA, TOPSIS method proved to be more apt for the determination of suitable treatment technology. The objectivity of the decision problem is not considered in determining the criteria weights as the considered weighting method is purely based on the judgement of the decision-makers which would be a limitation to the proposed problem. From the sensitivity analysis, it is clear that the proposed methodology is dependable on the criteria weights. When dealing with complex decision making problems the restriction with membership and non-membership conditions may be difficult to deal at some circumstances. In the future, we may consider appropriately disposing of old PPE kits and other single-use medical equipment at a suitable location involving different forms of MCDM techniques in a sophisticated q-rung orthopair fuzzy approach. Furthermore, considering several factors in evaluating the problem would help in obtaining an efficient treatment technique.

Author Contribution DK: conceptualization, data curation, methodology, processing and analysis of the data, simulation, writing. AA: writing—original draft, conceptualization, methodology, supervision. SN: data curation, methodology, processing and analysis of the data supervision, validation—reviewing original draft. MG: validation of data and final editing. AA: conceptualization, methodology, supervision, writing—review and editing.

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Data availability All the data and tools/models used for this work are publicly available.

Declarations

Ethics approval and consent to participate This manuscript does not involve researching about humans or animals.

Consent for publication All of the authors consented to publish this manuscript.

Conflict of interest The authors declare no competing interests.

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