The University of Tehran Press

Pollution

Print ISSN: 2383-451X
Online ISSN: 2383-4501

https://jpoll.ut.ac.ir/

# A framework of Trapezoidal Fuzzy Best-Worst Method in Location Selection for Surface Water Treatment Plant

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**Article Info**

**Article type:**
Research Article

**Article history:**
Received: 10 October 2022
Revised: 11 November 2022
Accepted: 2 December 2023

**Keywords:**
*Fuzzy best-worst method*
*Trapezoidal Fuzzy number*
*Multi-criteria decision-making*
*Surface water treatment plant*

**ABSTRACT**

Decision-making under uncertainty refers to a dilemma when a decision-maker is aware of a variety of potential natural states but lacks adequate information to assign any probabilities of occurrence to them. The uncertainty related to the input parameters is one of the main issues in the majority of decision-making situations. Uncertainty may produce some irrational results, which could make the decision-making process even more challenging. To overcome this challenge, a fuzzy extension of Best-Worst Method (BWM) has been proposed, using trapezoidal fuzzy sets, to combine the advantages of a reduced number of pair-wise comparisons and easy handling of ambiguity. The criteria and alternatives have been evaluated by the proposed Trapezoidal Fuzzy Best-Worst Method (TrFBWM), where the weight of each element is represented by a Trapezoidal Fuzzy Number (TrFN). To verify the coherence of judgment, the consistency ratio is evaluated for TrFBWM. The proposed method is then applied to the location selection of a water treatment plant along the bank of the Brahmaputra river in Assam. The obtained results are compared to one previous work and found that the outcomes of the proposed method indicate a good agreement with that. The outcomes of the study provide useful insights for selecting a suitable location for a surface water treatment plant which can also be extended to other service facilities.

**Cite this article:** Debnath, K., Debnath, P., Choudhury, S., Saha, A.K., & Majumdar, A. (2024). A framework of Trapezoidal Fuzzy Best-Worst Method in Location Selection for Surface Water Treatment Plant. *Pollution*, 10 (1), 1-16. https://doi.org/10.22059/poll.2023.349799.1656


DOI: https://doi.org/10.22059/poll.2023.349799.1656

## INTRODUCTION

Multi-Criteria Decision Making (MCDM) is a quantitative process that deals with the selection of the best alternative or ranking of alternatives from several prospective candidates (Calizaya, 2010). The decision criteria or attributes may be objective or subjective in nature. Decision-makers (DMs) always attempt to select the ideal solution, unfortunately, which exists only for a single criterion. In the actual decision-making scenario, almost every choice includes some compromise or discontent. AHP, ANP, TOPSIS, ELECTRE, PROMETHEE, DEMATEL, FUCOM, and MOORA are some of the widely used MCDM methods (Hoet al., 2010; Govindan et al., 2015, Ghosh et al., 2015).

AHP, developed by Saaty (1980), is one of the most popular methods of decision-making. Which has been used extensively in many problems related to science, engineering, and management, including site selection (Sánchez-Lozano et al., 2015; Wichapa & Khokhajaikiat,

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2017; Ramya & Devadas, 2019; Karastan et al., 2019). AHP is based on a pair-wise comparison of elements (criteria or alternatives), which is not only tedious but also causes inconsistency. To overcome these drawbacks, Rezaei (2015, 2016) introduced the Best-Worst Method (BWM) of MCDM, which can elicit the weights of criteria based on pairwise comparisons concerning only the best and the worst criteria. The fuzzy extension of BWM has been used by many researchers (Scarpa, 2011; Chen et al., 2020; Karimi et al., 2020; Moslem et al., 2020; Omrani et al., 2018). In most of the reported literature, TFN has been used to incorporate fuzziness (Chen et al., 2006, Xiao et al., 2012; Barkan & Trubatch, 2000).

The selection of location for surface water treatment plants (SWTP) is of paramount importance as this decision affects a large population. A few research publications demonstrate the applications of MCDM to solve the location selection problem of SWTP (Pedrera et al., 2011; Wondim and Dzwairo, 2018; Jajac at al., 2019; Vasiloglou and Gravanis, 2009; Arabani and Pirous, 2016; Saha et al., 2017, Shimray et al., 2017; Choudhury et al., 2020).

Our literature review demonstrates that though MCDM techniques have been used in the site selection problem of a water treatment plant, the decision-making under a fuzzy environment needs greater attention. The objective of this research is to extend the BWM in the fuzzy environment for solving the location selection problem. BWM has been modified to capture the ambiguity involved in a fuzzy environment using TrFN. The trapezoidal fuzzy BWM (TrFBWM) is easier to implement and involves fewer redundant steps, rather than fuzzy AHP, as secondary comparisons are not performed in the case of the former. The application of the method has been demonstrated through a real case study of location selection for SWTP. As a result of having fewer pairwise comparisons compare to AHP, BWM is preferred in terms of the weighting of the criterion. Thus, the goal is to create a novel MCDM technique called the Trapezoidal Fuzzy Best-Worst Method (TrFBWM) based on trapezoidal fuzzy numbers and BWM. The novelty of the present study includes:

• Here, the TrFBWM decision-making technique has been used to overcome the drawbacks of the MCDM method.

• Moreover, for the first time, to propose this MCDM technique to select the best location for the installation of SWTPs.

The contribution of this study is as follows:

• BWM has been utilized in this study in a Trapezoidal fuzzy environment.
• This has been applied to evaluate the best and worst criteria as well as an alternative.
• It has been used to select an optimal location for the installation of SWTP.
• Through comparative and sensitivity analysis, the suggested method's consistency and robustness have been verified.

## MATERIALS AND METHODS

The concepts of fuzzy sets and related definitions that are used to developTrFBWM have been explained in this section. The fuzzy set theory was introduced by Zadeh in 1965 [32] to deal with ambiguity and vagueness in decision-making. Fuzzy sets are the extensions of crisp sets, and the boundaries are not clearly defined in the case of the former.

A fuzzy set (Zadeh, 1965), $\alpha=\{(x,\mu\alpha(x)):x\in X\}$ is a set of ordered pairs, and X is a subset of real numbers R, in which μα(x) is the membership function of object $x$ to the fuzzy set. The range of membership ranges from zero to one.

A TrFN (Xiao et al., 2012) can be denoted as $\hat{A} = (\alpha, \beta, \gamma, \delta)$ where the membership function $\mu_{\hat{A}}$ of $\hat{A}$ is given by

$$\mu_{\hat{A}} = \begin{cases} 0, & x < \alpha \\ \dfrac{x-\alpha}{\beta-\alpha}, & \alpha \le x \le \beta \\ 1, & \beta \le x \le \gamma \\ \dfrac{\delta - x}{\delta-\gamma}, & \gamma \le x \le \delta \\ 0, & x > \delta \end{cases} \quad (1)$$

Where $[\beta,\gamma]$ is the mode interval of $\hat{A}$ and parameters $\alpha$ and $\delta$ are the lower and upper bound of $\hat{A}$, respectively, which limit the field of possible evaluations.

When the two most promising values of a TrFN are the same number, it becomes a TFN. Therefore, TFNs are special cases of TrFN. The former is used in pessimistic or conservative cases as full membership is given only at a specific value of the universe of discourse, whereas the latter is used in optimistic or tolerant cases where full membership is given for a large region of the universe of discourse. Therefore, a TrFN can deal with more tolerant and optimistic situations (Berkan & Trubatch, 2000). If the two positive TrFNs $\hat{A}=(\alpha_1,\beta_1,\gamma_1,\delta_1)$ and $\hat{B}=(\alpha_2,\beta_2,\gamma_2,\delta_2)$, then the operational laws of these two TrFNs are as follows (Chen, 2007):

$$\hat{A}\oplus\hat{B}=(\alpha_1,\beta_1,\gamma_1,\delta_1)\oplus(\alpha_2,\beta_2,\gamma_2,\delta_2)=(\alpha_1+\alpha_2,\beta_1+\beta_2,\gamma_1+\gamma_2,\delta_1+\delta_2) \quad (2)$$

$$\hat{A}\ominus\hat{B}=(\alpha_1,\beta_1,\gamma_1,\delta_1)\ominus(\alpha_2,\beta_2,\gamma_2,\delta_2)=(\alpha_1-\delta_2,\beta_1-\gamma_2,\gamma_1-\beta_2,\delta_1-\alpha_2) \quad (3)$$

$$\hat{A}\otimes\hat{B}=(\alpha_1,\beta_1,\gamma_1,\delta_1)\otimes(\alpha_2,\beta_2,\gamma_2,\delta_2)=(\alpha_1\alpha_2,\beta_1\beta_2,\gamma_1\gamma_2,\delta_1\delta_2) \quad (4)$$

$$\hat{A}\oslash\hat{B}=(\alpha_1,\beta_1,\gamma_1,\delta_1)\oslash(\alpha_2,\beta_2,\gamma_2,\delta_2)=\left(\frac{\alpha_1}{\delta_2},\frac{\beta_1}{\gamma_2},\frac{\gamma_1}{\beta_2},\frac{\delta_1}{\alpha_2}\right) \quad (5)$$

$$k\hat{A}=(k\alpha_1,k\beta_1,k\gamma_1,k\delta_1),\ k>0 \quad (6)$$

$$\hat{A}^{-1}=\left(\frac{1}{\delta_1},\frac{1}{\gamma_1},\frac{1}{\beta_1},\frac{1}{\alpha_1}\right) \quad (7)$$

The operation of converting a fuzzy number into a crisp number is called defuzzification. It is an inverse transformation which maps the output from the fuzzy domain back into the crisp domain. If $\hat{A}=(\alpha_1,\beta_1,\gamma_1,\delta_1)$ be a TrFN, then the matching crisp value $N$ can be obtained by Eq.(8) (Rahmani et al., 2016).

$$N=\frac{2\alpha_1+7\beta_1+7\gamma_1+2\delta_1}{18} \quad (8)$$

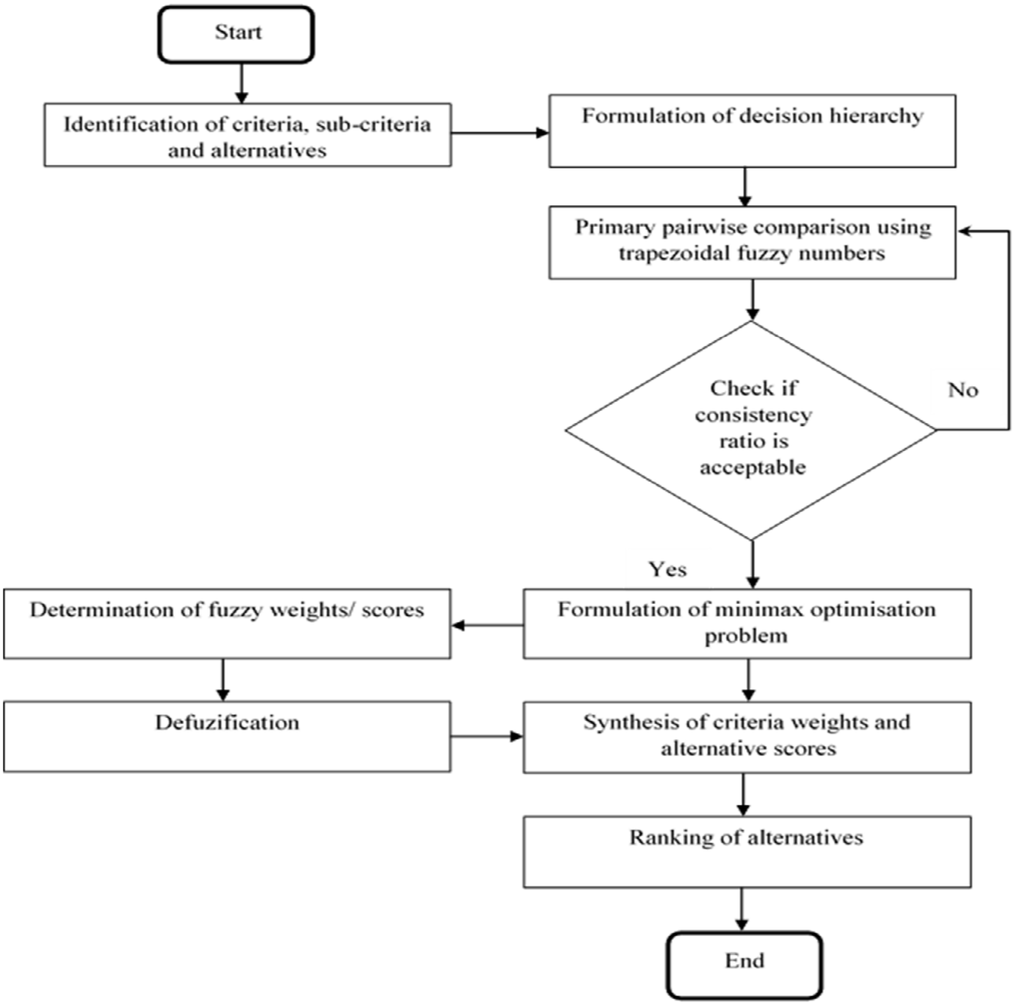


**Fig. 1.** Flowchart of the TrFBWM

The Best-Worst Method (BWM) is a relatively new MCDM method developed by Rezaei (2015). In BWM, the decision-maker first ascertains the best and the worst criteria. The best criterion is the one having the most dominant importance, and on the other hand, the worst criterion has the least importance. Then the decision-maker provides the preferences of the best criterion over all the other criteria and also the preferences of all the criteria over the worst criterion. These comparisons involving the best and worst criteria are called reference comparisons. Secondary comparisons involving criteria other than the best and the worst are not performed in BWM, thereby reducing the number of pairwise comparisons to a significant extent. The reference pairwise comparisons are then used as input to formulate a minimax-type optimization problem. The criteria weights are determined by solving the optimization problem. BWM not only eliminated the redundant secondary pairwise comparisons but also ensures better consistency in judgment compared to AHP.

The flowchart of the methodology of this study is depicted in Figure 1. For an MCDM problem consisting of $n$ criteria, the fuzzy pairwise comparisons can be done based on the linguistic rating given by the decision-makers, such as equally important (EI), weakly important (WI), fairly Important (FI), very important (VI), and absolutely important (AI). Then, the linguistic ratings of decision-makers can be transformed into fuzzy numbers represented by TrFNs as per the scale given in Table 1 (Do et al., 2015).

**Table 1.** The scale for pairwise comparison

| The scale of relative importance (crisp number) | Trapezoidal fuzzy number | Linguistic rating |
|---|---|---|
| 1 | (1,1,1,1) | Equally important |
| 3 | $\left(2,\frac{5}{2},\frac{7}{2},4\right)$ | Weakly important |
| 5 | $\left(4,\frac{9}{2},\frac{11}{2},6\right)$ | Essentially important |
| 7 | $\left(6,\frac{13}{2},\frac{15}{2},8\right)$ | Very strongly important |
| 9 | $\left(8,\frac{17}{2},\frac{19}{2},10\right)$ | Absolutely important |
| $x=2,4,6,8$ are intermediate scales $\left(x-1,x-\frac{1}{2},x+\frac{1}{2},x+1\right)$ | | |

The fuzzy comparison matrix can be obtained as follows,

$$\left[\hat{A}\right]=\begin{bmatrix} \hat{x}_{11} & \hat{x}_{12} & \dots & \hat{x}_{1n} \\ \hat{x}_{21} & \hat{x}_{22} & \dots & \hat{x}_{21} \\ \dots & \dots & \dots & \dots \\ \hat{x}_{n1} & \hat{x}_{n2} & \dots & \hat{x}_{nn} \end{bmatrix} \tag{9}$$

Where, $\hat{\boldsymbol{x}}_{ij}$ represents the relative fuzzy preference of criterion $i$ to criterion $j$, which is a TrFN $\hat{\boldsymbol{x}}_{ij}=(1,1,1,1)$ when $i=j$.

Here, $\hat{\boldsymbol{x}}_{ij}$ defined as a fuzzy reference comparison if $i$ is the best element and/or $j$ is the worst element. For $\widehat{\boldsymbol{A}}$, there are totally $(2n-3)$ fuzzy reference comparisons, which need to be implemented for fuzzy BWM. Using fuzzy BWM, it is possible to determine the fuzzy weights of criteria as well as scores of alternatives concerning criteria also (Rezaei, 2015).

Step 1. Construct the set of decision criteria

A set is formed consisting of all the decision criteria. In general, let there be $n$ decision criteria $\{c_i, i=1,2,...,n\}$.

Step 2. Identify the best and the worst criteria

The best and the worst criteria are identified by the decision-maker. The best criterion is represented as $c_B$, and the worst criterion is represented $c_W$.

Step 3. Perform the fuzzy reference comparisons

The fuzzy reference comparison plays a vital role in TrFBWM. It has two aspects: first case is the pairwise comparison $\hat{\boldsymbol{x}}_{Bj}$ where B is the best element and $c_B$ is the best criterion; the other case is the pairwise comparison $\widehat{\boldsymbol{x}}_{iW}$, where W is the worst element, and $c_W$ is the worst criterion. As mentioned in section 2, the fuzzy preferences of the best criterion over all the criteria are determined in the first case. According to the transformation rule, as mentioned in Table 1, the acquired fuzzy preferences are then converted into TrFNs. Assuming that the obtained fuzzy Best-to-Others vector is of the form:

$$\hat{\boldsymbol{x}}_B=\left\{\hat{\boldsymbol{x}}_{B1}, \hat{\boldsymbol{x}}_{B2}, \ldots\ldots\hat{\boldsymbol{x}}_{Bn}\right\}$$

Where the fuzzy Best-to-Others vector is symbolized as $\hat{\boldsymbol{x}}_B$; $\hat{\boldsymbol{x}}_{Bj}$ signifies the fuzzy preference of the best criterion $c_B$ over criterion $c_j, j=1,2,...,n$ and $\hat{\boldsymbol{x}}_{BB}=(1,1,1,1)$.

The fuzzy reference comparison for the worst criterion is also done in this step. . The fuzzy Others-to-Worst vector can be represented as:

$$\hat{x}_W = \{\hat{x}_{1W}, \hat{x}_{2W}, \ldots .\hat{x}_{nW}\}$$

Where the fuzzy Best-to-Others vector is symbolized as $\hat{x}_W$ ; $\hat{x}_{jW}$ reflects the fuzzy preference of the best criterion $c_i$ over criterion $c_W, W = 1, 2, \ldots, n$ and $\hat{x}_{WW} = (1,1,1,1)$.

Step 4. Calculate the optimal fuzzy weights

For each criterion and alternative, the optimal fuzzy weight satisfiesthe conditions $\frac{\hat{w}_B}{\hat{w}_j} = \hat{x}_{Bj}$ and $\frac{\hat{w}_j}{\hat{w}_W} = \hat{x}_{jW}$. To meet the above conditions, the solution should minimize the absolute maximum of $\left|\frac{\hat{w}_B}{\hat{w}_j} - \hat{x}_{Bj}\right|$ and $\left|\frac{\hat{w}_j}{\hat{w}_W} - \hat{x}_{jW}\right|$ for all $j$. It is worth noting that all the weights in TrFBWM are TrFNs. For the optimal solution, we use, $\hat{w}_j = (\alpha_j^w, \beta_j^w, \gamma_j^w, \delta_j^w)$, $j = 1, 2, \ldots, n$. After obtaining the fuzzy weights of the criteria, the crisp value can be achieved by using the transformation shown in Eq. (8). Thus, the following optimization problem is formulated:

$$\min max_j \left\{ \left| \frac{\hat{w}_B}{\hat{w}_j} - \hat{x}_{Bj} \right|, \left| \frac{\hat{w}_j}{\hat{w}_W} - \hat{x}_{jW} \right| \right\}$$

$$\begin{cases} \sum_{j=1}^{n} R(\hat{w}_j) = 1 \\ \alpha_j^w \le \beta_j^w \le \gamma_j^w \le \delta_j^w, \ j = 1, 2, ..n \\ \alpha_j^w \ge 0 \end{cases} \tag{10}$$

such that

where,

$\hat{w}_B = (\alpha_B^w, \beta_B^w, \gamma_B^w, \delta_B^w)$,

$\hat{w}_j = (\alpha_j^w, \beta_j^w, \gamma_j^w, \delta_j^w)$, $\hat{w}_W = (\alpha_W^w, \beta_W^w, \gamma_W^w, \delta_W^w)$ and $\hat{x}_{Bj} = (\alpha_{Bj}, \beta_{Bj}, \gamma_{Bj}, \delta_{Bj})$,

$\hat{x}_{jW} = (\alpha_{jW}, \beta_{jW}, \gamma_{jW}, \delta_{jW})$.

The above optimization problem can be transformed into a constrained one, as demonstrated below.

$$\min \hat{\phi}$$

$$\text{Subject to} \begin{cases} \left| \frac{\hat{w}_B}{\hat{w}_j} - \hat{x}_{Bj} \right| \le \hat{\phi} \\ \left| \frac{\hat{w}_j}{\hat{w}_W} - \hat{x}_{jW} \right| \le \hat{\phi} \\ \sum_{j=1}^{n} R(\hat{w}_j) = 1 \\ \acute{a}_j^w \le \hat{a}_j^w \le \tilde{a}_j^w \le \ddot{a}_j^w, \ j = 1, 2, ..n \\ \acute{a}_j^w \ge 0 \end{cases} \tag{11}$$

where $\hat{\phi} = (\alpha^{\phi}, \beta^{\phi}, \gamma^{\phi}, \delta^{\phi})$.

Considering, $\lambda^* = \alpha^{\phi}$, and $\hat{\phi} = (\lambda^*, \lambda^*, \lambda^*, \lambda^*)$, the Eq. (11) can be transformed to the following optimization problem.

$$\min \hat{\phi}$$

$$\text{Subject to } \begin{cases} \left| \frac{(\alpha_B^w, \beta_B^w, \gamma_B^w, \delta_B^w)}{(\alpha_j^w, \beta_j^w, \gamma_j^w, \delta_j^w)} - (\alpha_{Bj}, \beta_{Bj}, \gamma_{Bj}, \delta_{Bj}) \right| \le \hat{\phi} \\ \left| \frac{(\alpha_j^w, \beta_j^w, \gamma_j^w, \delta_j^w)}{(\alpha_W^w, \beta_W^w, \gamma_W^w, \delta_W^w)} - (\alpha_{jW}, \beta_{jW}, \gamma_{jW}, \delta_{jW}) \right| \le \hat{\phi} \\ \sum_{j=1}^{n} R(\hat{w}_j) = 1 \\ \alpha_j^w \le \beta_j^w \le \gamma_j^w \le \delta_j^w, \ j = 1, 2, ..n \\ \alpha_j^w \ge 0 \end{cases} \tag{12}$$

By solving the optimization problem shown in Eq. (12), the optimal fuzzy weights $\hat{W} = (w_1, w_2, \ldots, w_n)$ can be obtained. Consistency ratio (CR) is an important measure to find out the degree of consistency in a pairwise comparison. For a fully consistent comparison matrix $\hat{x}_{Bj} \times \hat{x}_{jW} = \hat{x}_{BW}$. The inconsistency arises in a fuzzy pairwise matrix only when the value of $\hat{x}_{Bj} \times \hat{x}_{jW} \ne \hat{x}_{BW}$. Extreme possible inconsistency occurs if $\hat{x}_{Bj}$ and $\hat{x}_{jW}$ both take the value $\hat{x}_{BW}$ and it results in the creation of $\hat{\phi}$. Considering extreme possible inconsistency, the equation $\hat{x}_{Bj} \times \hat{x}_{jW} = \hat{x}_{BW}$ can be transformed into the following equation.

$$(\hat{x}_{Bj} - \hat{\phi}) \times (\hat{x}_{jW} - \hat{\phi}) = (\hat{x}_{BW} + \hat{\phi}) \tag{13}$$

Since for extreme possible inconsistency ($\hat{x}_{Bj} = \hat{x}_{jW} = \hat{x}_{BW}$), the above equation can be rewritten as follows.

$$\hat{\phi}^2 - (1 + 2\hat{x}_{BW})\hat{\phi} + (\hat{x}_{BW}{}^2 - \hat{x}_{BW}) = 0 \tag{14}$$

where, $\hat{\phi} = (\alpha^{\phi}, \beta^{\phi}, \gamma^{\phi}, \delta^{\phi})$ is a TrFN $\hat{x}_{BW} = (\alpha_{BW}, \beta_{BW}, \gamma_{BW}, \delta_{BW})$

The maximum value of $\hat{x}_{BW}$ is $\left(8, \frac{17}{2}, 9, 9\right)$ where $\alpha_{BW} = 8$, $\beta_{BW} = \frac{17}{2}$, $\gamma_{BW} = 9$, $\delta_{BW} = 9$, which corresponds to the crisp rating 9. If we take the largest among $\alpha_{BW}, \beta_{BW}, \gamma_{BW}, \delta_{BW}$, then the consistency index for this TrFN is $13.77$. Similarly, if we compute the consistency index for the other linguistic values in terms of TrFN, then we obtain the CI for TrFBWM, as shown in Table 2. Here, if we use the upper boundary $x_{BW}$ to measure the consistency index, all object associated with TrFN that use this consistency index remain relevant and adaptable as the consistency index of $\hat{x}_{BW}$ is the largest in the interval. Thus, in the case of CI value, the maximum possible crisp value of $\hat{\phi}$ can be found in Table 2, which is the maximum root of the above quadratic equation.

## RESULT AND DISCUSSION

To demonstrate the application of TrFBWM, a real case of SWTP has been presented. Water treatment is a process of making water useable for specific purposes like drinking, irrigation, and industrial use. The treatment of water, which involves primary, secondary, and tertiary processes, removes the contaminants or reduces their concentration so that water becomes fit

**Table 2.** CI for TrFBWM.

| Trapezoidal fuzzy number | CI |
|---|---|
| $(1, 1, 1, 1)$ | 3 |
| $(2, \frac{5}{2}, \frac{7}{2}, 4)$ | 7.37 |
| $(4, \frac{9}{2}, \frac{11}{2}, 6)$ | 10 |
| $(6, \frac{13}{2}, \frac{15}{2}, 8)$ | 12.58 |
| $(8, \frac{17}{2}, \frac{19}{2}, 10)$ | 13.77 |

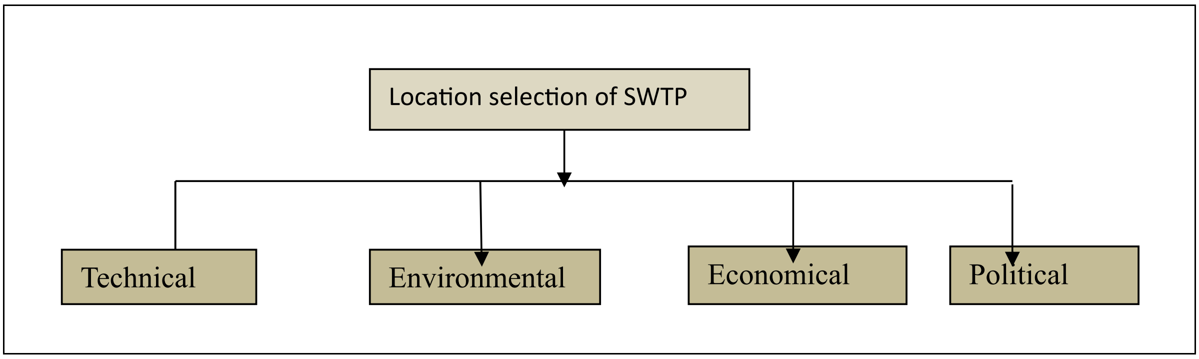

**Fig. 2.** The selected criteria

**Table 3.** The description of the selected criteria

| Criteria | Description |
|---|---|
| Technical (Pedreroa et al., 2011; Jajac, 2019) | Technical can relate to hardware and actually to any requirement or criteria that are related to technologies that are used. |
| Environmental (Wondim & Dzwairo, 2018; Arabani & Pirouz, 2016) | The criteria can be used to assess any potential environmental concerns that a treatment plant may face and how it is addressing those risks. |
| Economical (Wondim & Dzwairo, 2018; Jajac, 2019; Vasiloglou et al., 2009) | Any decision involving investments must first conduct an economic study. An investment in a project is dependent on its expected return from an economic standpoint; the more likely future profits are to increase, the more appealing the project becomes. |
| Political (Choudhury et al., 2019) | Political criteria can be defined as the stability of institutions guaranteeing democracy, the rule of law, human rights, and respect for and protection of minorities. |

for the intended use. Five locations in and around the peri-urban metropolitan city of Guwahati, India, situated on the banks of the Brahmaputra river, are considered alternative locations for the installation of SWTP. The Brahmaputra is a major Asian river, flowing through China, India, and Bangladesh. Along with much of its 2,900 km length, it plays a vital role in irrigation and transportation. The average depth of the river is 38 m with a maximum depth of 116 m. The combined suspended sediment load of this river system is about 1.84 billion tons per year

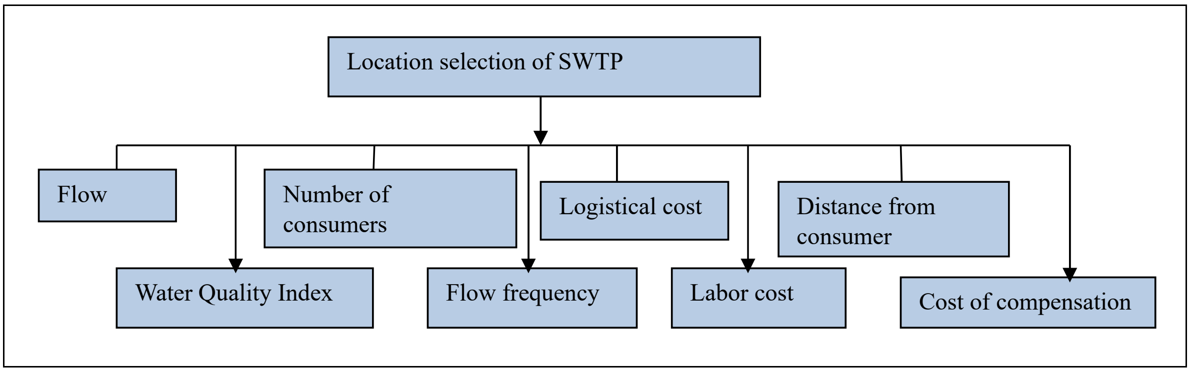


**Fig. 3.** Selected Sub-criteria.

**Table 4.** Description of sub-criteria for location selection of water treatment plant

| Sub-criteria | Description |
|---|---|
| Flow (Choudhury et al., 2019) | The amount of surface water that is available for collection and treatment. With an increase in water in the water sources, the place becomes more viable. |
| Water Quality Index (WQI) (Choudhury et al., 2019) | The weighted average of the importance and focus of the criteria. Their unidirectional weighing with that importance reveals the significance of this indicator. |
| Number of consumers (Choudhury et al., 2019) | The average water quality in the surface water sources that are accessible for treatment is flow frequency. |
| Flow frequency (Choudhury et al., 2018) | The SWTP can supply a large number of consumers, and the advantages of a location. grow as more users are found nearby. |
| Logistical cost (Wondim & Dzwairo, 2018) | Distance to the surrounding users. The less likely it is that an SWTP can be installed, the farther away the nearest consumers are. |
| Labor cost (Wondim & Dzwairo, 2018; Choudhury et al., 2020) | Cost of logistical expenditures. The feasibility of a site is inversely correlated with the price of land. |
| Distance from the consumer (Vasiloglou et al., 2009; Arabani & Pirouz, 2016) | The expense of repairing environmental harm and compensating displaced populations. |
| Cost of compensation (Arabani & Pirouz, 2016) | Investment is required to hire professional and unskilled workers for the installation or relocation of a new SWTP. |

which is the highest in the world (Choudhury et al., 2019). Among the five alternative locations considered, only three locations, namely Dhubri, Goalpara, and Guwahati, have SWTP installed. Based on the administrative importance, IIT Guwahati and Mangaldoi have also been added to this study.

The relevant decision criteria and sub-criteria have been selected through the review of appropriate literature, government reports and associated records, and the opinion of experts (Choudhury et al., 2019). The selected criteria are given in the figure below.

There are some sub-criteria also, which were selected based on the criteria by Choudhury et al. (2019). These are illustrated in Table 4.

Following the choice of a set of criteria and sub-criteria, a group of domain experts was called for a focus group. The team consisted of ten technologists and scientists working in the area of SWTP. Each one of them had at least 10 years of experience in the domain of surface water treatment. The experts were first asked to identify the most important (best) and least important (worst) decision criteria. Subsequently, they were asked to give linguistic ratings by comparing the best (and the worst) criterion to each of the remaining criteria. In case of divergence of opinion, a consensus was reached through lengthy discussions. The best and worst criteria were $\hat{w}_B = (\alpha_1^w, \beta_1^w, \gamma_1^w, \delta_1^w)$ and $\hat{w}_w = (\alpha_4^w, \beta_4^w, \gamma_4^w, \delta_4^w)$, respectively.

The fuzzy Best-to-Others vector $\hat{x}_{BJ} = \left[(1,1,1,1),\left(6,\frac{13}{2},\frac{15}{2},8\right),\left(4,\frac{9}{2},\frac{11}{2},6\right),\left(8,\frac{17}{2},9,9\right)\right]$ and the fuzzy Others-to-Worst vector $\hat{x}_{JW} = \left[\left(8,\frac{17}{2},9,9\right),\left(2,\frac{5}{2},\frac{7}{2},4\right),\left(4,\frac{9}{2},\frac{11}{2},6\right),(1,1,1,1)\right]$. The optimization problem formulated to elicit the fuzzy weight of criteria is given below:

$$\min \hat{\phi}$$

$$\text{Subject to} \begin{cases} \left|\frac{(\alpha_1^w,\beta_1^w,\gamma_1^w,\delta_1^w)}{(\alpha_1^w,\beta_1^w,\gamma_1^w,\delta_1^w)} - (\alpha_{11},\beta_{11},\gamma_{11},\delta_{11})\right| \le (\lambda^*,\lambda^*,\lambda^*,\lambda^*) \\ \left|\frac{(\alpha_1^w,\beta_1^w,\gamma_1^w,\delta_1^w)}{(\alpha_2^w,\beta_2^w,\gamma_2^w,\delta_2^w)} - (\alpha_{12},\beta_{12},\gamma_{12},\delta_{12})\right| \le (\lambda^*,\lambda^*,\lambda^*,\lambda^*) \\ \left|\frac{(\alpha_1^w,\beta_1^w,\gamma_1^w,\delta_1^w)}{(\alpha_3^w,\beta_3^w,\gamma_3^w,\delta_3^w)} - (\alpha_{13},\beta_{13},\gamma_{13},\delta_{13})\right| \le (\lambda^*,\lambda^*,\lambda^*,\lambda^*) \\ \left|\frac{(\alpha_1^w,\beta_1^w,\gamma_1^w,\delta_1^w)}{(\alpha_4^w,\beta_4^w,\gamma_4^w,\delta_4^w)} - (\alpha_{14},\beta_{14},\gamma_{14},\delta_{14})\right| \le (\lambda^*,\lambda^*,\lambda^*,\lambda^*) \\ \left|\frac{(\alpha_1^w,\beta_1^w,\gamma_1^w,\delta_1^w)}{(\alpha_4^w,\beta_4^w,\gamma_4^w,\delta_4^w)} - (\alpha_{14},\beta_{14},\gamma_{14},\delta_{14})\right| \le (\lambda^*,\lambda^*,\lambda^*,\lambda^*) \\ \left|\frac{(\alpha_2^w,\beta_2^w,\gamma_2^w,\delta_2^w)}{(\alpha_4^w,\beta_4^w,\gamma_4^w,\delta_4^w)} - (\alpha_{24},\beta_{24},\gamma_{24},\delta_{24})\right| \le (\lambda^*,\lambda^*,\lambda^*,\lambda^*) \\ \left|\frac{(\alpha_3^w,\beta_3^w,\gamma_3^w,\delta_4^w)}{(\alpha_4^w,\beta_4^w,\gamma_4^w,\delta_4^w)} - (\alpha_{34},\beta_{34},\gamma_{34},\delta_{34})\right| \le (\lambda^*,\lambda^*,\lambda^*,\lambda^*) \\ \left|\frac{(\alpha_4^w,\beta_4^w,\gamma_4^w,\delta_4^w)}{(\alpha_4^w,\beta_4^w,\gamma_4^w,\delta_4^w)} - (\alpha_{44},\beta_{44},\gamma_{44},\delta_{44})\right| \le (\lambda^*,\lambda^*,\lambda^*,\lambda^*) \\ \frac{1}{6}\alpha_1^w + \frac{2}{6}\beta_1^w + \frac{2}{6}\gamma_1^w + \frac{1}{6}\delta_1^w + \frac{1}{6}\alpha_2^w + \frac{2}{6}\beta_2^w + \frac{2}{6}\gamma_2^w \\ \quad + \frac{1}{6}\delta_2^w + \frac{1}{6}\alpha_3^w + \frac{2}{6}\beta_3^w + \frac{2}{6}\gamma_3^w + \frac{1}{6}\delta_3^w + \\ \quad + \frac{1}{6}\alpha_4^w + \frac{2}{6}\beta_4^w + \frac{2}{6}\gamma_4^w + \frac{1}{6}\delta_4^w = 1 \\ \alpha_j^w \le \beta_j^w \le \gamma_j^w \le \delta_j^w,\ j = 1,2,3,4 \\ \alpha_j^w \ge 0 \\ \lambda \ge 0 \end{cases} \quad (15)$$

The aforesaid problem was converted to a nonlinearly constrained optimization problem as follows:

$$\min \lambda^*$$

$$\textbf{Subject to} \begin{cases} \alpha_1 - 8\delta_2 \le \lambda\delta_2;\ \alpha_1 - 8\delta_2 \ge -\lambda\delta_2 \\ \beta_1 - \frac{15}{2}\delta_2 \le \lambda\delta_2;\ \beta_1 - \frac{15}{2}\delta_2 \ge -\lambda\delta_2 \\ \gamma_1 - \frac{13}{2}\beta_2 \le \lambda\beta_2;\ \gamma_1 - \frac{13}{2}\beta_2 \ge -\lambda\beta_2 \\ \delta_1 - 6\alpha_2 \le \lambda\alpha_2;\ \delta_1 - 6\alpha_2 \ge -\lambda\alpha_2 \\ \alpha_1 - 6\delta_3 \le \lambda\delta_3;\ \alpha_1 - 6\delta_3 \ge -\lambda\delta_3 \\ \beta_1 - \frac{11}{2}\gamma_3 \le \lambda\gamma_3;\ \beta_1 - \frac{11}{2}\gamma_3 \ge -\lambda\gamma_3 \\ \gamma_1 - \frac{9}{2}\beta_3 \le \lambda\beta_3;\ \gamma_1 - \frac{9}{2}\beta_3 \ge -\lambda\beta_3 \\ \delta_1 - 4\alpha_3 \le \lambda\alpha_3;\ \delta_1 - 4\alpha_3 \ge -\lambda\alpha_3 \\ \alpha_1 - 9\delta_4 \le \lambda\delta_4;\ \alpha_1 - 9\delta_4 \ge -\lambda\delta_4 \\ \beta_1 - 9\gamma_4 \le \lambda\gamma_4;\ \beta_1 - 9\gamma_4 \ge -\lambda\gamma_4 \\ \gamma_1 - \frac{17}{2}\beta_4 \le \lambda\beta_4;\ \gamma_1 - \frac{17}{2}\beta_4 \ge -\lambda\beta_4 \\ \delta_1 - 8\alpha_4 \le \lambda\alpha_4;\ \delta_1 - 8\alpha_4 \ge -\lambda\alpha_4 \\ \alpha_2 - 4\delta_4 \le \lambda\delta_4;\ \alpha_2 - 4\delta_4 \ge -\lambda\delta_4 \\ \beta_2 - \frac{7}{2}\gamma_4 \le \lambda\gamma_4;\ \beta_2 - \frac{7}{2}\gamma_4 \ge -\lambda\gamma_4 \\ \gamma_2 - \frac{5}{2}\beta_4 \le \lambda\beta_4;\ \gamma_1 - \frac{5}{2}\beta_4 \ge -\lambda\beta_4 \\ \delta_2 - 2\alpha_4 \le \lambda\alpha_4;\ \delta_2 - 2\alpha_4 \ge -\lambda\alpha_4 \\ \alpha_3 - 6\delta_4 \le \lambda\delta_4;\ \alpha_3 - 6\delta_4 \ge -\lambda\delta_4 \\ \beta_3 - \frac{11}{2}\gamma_4 \le \lambda\gamma_4;\ \beta_3 - \frac{11}{2}\gamma_4 \ge -\lambda\gamma_4 \\ \gamma_3 - \frac{9}{2}\beta_4 \le \lambda\beta_4;\ \gamma_3 - \frac{9}{2}\beta_4 \ge -\lambda\beta_4 \\ \delta_3 - 4\alpha_4 \le \lambda\alpha_4;\ \delta_3 - 4\alpha_4 \ge -\lambda\alpha_4 \\ \frac{1}{6}\alpha_1 + \frac{2}{6}\beta_1 + \frac{2}{6}\gamma_1 + \frac{1}{6}\delta_1 + \frac{1}{6}\alpha_2 + \frac{2}{6}\beta_2 + \frac{2}{6}\gamma_2 + \frac{1}{6}\delta_2 + \frac{1}{6}\alpha_3 + \frac{2}{6}\beta_3 + \frac{2}{6}\gamma_3 + \frac{1}{6}\delta_3 + \frac{1}{6}\alpha_4 + \frac{2}{6}\beta_4 + \frac{2}{6}\gamma_4 + \frac{1}{6}\delta_4 = 1 \\ \alpha_j \le \beta_j \le \gamma_j \le \delta_j,\ j = 1,2\ 3,4 \\ \alpha_j \ge 0,\ j = 1,2\ 3,4 \\ \lambda \ge 0 \end{cases} \quad \textbf{(16)}$$

By solving the optimization problem given in Eq. 16, the optimal fuzzy weights of the four criteria were determined.

$$\hat{w}_1 = (\alpha_1, \beta_1, \gamma_1, \delta_1) = (0.6541, 0.6541, 0.6541, 0.6541),$$

$$\hat{w}_2 = (\alpha_2, \beta_2, \gamma_2, \delta_2) = (0.0778, 0.0778, 0.0778, 0.1219),$$

$$\widehat{w}_3 = (\alpha_3, \beta_3, \gamma_3, \delta_3) = (0.1997, 0.1997, 0.1997, 0.1997),$$

$$\hat{w}_4 = (\alpha_4, \beta_4, \gamma_4, \delta_4) = (0.061, 0.061, 0.061, 0.061),$$

$$\lambda^* = (2.7250, 2.7250, 2.7250, 2.7250).$$

Then by Eq. (8), the crisp weights of the four criteria were determined. The results are shown in Table 4. The technical criterion is having the maximum weight (0.6541), and the consistency index for this criterion is 13.77. Therefore the CR for this criterion is $\frac{2.7250}{13.77} = 0.1979.$ Similarly, the weights of the selected sub-criteria were determined, as shown in Table 5. The decision matrix and final priority scores of five locations are given in Table 6. Dhubri got the highest priority

**Table 4.** Weighs of decision criteria

| Criteria | Weight |
|---|---|
| Technical | 0.654 |
| Environmental | 0.084 |
| Economical | 0.200 |
| Political | 0.062 |

**Table 5.** Weighs of sub-criteria

| Sub-criteria | Weight | Rank |
|---|---|---|
| Flow | 0.188 | 2 |
| Water Quality Index (WQI) | 0.302 | 1 |
| Number of consumers | 0.096 | 5 |
| Flow frequency | 0.065 | 6 |
| Logistical cost | 0.034 | 7 |
| Labor cost | 0.157 | 3 |
| Distance from consumer | 0.031 | 8 |
| Cost of compensation | 0.127 | 4 |

**Table 6.** Decision matrix and priority scores of alternative locations

| Location | Flow | Water Quality Index (WQI) | Number of consumers | Flow frequency | Logistical cost | Labor cost | Distance from consumer | Cost of compensation | Priority score |
|---|---|---|---|---|---|---|---|---|---|
| Dhubri | 0.089 | 0.143 | 0.022 | 0.031 | 0.003 | 0.074 | 0.007 | 0.067 | 0.436 |
| Goalpara | 0.049 | 0.079 | 0.015 | 0.010 | 0.009 | 0.041 | 0.007 | 0.037 | 0.249 |
| Guwahati | 0.030 | 0.048 | 0.015 | 0.017 | 0.007 | 0.025 | 0.008 | 0.007 | 0.158 |
| IIT Guwahati | 0.010 | 0.016 | 0.028 | 0.003 | 0.009 | 0.008 | 0.003 | 0.007 | 0.085 |
| Mangaldoi | 0.010 | 0.016 | 0.015 | 0.003 | 0.005 | 0.008 | 0.007 | 0.007 | 0.072 |

**Table 7.** Comparison of different MCDM methods

| Different methods | | Ranking orders of alternatives |
|---|---|---|
| 1. | TrFWASPAS | $A_1 > A_2 > A_3 > A_4 > A_5$ |
| 2. | TrFAHP | $A_1 > A_3 > A_2 > A_4 > A_5$ |
| 3. | AHP | $A_1 > A_3 > A_2 > A_4 > A_5$ |
| 4. | LOPCOW | $A_1 > A_2 > A_3 > A_4 > A_5$ |
| 5. | SAHP | $A_1 > A_2 > A_3 > A_4 > A_5$ |
| 6. | TrFBWM | $A_1 > A_2 > A_3 > A_4 > A_5$ |

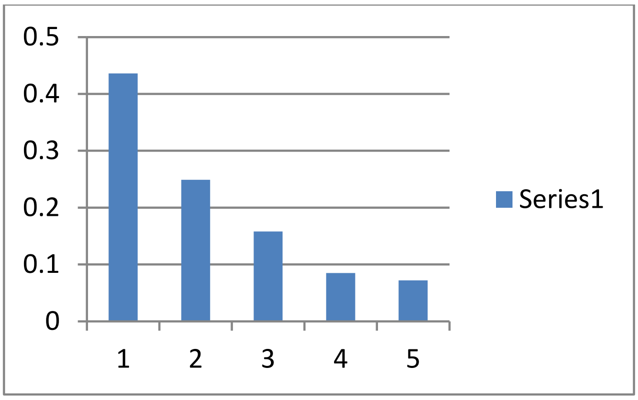


**Fig. 4.** Ranking of the alternatives obtained from TrFBWM

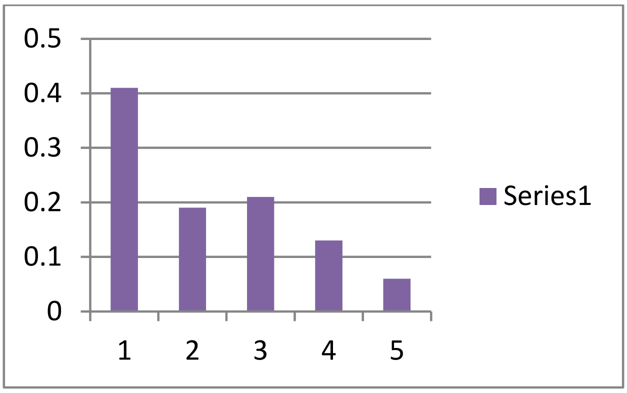


**Fig. 5.** Ranking of the alternatives obtained from TrFAHP

score followed by Goalpara and Guwahati. To analyze the robustness of the decision, sensitivity analysis was conducted by varying the weights of the two most important criteria (water quality index and flow) in steps. It was found that the change of weights between -20% to +20% while adjusting the weights of remaining sub-criteria so that the overall weight remains 1, did not change the ranking of alternatives. This implies that the obtained ranking of alternatives is not susceptible to change due to any reasonable change in the weights of sub-criteria.

To check whether the result is consistent or not, some different methods such as Trapezoidal fuzzy WASPAS, Logarithmic Percentage Change-driven Objective Weighting (LOPCOW), AHP, and Trapezoidal Fuzzy AHP have been applied in the same case study. Also, we have compared the result with the method of Sinosoidal AHP (SAHP) introduced by Choudhury et al. (2019). Table 7 compares the rankings generated by Trapezoidal Fuzzy BWM to those

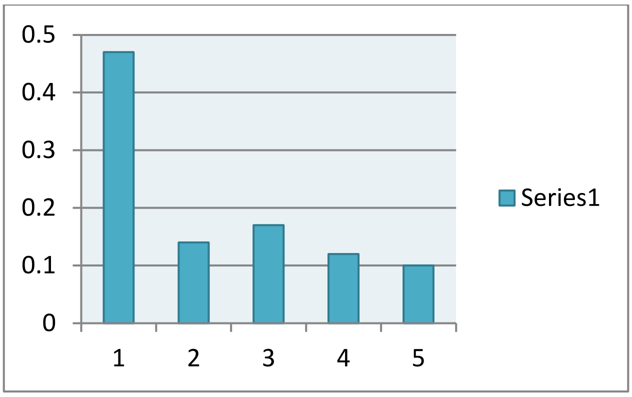


**Fig.6.** Ranking of the alternatives obtained from AHP

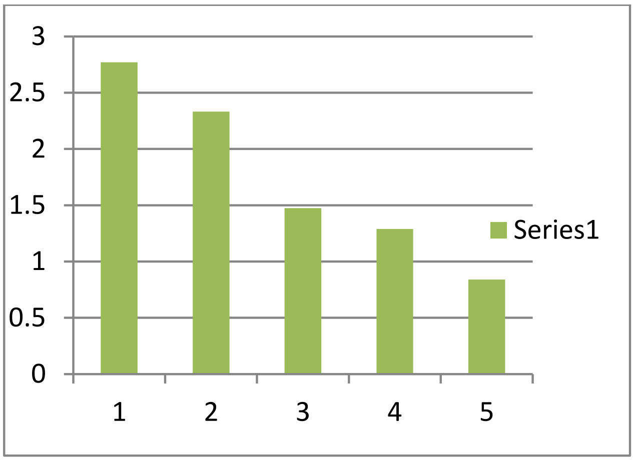


**Fig. 7.** Ranking of the alternatives obtained from LOPCOW

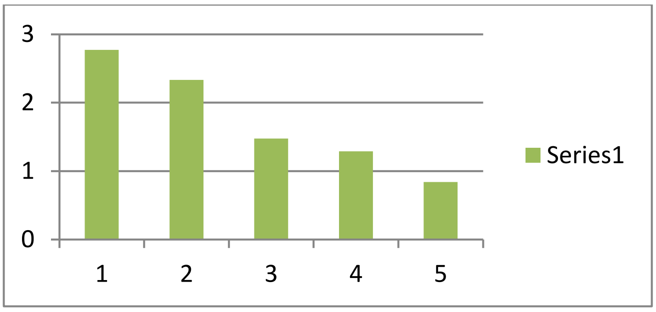


**Fig. 8.** Ranking of the alternatives obtained from LOPCOW

**Table 8.** Sensitivity analysis result

| Sl. No | Variation in weights of criteria | Ranking of alternatives |
|---|---|---|
| Case 1 | Weights obtained through TrFBWM | $A_1 > A_2 > A_3 > A_4 > A_5$ |
| Case 2 | Assigning equal weights to each criterion | $A_1 > A_2 > A_3 > A_4 > A_5$ |
| Case 3 | 50 % weights assigned to beneficial criteria | $A_1 > A_2 > A_3 > A_4 > A_5$ |
| Case 4 | 70 % weights assigned to beneficial criteria | $A_1 > A_2 > A_3 > A_4 > A_5$ |
| Case 5 | 80 % weights assigned to beneficial criteria | $A_1 > A_2 > A_3 > A_4 > A_5$ |

generated by the other MCDM approaches.

From the comparison, it is clear that the three methods namely TrFWASPAS, LOPCOW, SAHP have the same ranking as the method applied in this study. It has been noticed that, in all five cases, the best alternative is sam which is Dhubri as the optimal location for installation of SWTP. In TrFAHP and AHP the ranking of the second and third alternative has changed but the best and the worst alternative is similar. The results of the various methods are depicted below:

When MCDM is implemented, it frequently encounters issues that affect the decision-making process, resulting in erroneous and unstable results in the final ranking method. As a result, doing a proper sensitivity analysis can be beneficial in determining the initial input factors or parameters that may affect the accuracy of the tested model's ultimate output performance. Furthermore, by examining the decision-making model's applicability in the targeted field, in our case, material selection, this analysis can assess the model's major goal. Researchers have studied the end outcomes ranking behavior under various settings, which is a popular strategy. This can be accomplished by specifying the most critical input and adjusting its values slightly to see how sensitive the model is to these modest changes. Furthermore, the goal of constructing and applying the tested decision-making process has a significant impact on the measurement of the model outputs' robustness and stability. As a result, before analyzing the offered approaches, it is necessary to first specify the relevant parameters that may influence the outcome performance.

## CONCLUSIONS

In this study, the BWM is extended to the trapezoidal fuzzy environment, and a trapezoidal fuzzy best-worst method (TrBWM) is proposed which combines the BWM method of MCDM and fuzzy numbers. The use of trapezoidal fuzzy numbers (TrFN) in BWM makes the decision-making framework more tolerant and optimistic. Also, the proposed technique is applied to solve the location selection problem for the SWTP. A case study is presented at the bank of the Brahmaputra river in Assam. The weights of four decision criteria and eight sub-criteria are determined by solving the optimization problem, which is developed based on the primary pairwise comparisons performed by a group of domain experts. Five potential locations were taken as alternatives out of which three locations already had SWTP installed. The results of TrBWMare compared with the sinusoidal AHP method. It is found that the results of the two methods are in reasonable agreement. The results are also validated by the fact that the locations where SWTP is already installed have received higher priority scores compared to the locations where SWTP is not installed.

The study can be extended by incorporating trapezoidal fuzzy numbers with other MCDMs, such as FUCOM, WASPAS, OPA, etc. The proposed method can further be modified by incorporating different extensions of fuzzy sets like type 2 fuzzy set, intuitionistic fuzzy set, spherical fuzzy set, hesitant fuzzy set, etc. Moreover, the proposed TrBWM can also be used to find a suitable location for the installation of any kind of facilities such as power plants, bus or railway stations, shopping malls, etc.

## GRANT SUPPORT DETAILS

The present research did not receive any financial support.

## CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

## LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

## DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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