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Landscape Design Quality Evaluation of Abandoned Coal Mine Sites Using Single-Valued Triangular Neutrosophic Numbers

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Abstract: This research uses Single-Valued Triangular Neutrosophic Numbers (SVTNNs) to address uncertainty and vague problems in the Abandoned Coal Mine Sites evaluation. By adjusting the subjective assessments, Single-Valued Triangular Neutrosophic Numbers handle degrees of affiliation and disassociation as well as additional unclear degrees of neutral opinion. The WENSLO approach is used to compute criteria weights. To develop a hybrid model that handles ambiguity more adaptable, this study combines the WENSLO method with the Single-Valued Triangular Neutrosophic Numbers-based REGIME strategy. In conclusion, we used these methods to confirm the precision of the calculations made using the suggested approach. The fundamental idea behind the REGIME technique is to use a preference function to capture the degree of dominance and rank alternatives by evaluating their pairwise performance across several criteria. Combining qualitative and quantitative data eliminates the need for preset weights and preserves consistency in the way decisions are made. For simplicity of comprehension, a flowchart is provided to show the Single-Valued Triangular Neutrosophic Numbers WENSLO-REGIME approach. The Single-Valued Triangular Neutrosophic Numbers WENSLO-REGIME approach is used to solve a thorough case study and identify the optimal alternative to evaluate the effectiveness of the proposed method. Analysis of sensitivity is carried out.

Keywords: Single-Valued Triangular Neutrosophic Numbers; Abandoned Coal Mine Sites; WENSLO Method; REGIME Method.

1. Introduction

A country may benefit economically from coal extraction. However, if safeguards are not taken, it could cause significant environmental harm. Degradation of the land, topographical changes, pollution of the soil and water, and ecological decline can all result from mining operations. Another environmental issue associated with coal mining is acid mine drainage, which can cause soil and water bodies to become more acidic[1], [2]. Acidification would accelerate the breakdown of hazardous metals from open pits, waste rock heaps, and water-permeable tailings. Ecosystems in the soil and water will be affected in exchange. Abandoned mining sites may also be linked to these issues[3], [4]. For years, these locations have kept contaminating the land and water.

For instance, Navarro et al. demonstrate that metals released downstream and downslope from tailings by surface runoff continue to contaminate the environment at an abandoned mining site in Cabezo Rajao, Spain[5], [6].

Contaminants from coal mining operations can travel great distances. The primary transport mechanisms are mechanical dispersion brought on by wind action and surface runoff. Transport is further improved by enhanced acidification-induced breakdown of hazardous metals[7], [8]. The significance of streams and surface runoff channels in the movement of pollutants from coal mining sites has been demonstrated in a small number of case studies. For example, the Handlova–Cigel brown coal district's freely flowing water carried a lot of harmful substances into surface streams, which subsequently poisoned a larger area. In 1980, the Ohio River in Pittsburgh received 1.2 million tons of sulfate from the Allegheny River and 1.35 million tons from the Monongahela River. Sams and Beer demonstrated that the trends in coal production rates in sub-basins that contribute to pollution transport are consistent with the trends in pollutant concentrations over time[9], [10]. This study evaluates the Abandoned Coal Mine Sites by using a set of criteria.

Traditional MCDM models need precise data, which might not always be available in practical settings. However, data are often complex, imprecise, and unstable, making it impossible to measure them precisely. The theory of fuzzy sets (FSs) was first put forth by Zadeh in opposition to specific logic. Numerous researchers investigated this subject after this study; specifics of various methods are visible. Additionally, several scholars put out certain MCDM models in a fuzzy context.

But Zadeh's fuzzy sets only consider the membership function; they are unable to handle other vague characteristics. Atanassov developed intuitionistic fuzzy sets (IFSs), an extension of FSs, to address this knowledge gap. Additionally, several MCDM models use intuitionistic fuzzy data[11], [12].

While incomplete information for a variety of real-world problems can be handled by the theory of IFSs, it is unable to manage all forms of uncertainty, including inconsistent and ambiguous data. Smarandache therefore developed the neutrosophic set (NS) as a strong generic framework that extends classical and various fuzzy sets (FSs and IFSs)[13], [14].

When the indeterminacy is quantified, NSs can handle contradictory, ambiguous, and indeterminate information. They can also separately create three types of membership functions. A variety of NSs have been introduced in recent years, including interval neutrosophic sets, bipolar neutrosophic sets, single-valued neutrosophic sets, and neutrosophic linguistic sets[15], [16]. Furthermore, logic, measure, probability, statistics, pre-calculus, calculus, and their applications in various fields have been expanded in the field of neutrosophic sets.

2. Basic Definitions

The neutrosophic set, as defined by Smarandache, is distinguished by its truth-membership function, indeterminacy-membership function, and falsity membership function. From a philosophical perspective, the idea of a neutrosophic set was developed to convey ambiguous and inconsistent data[17], [18]. The following is a definition of a neutrophilic set:

Definition 1

Let the $a = \left((a,b,c); T_a\ , I_a, F_a\right)$ and their membership functions can be computed such as:

$$T_a(x) = \begin{cases} \frac{(x-a)T_a}{b-a}, & a \le x \le b \\ \frac{(c-x)T_a}{c-b}, & b \le x \le c \\ 0 & otherwise \end{cases} \tag{1}$$

$$I_a(x) = \begin{cases} \frac{(b-x+I_a\,(x-a)\,)}{b-a}, & a \le x \le b \\ \frac{(x-b+I_a(c-x))}{c-b}, & b \le x \le c \\ 0 & otherwise \end{cases} \tag{2}$$

$$F_a(x) = \begin{cases} \frac{(b-x+F_a\,(x-a)\,)}{b-a}, & a \le x \le b \\ \frac{(x-b+F_a(c-x))}{c-b}, & b \le x \le c \\ 0 & otherwise \end{cases} \tag{3}$$

Let two single valued triangular neutrosophic numbers (SVTNNs) such as:

$$a_1 = \left((a_1, b_1, c_1); T_{a_1}(x)\ , I_{a_1}(x), F_{a_1}(x)\right)$$

$$a_2 = \left((a_2, b_2, c_2); T_{a_2}(x)\ , I_{a_2}(x), F_{a_2}(x)\right)$$

$$a_1a_2 = \begin{pmatrix} \begin{pmatrix} (a_1a_2, b_1b_2, c_1c_2); \min\{T_{a_1}(x), T_{a_2}(x)\}, \\ \max\{I_{a_1}(x), I_{a_2}(x)\}, \max\{F_{a_1}(x), F_{a_2}(x)\} \\ ,\ (c_1 > 0, c_2 > 0) \end{pmatrix} \\ \begin{pmatrix} (a_1c_2, b_1b_2, c_1a_2); \min\{T_{a_1}(x), T_{a_2}(x)\} \\ , \max\{I_{a_1}(x), I_{a_2}(x)\}, \max\{F_{a_1}(x), F_{a_2}(x)\} \\ ,\ (c_1 < 0, c_2 > 0) \end{pmatrix}, \\ \begin{pmatrix} (c_1c_2, b_1b_2, a_1a_2); \min\{T_{a_1}(x), T_{a_2}(x)\}, \\ \max\{I_{a_1}(x), I_{a_2}(x)\}, \max\{F_{a_1}(x), F_{a_2}(x)\} \\ ,\ (c_1 < 0, c_2 < 0) \end{pmatrix} \end{pmatrix} \tag{4}$$

$$a_1 + a_2 = \begin{pmatrix} (a_1 + a_2, b_1 + b_1. c_1 + c_1); \min\{T_{a_1}(x), T_{a_2}(x)\}; \\ \max\{i_{a_1}(x), I_{a_2}(x)\}; \\ \max\{F_{a_1}(x), F_{a_2}(x)\} \end{pmatrix} \tag{5}$$

$$\varphi a_1 = \left((\varphi a_1, \varphi b_1, \varphi c_1); T_{a_1}(x), I_{a_1}(x), F_{a_1}(x)\right) \tag{6}$$

Create the decision matrix.
Normalize the decision matrix.
Compute the ultimate ranking of alternatives.
Compute the criterion slope.
Compute the criterion envelope.
Compute the envelope-slope ratio.
Compute the criteria weights.

- The WENSLO method for determining the weighting coefficients of the criteria

Start with a combined decision matrix.
Compute the superiority index.
Compute the superiority identifier.
Build the impact matrix.
Build the REGIME matrix between the alternatives.
Compute the guide index.
Rank the alternatives.

- Extended REGIME method utilizing single valued triangular neutrosophic numbers

Fig 1. The MCDM steps.

3. MCDM Approach

This section shows the steps of the proposed approach. Fig 1 shows the steps of the proposed approach.

The WENSLO method for determining the weighting coefficients of the criteria.

It is advised that criteria weights be determined using the methods suggested in this study. For this reason, Pamucar et al. have developed a novel technique that falls under the domain of objective weighing methods and is called WENSLO (Weights by ENvelope and SLOpe). The technique depends on each criterion's envelope-to-slope ratio[19]. The computation process is simple and easy to comprehend. When the slope value is low and the envelope value is large, a criterion is given a higher weight[19]. The basic phases of the WENSLO technique for determining criteria weight are described in the next section.

Step 1. Create the decision matrix

$$[x_{ij}]_{m\times n} = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \tag{7}$$

Step 2. Normalize the decision matrix

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{8}$$

Step 3. Compute the ultimate ranking of alternatives

$$z_j = \frac{\max\limits_{1<i\leq m} r_{ij} - \min\limits_{1<i\leq m} r_{ij}}{1+3.322\times\log(m)} \tag{9}$$

Step 4. Compute the criterion slope

$$q_j = \frac{\sum_{i=1}^{m} r_{ij}}{(m-1)\times z_j} \tag{10}$$

Step 5. Compute the criterion envelope.

$$N_j = \sum_{i=1}^{m-1} \sqrt{\left(r_{i+1j} - z_{ij}\right)^2 + z_j^2} \tag{11}$$

Step 6. Compute the envelope-slope ratio

$$s_j = \frac{N_j}{q_j} \tag{12}$$

Step 7. Compute the criteria weights.

$$w_j = \frac{s_j}{\sum_{i=1}^{n} s_j} \tag{13}$$

Extended REGIME method utilizing single valued triangular neutrosophic numbers[20]

Step 1. Start with a combined decision matrix.

Step 2. Compute the superiority index E_{fl}.

Step 3. Compute the superiority identifier.

$$E_{fl} = \sum_{j\in E_{fl}} w_j \tag{14}$$

Step 4. Build the impact matrix.

Step 5. Build the REGIME matrix between the alternatives.

$$E_{fl,j} = \begin{cases} -1 & if\ a_{fj} < a_{lj} \\ 0 & if\ a_{fj} = a_{lj} \\ +1 & if\ a_{fj} > a_{lj} \end{cases} \tag{15}$$

Step 6. Compute the guide index.

$$E_{fl} = \sum_{j=1}^{n} E_{fl}\, w_j \tag{16}$$

Step 7. Rank the alternatives.

4. An application

This section shows the outcomes of the proposed approach to computing the criteria weights and rank the alternatives. Six criteria and ten alternatives are used in this study as shown in Fig 2. These criteria and alternatives are evaluated using three experts and decision-makers who have experience in MCDM issues.

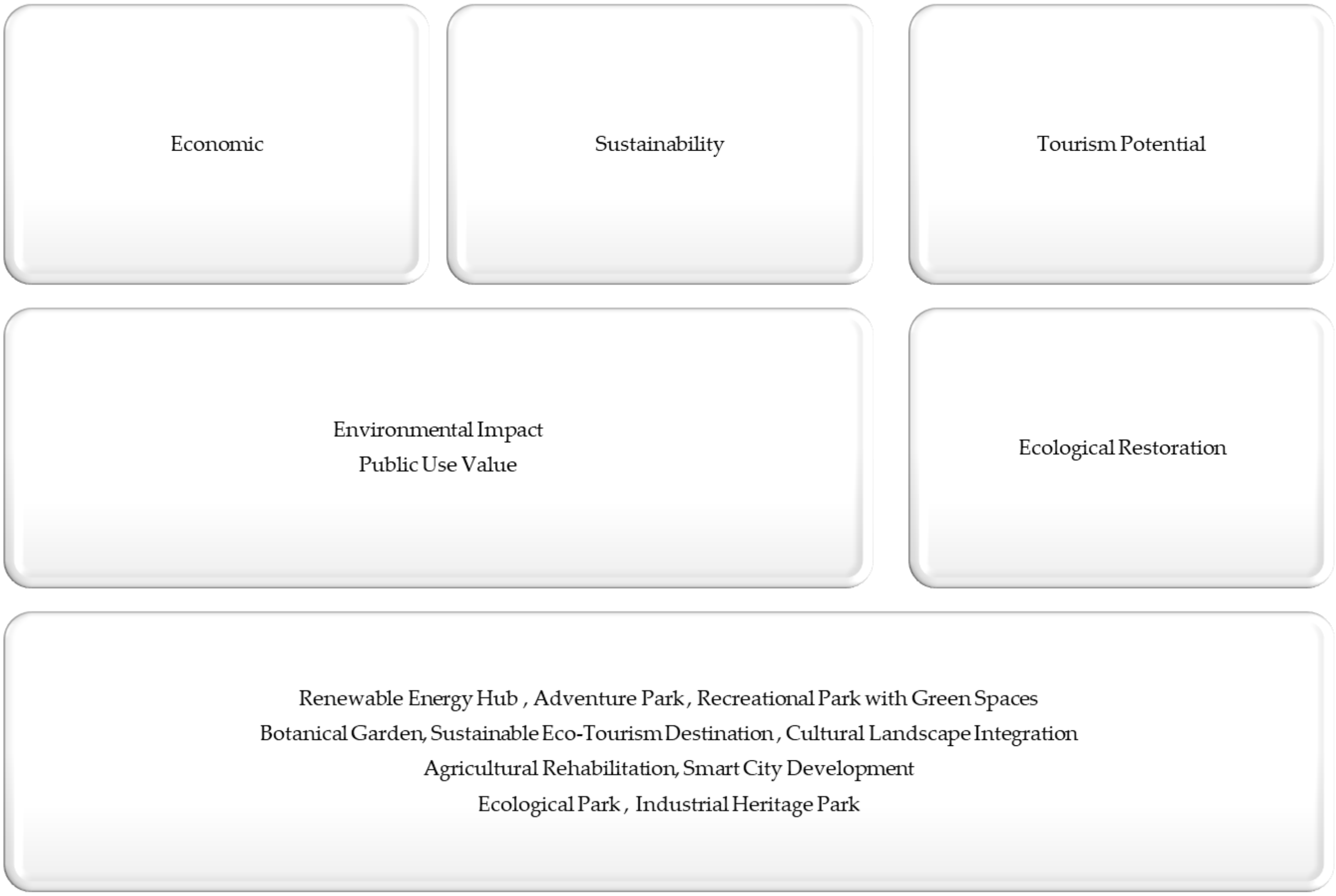


Fig 2. The criteria of Abandoned Coal Mine Sites.

The results of the WENSLO method.

Step 1. Eq. (7) is used to create the decision matrix. We use the neutrosophic numbers to evaluate the decision matrix as shown in Table 1.

Step 2. Eq. (8) is used to normalize the decision matrix as shown in Table 2.

Step 3. Eq. (9) is used to Compute the ultimate ranking of alternatives.

Step 4. Eq. (10) is used to Compute the criterion slope.

Step 5. Eq. (11) is used to compute the criterion envelope.

Step 6. Eq. (12) is used to compute the envelope-slope ratio.

Step 7. Eq. (13) is used to compute the criteria weights as shown in fig 3.

Table 1. The SVTNNs matrix.

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)	((4.4,5.9,7.2);0.7,0.2,0.3)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)
A_2	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.4,5.9,7.2);0.7,0.2,0.3)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)
A_3	((5.8,6.9,8.5);0.6,0.2,0.3)	((7.1,7.7,8.3);0.5,0.2,0.4)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)	((6.2,8.9,9.1);0.6,0.3,0.5)	((7.1,7.7,8.3);0.5,0.2,0.4)
A_4	((4.4,5.9,7.2);0.7,0.2,0.3)	((6.2,8.9,9.1);0.6,0.3,0.5)	((4.4,5.9,7.2);0.7,0.2,0.3)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)
A_5	((7.1,7.7,8.3);0.5,0.2,0.4)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)	((4.4,5.9,7.2);0.7,0.2,0.3)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)
A_6	((6.2,8.9,9.1);0.6,0.3,0.5)	((4.4,5.9,7.2);0.7,0.2,0.3)	((6.2,8.9,9.1);0.6,0.3,0.5)	((7.1,7.7,8.3);0.5,0.2,0.4)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)
A_7	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((7.1,7.7,8.3);0.5,0.2,0.4)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)	((6.2,8.9,9.1);0.6,0.3,0.5)	((7.1,7.7,8.3);0.5,0.2,0.4)
A_8	((4.6,5.5,8.6);0.4,0.7,0.2)	((6.2,8.9,9.1);0.6,0.3,0.5)	((5.8,6.9,8.5);0.6,0.2,0.3)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)
A_9	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.4,5.9,7.2);0.7,0.2,0.3)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)
A_{10}	((5.8,6.9,8.5);0.6,0.2,0.3)	((4.4,5.9,7.2);0.7,0.2,0.3)	((7.1,7.7,8.3);0.5,0.2,0.4)	((6.2,8.9,9.1);0.6,0.3,0.5)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.6,5.5,8.6);0.4,0.7,0.2)
	C_1	C_2	C_3	C_4	C_5	C_6
A_1	((4.6,5.5,8.6);0.4,0.7,0.2)	((6.2,8.9,9.1);0.6,0.3,0.5)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)	((4.6,5.5,8.6);0.4,0.7,0.2)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)
A_2	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.6,5.5,8.6);0.4,0.7,0.2)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)
A_3	((6.2,8.9,9.1);0.6,0.3,0.5)	((4.6,5.5,8.6);0.4,0.7,0.2)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)	((5.8,6.9,8.5);0.6,0.2,0.3)	((4.6,5.5,8.6);0.4,0.7,0.2)
A_4	((7.1,7.7,8.3);0.5,0.2,0.4)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.6,5.5,8.6);0.4,0.7,0.2)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)
A_5	((4.4,5.9,7.2);0.7,0.2,0.3)	((4.6,5.5,8.6);0.4,0.7,0.2)	((4.4,5.9,7.2);0.7,0.2,0.3)	((4.6,5.5,8.6);0.4,0.7,0.2)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)
A_6	((6.2,8.9,9.1);0.6,0.3,0.5)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.6,5.5,8.6);0.4,0.7,0.2)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)	((7.1,7.7,8.3);0.5,0.2,0.4)
A_7	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)
A_8	((4.6,5.5,8.6);0.4,0.7,0.2)	((7.1,7.7,8.3);0.5,0.2,0.4)	((6.2,8.9,9.1);0.6,0.3,0.5)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)	((7.1,7.7,8.3);0.5,0.2,0.4)
A_9	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.4,5.9,7.2);0.7,0.2,0.3)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)	((4.4,5.9,7.2);0.7,0.2,0.3)	((4.4,5.9,7.2);0.7,0.2,0.3)
A_{10}	((5.8,6.9,8.5);0.6,0.2,0.3)	((4.4,5.9,7.2);0.7,0.2,0.3)	((4.4,5.9,7.2);0.7,0.2,0.3)	((6.2,8.9,9.1);0.6,0.3,0.5)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.6,5.5,8.6);0.4,0.7,0.2)
	C_1	C_2	C_3	C_4	C_5	C_6
A_1	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)	((5.8,6.9,8.5);0.6,0.2,0.3)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)
A_2	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.6,5.5,8.6);0.4,0.7,0.2)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)
A_3	((5.8,6.9,8.5);0.6,0.2,0.3)	((4.6,5.5,8.6);0.4,0.7,0.2)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)	((5.8,6.9,8.5);0.6,0.2,0.3)	((5.8,6.9,8.5);0.6,0.2,0.3)
A_4	((4.4,5.9,7.2);0.7,0.2,0.3)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((6.2,8.9,9.1);0.6,0.3,0.5)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.6,5.5,8.6);0.4,0.7,0.2)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)
A_5	((7.1,7.7,8.3);0.5,0.2,0.4)	((5.8,6.9,8.5);0.6,0.2,0.3)	((4.4,5.9,7.2);0.7,0.2,0.3)	((4.6,5.5,8.6);0.4,0.7,0.2)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.6,5.5,8.6);0.4,0.7,0.2)
A_6	((6.2,8.9,9.1);0.6,0.3,0.5)	((4.4,5.9,7.2);0.7,0.2,0.3)	((7.1,7.7,8.3);0.5,0.2,0.4)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)
A_7	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((7.1,7.7,8.3);0.5,0.2,0.4)	((4.4,5.9,7.2);0.7,0.2,0.3)	((5.8,6.9,8.5);0.6,0.2,0.3)	((6.2,8.9,9.1);0.6,0.3,0.5)	((6.2,8.9,9.1);0.6,0.3,0.5)
A_8	((4.6,5.5,8.6);0.4,0.7,0.2)	((6.2,8.9,9.1);0.6,0.3,0.5)	((5.8,6.9,8.5);0.6,0.2,0.3)	((4.4,5.9,7.2);0.7,0.2,0.3)	((7.1,7.7,8.3);0.5,0.2,0.4)	((7.1,7.7,8.3);0.5,0.2,0.4)
A_9	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.4,5.9,7.2);0.7,0.2,0.3)	((4.4,5.9,7.2);0.7,0.2,0.3)
A_{10}	((5.8,6.9,8.5);0.6,0.2,0.3)	((4.4,5.9,7.2);0.7,0.2,0.3)	((7.1,7.7,8.3);0.5,0.2,0.4)	((6.2,8.9,9.1);0.6,0.3,0.5)	((5.3, 7.3, 8.7); 0.7, 0.4, 0.8)	((4.6,5.5,8.6);0.4,0.7,0.2)

Table 2. The normalized matrix for criteria weights.

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0.098355927	0.113736	0.105649	0.085976	0.090975	0.105572

A_2	0.100374964	0.087635	0.101423	0.113471	0.10796	0.086657
A_3	0.104701471	0.095363	0.105649	0.085976	0.104506	0.10044
A_4	0.092875685	0.104404	0.101	0.104743	0.092702	0.106745
A_5	0.100519181	0.098425	0.090717	0.087431	0.097452	0.102933
A_6	0.112489184	0.092447	0.100296	0.104452	0.10796	0.100733
A_7	0.10383617	0.110819	0.095366	0.109543	0.110839	0.103666
A_8	0.087395443	0.112278	0.102268	0.099942	0.098892	0.111437
A_9	0.098644361	0.098717	0.099451	0.094996	0.085073	0.092962
A_{10}	0.100807615	0.086177	0.098183	0.113471	0.103642	0.088856

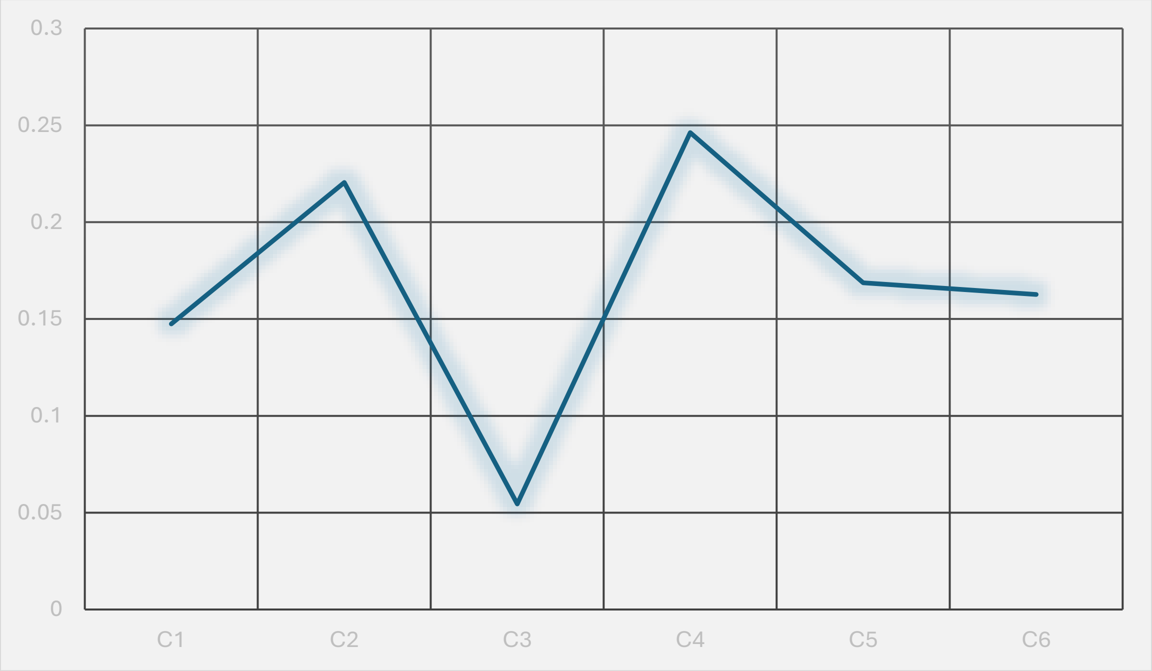


Fig 3. The criteria weights.

Results of REGIME method

Step 1. We used the combined decision matrix.

Step 2. We computed the superiority index E_{fl}.

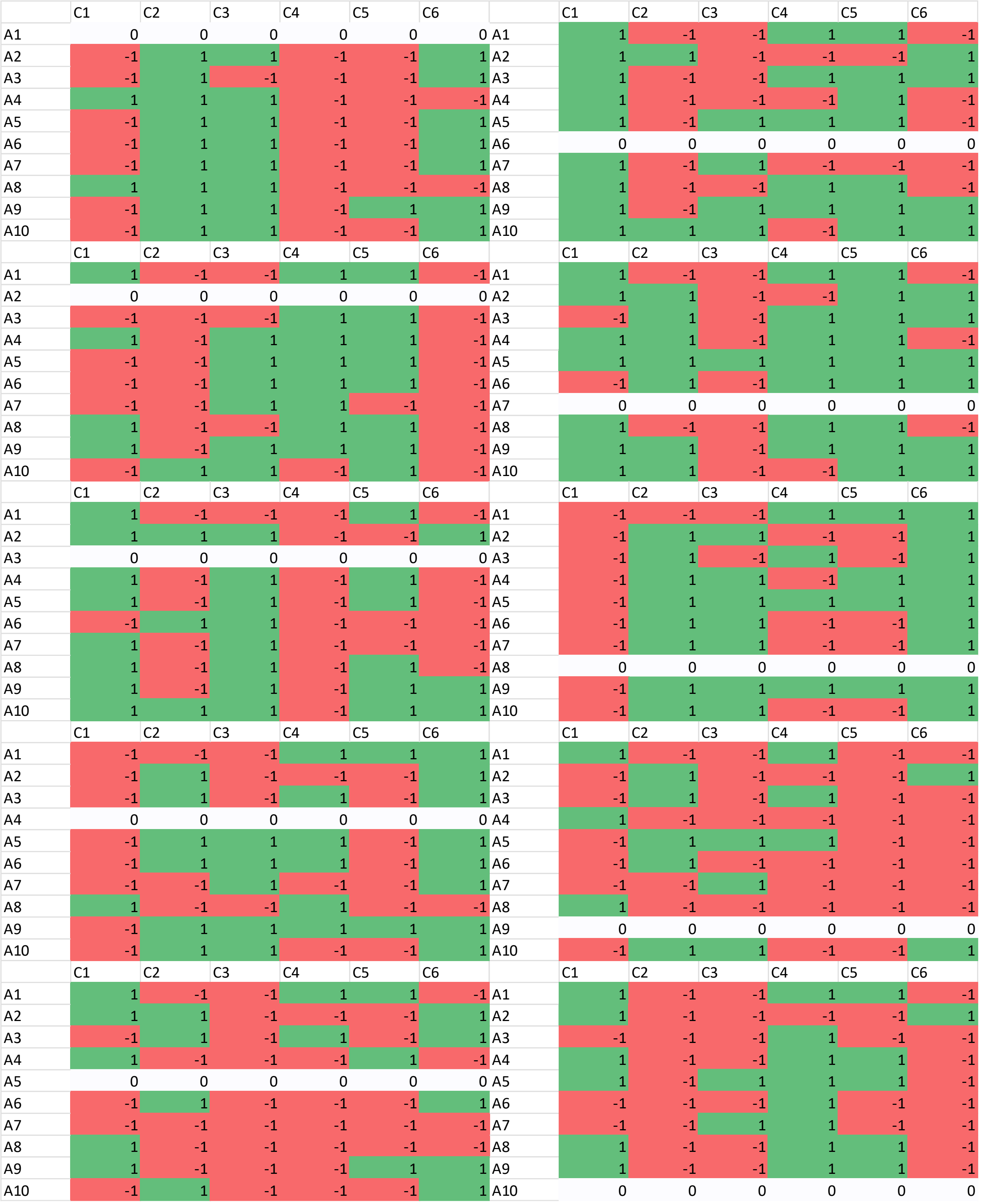
Step 3. We computed the superiority identifier.

Step 4. We built the impact matrix.

Step 5. We built the REGIME matrix between the alternatives using Eq. (15) as shown in Fig 4.

Step 6. Eq. (16) is used to compute the guide index as shown in Fig 5.

Step 7. Rank the alternatives as shown in Fig 6.



	C1	C2	C3	C4	C5	C6		C1	C2	C3	C4	C5	C6
A1	0	0	0	0	0	0	A1	1	-1	-1	1	1	-1
A2	-1	1	1	-1	-1	1	A2	1	1	-1	-1	-1	1
A3	-1	1	-1	-1	-1	1	A3	1	-1	-1	1	1	1
A4	1	1	1	-1	-1	-1	A4	1	-1	-1	-1	1	-1
A5	-1	1	1	-1	-1	1	A5	1	-1	1	1	1	-1
A6	-1	1	1	-1	-1	1	A6	0	0	0	0	0	0
A7	-1	1	1	-1	-1	1	A7	1	-1	1	-1	-1	-1
A8	1	1	1	-1	-1	-1	A8	1	-1	-1	1	1	-1
A9	-1	1	1	-1	1	1	A9	1	-1	1	1	1	1
A10	-1	1	1	-1	-1	1	A10	1	1	1	-1	1	1

	C1	C2	C3	C4	C5	C6		C1	C2	C3	C4	C5	C6
A1	1	-1	-1	1	1	-1	A1	1	-1	-1	1	1	-1
A2	0	0	0	0	0	0	A2	1	1	-1	-1	1	1
A3	-1	-1	-1	1	1	-1	A3	-1	1	-1	1	1	1
A4	1	-1	1	1	1	-1	A4	1	1	-1	1	1	-1
A5	-1	-1	1	1	1	-1	A5	1	1	1	1	1	1
A6	-1	-1	1	1	1	-1	A6	-1	1	-1	1	1	1
A7	-1	-1	1	1	-1	-1	A7	0	0	0	0	0	0
A8	1	-1	-1	1	1	-1	A8	1	-1	-1	1	1	-1
A9	1	-1	1	1	1	-1	A9	1	1	-1	1	1	1
A10	-1	1	1	-1	1	-1	A10	1	1	-1	-1	1	1

	C1	C2	C3	C4	C5	C6		C1	C2	C3	C4	C5	C6
A1	1	-1	-1	-1	1	-1	A1	-1	-1	-1	1	1	1
A2	1	1	1	-1	-1	1	A2	-1	1	1	-1	-1	1
A3	0	0	0	0	0	0	A3	-1	1	-1	1	-1	1
A4	1	-1	1	-1	1	-1	A4	-1	1	1	-1	1	1
A5	1	-1	1	-1	1	-1	A5	-1	1	1	1	1	1
A6	-1	1	1	-1	-1	-1	A6	-1	1	1	-1	-1	1
A7	1	-1	1	-1	-1	-1	A7	-1	1	1	-1	-1	1
A8	1	-1	1	-1	1	-1	A8	0	0	0	0	0	0
A9	1	-1	1	-1	1	1	A9	-1	1	1	1	1	1
A10	1	1	1	-1	1	1	A10	-1	1	1	-1	-1	1

	C1	C2	C3	C4	C5	C6		C1	C2	C3	C4	C5	C6
A1	-1	-1	-1	1	1	1	A1	1	-1	-1	1	-1	-1
A2	-1	1	-1	-1	-1	1	A2	-1	1	-1	-1	-1	1
A3	-1	1	-1	1	-1	1	A3	-1	1	-1	1	-1	-1
A4	0	0	0	0	0	0	A4	1	-1	-1	-1	-1	-1
A5	-1	1	1	1	-1	1	A5	-1	1	1	1	-1	-1
A6	-1	1	1	1	-1	1	A6	-1	1	-1	-1	-1	-1
A7	-1	-1	1	-1	-1	1	A7	-1	-1	1	-1	-1	-1
A8	1	-1	-1	1	-1	-1	A8	1	-1	-1	-1	-1	-1
A9	-1	1	1	1	1	1	A9	0	0	0	0	0	0
A10	-1	1	1	-1	-1	1	A10	-1	1	1	-1	-1	1

	C1	C2	C3	C4	C5	C6		C1	C2	C3	C4	C5	C6
A1	1	-1	-1	1	1	-1	A1	1	-1	-1	1	1	-1
A2	1	1	-1	-1	-1	1	A2	1	-1	-1	-1	-1	1
A3	-1	1	-1	1	-1	1	A3	-1	-1	-1	1	-1	-1
A4	1	-1	-1	-1	1	-1	A4	1	-1	-1	1	1	-1
A5	0	0	0	0	0	0	A5	1	-1	1	1	1	-1
A6	-1	1	-1	-1	-1	1	A6	-1	-1	-1	1	-1	-1
A7	-1	-1	-1	-1	-1	-1	A7	-1	-1	1	1	-1	-1
A8	1	-1	-1	-1	-1	-1	A8	1	-1	-1	1	1	-1
A9	1	-1	-1	-1	1	1	A9	1	-1	-1	1	1	-1
A10	-1	1	-1	-1	-1	1	A10	0	0	0	0	0	0

Fig 4. The REGIME matrix.

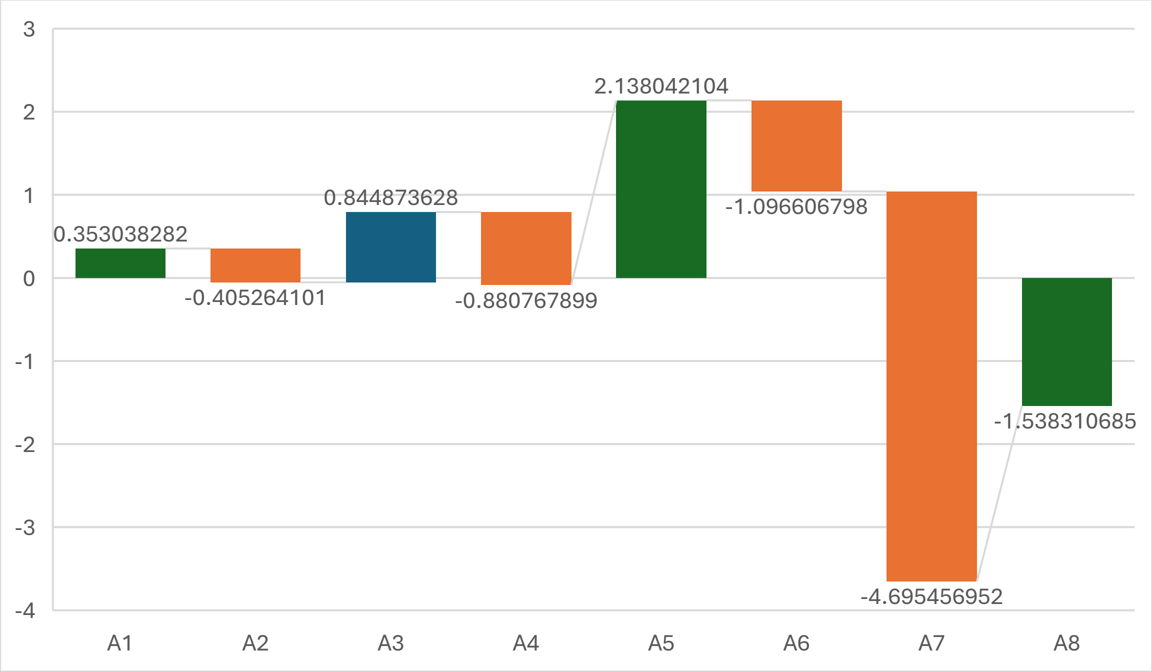


Fig 5. The guide index.

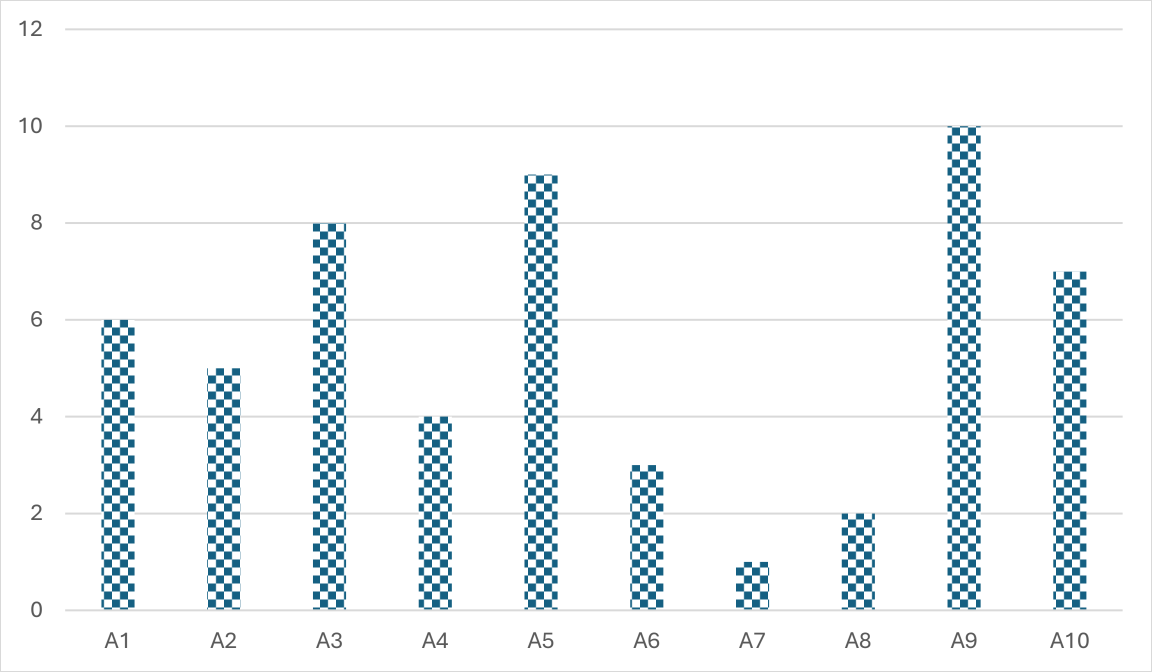


Fig 6. The rank of alternatives.

By conducting sensitivity analysis, we may learn more about how the framework behaves in various situations and use the results to inform our decision-making. This part does sensitivity analysis by adjusting the criteria weights that are established using the WENSLO technique to verify the criteria weights of our WENSLO-REGIME technique. The criteria weights are flipped pairwise throughout each sensitivity analysis step, while the other weights remain unchanged. Then, using a new set of weights and the same REGIME approach, the options are ranked.

Based on the guide index, the REGIME model is then used to rate each round. For every round, the ranking order is almost the same. The finest option out of all of them is the alternative 9. We are confident in the WENSLO-REGIME model's dependability because our sensitivity analysis demonstrates that its results are consistent over a wide range of input values. Fig 7 shows the ranks of alternatives. Fig 8 shows the guide index values.

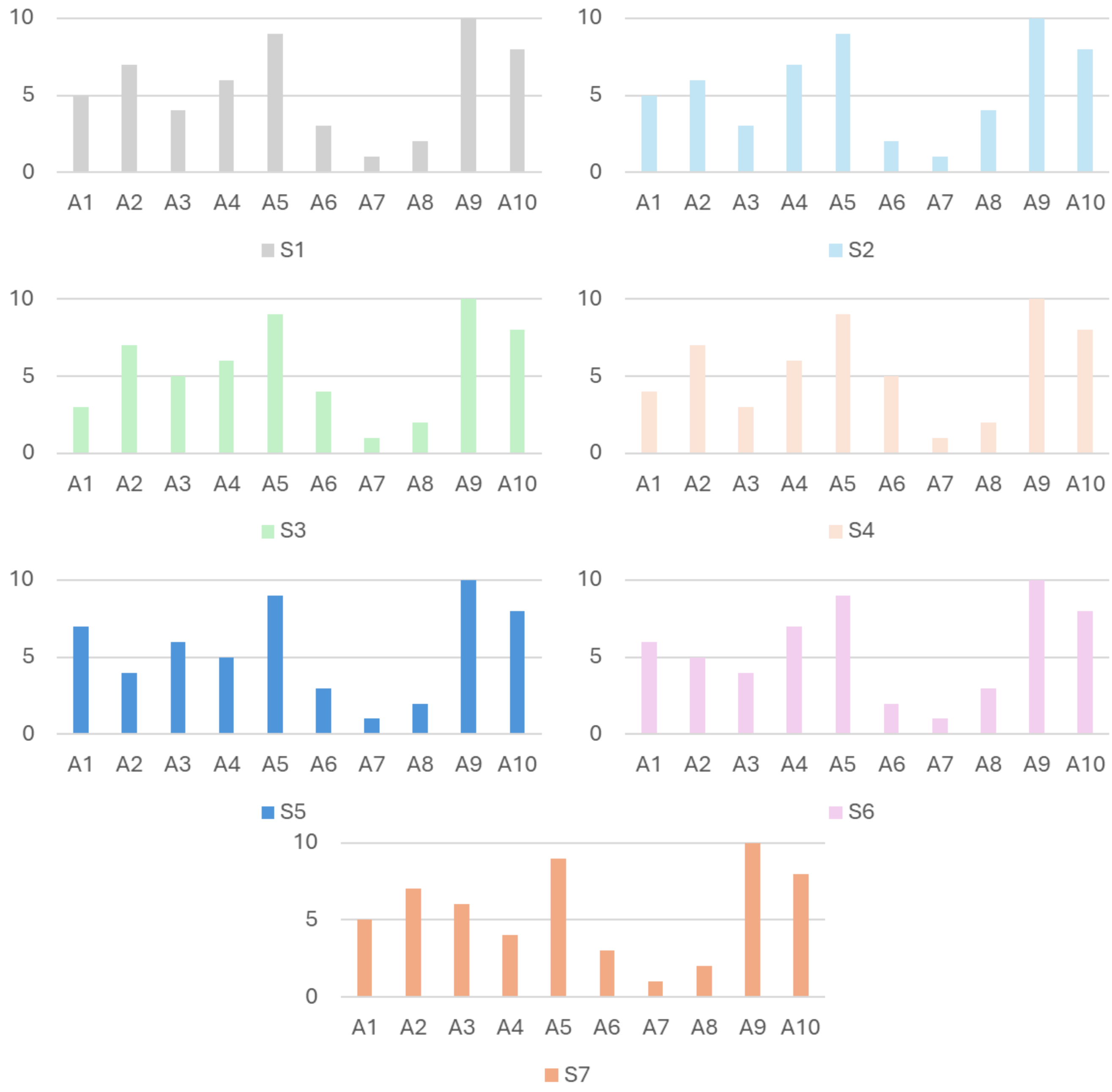


Fig 7. Results of sensitivity analysis.

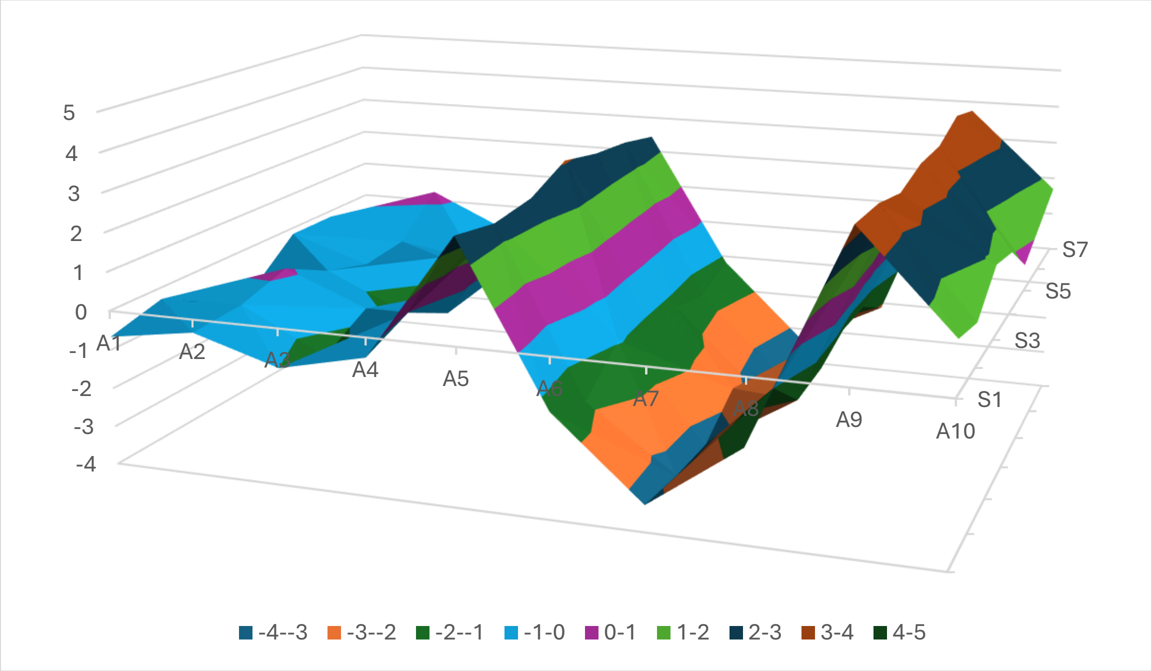


Fig 8. The guide index values.

Comprative analysis

This part comapres the proposed approach between other MCDM methods to show the effectiveness of the proposed approach. Fig shows the racnks of each method. Fig shows the coreelation between the proposed approach and other MCDM methods. The comparative aanlysis shows that the proposed is effective compred with other methods.

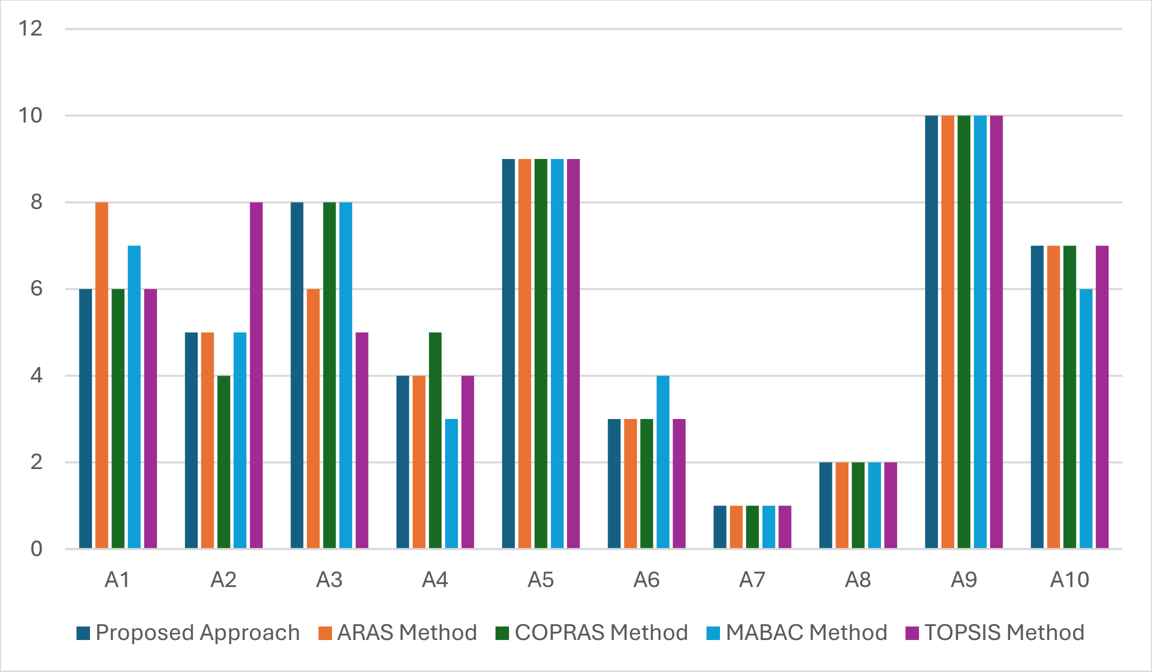
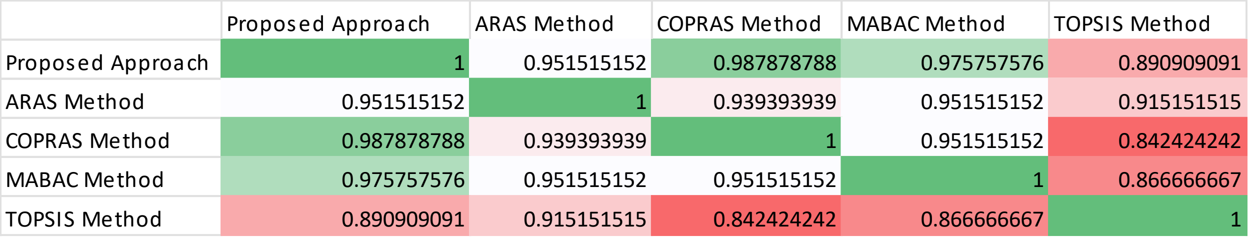


Fig . The ranks of each model.



	Proposed Approach	ARAS Method	COPRAS Method	MABAC Method	TOPSIS Method
Proposed Approach	1	0.951515152	0.987878788	0.975757576	0.890909091
ARAS Method	0.951515152	1	0.939393939	0.951515152	0.915151515
COPRAS Method	0.987878788	0.939393939	1	0.951515152	0.842424242
MABAC Method	0.975757576	0.951515152	0.951515152	1	0.866666667
TOPSIS Method	0.890909091	0.915151515	0.842424242	0.866666667	1

Fig . The correlation between our model and other models.

ARAS (Additive Ratio Assessment Method): ARAS evaluates alternatives by comparing their performance to an ideal alternative. It normalizes decision criteria and assigns weights to each factor before summing the weighted values. The alternative with the highest total utility value is considered the best. ARAS is simple, easy to implement, and does not require complex calculations. It is effective for straightforward decision-making problems where summation of benefits makes sense. It can be sensitive to the choice of normalization method, which may impact results. Additionally, it does not explicitly consider negative aspects of the alternatives. ARAS is often used in project evaluations, supplier selection, and economic analysis due to its straightforward approach.

COPRAS considers both beneficial and non-beneficial criteria while calculating a relative significance coefficient for each alternative. It determines positive and negative utility values to rank the alternatives proportionally. This method explicitly accounts for both advantages and disadvantages, offering a balanced evaluation. It is easy to use and provides a clear ranking system. COPRAS can be sensitive to subjective weight assignments and does not account for interdependencies between criteria. It is widely used in investment analysis, project selection, and risk assessment because of its ability to handle both costs and benefits effectively.

MABAC (Multi-Attributive Border Approximation Area Comparison Method): MABAC evaluates alternatives by measuring their relative distance from a border approximation area, which represents an ideal threshold between good and bad solutions. Unlike other methods that rely purely on distance-based ranking, MABAC also allows for more flexibility in handling nonlinear and complex decision environments. MABAC is useful in real-world scenarios where data is uncertain or when qualitative and quantitative criteria need to be combined. It is less sensitive to small changes in input data than other methods. The method is more computationally complex than ARAS and COPRAS, requiring advanced mathematical operations. Precise data inputs are necessary for accurate decision-making. It is commonly used in engineering design, environmental management, and policy evaluation, where decisions involve high levels of uncertainty.

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution): TOPSIS ranks alternatives based on their closeness to an ideal solution and distance from the worst solution. It uses Euclidean distance calculations to determine the best option. TOPSIS is widely recognized and applied in various industries because it effectively balances positive and negative aspects. It also provides a clear and logical ranking of alternatives. It does not consider interdependencies between criteria, meaning that each factor is evaluated independently. Additionally, small changes in data or weight assignments can significantly impact rankings. TOPSIS is commonly used in engineering, supply chain management, finance, and healthcare, where decisions need to be made by comparing multiple options in terms of their best and worst aspects.

5. Conclusions

By using the rough boundary approximation to capture the maximum unknown degrees, the neutrosophic- WENSLO -REGIME methodology. The study that is being presented is being used for the evaluation of abandoned coal mine sites. The significance of each criterion and its effect on the decision-making process have been assessed using the neutrosophic-WENSLO technique. Through pairwise comparisons of criteria, the neutrosophic-REGIME technique ranks alternatives, allocating scores according to their relative desirability. It makes decision-making flexible and objective by doing away with the requirement for preset weights. Alternative 9 was found to be the best option after we used the suggested approach to choosing the best alternative. The effectiveness and validity of the proposed approach have since been assessed through a comprehensive sensitivity analysis and comparative study.

Future directions

In the future directions, there are different MCDM methods can be applied to this MCDM problem to compute the criteria weights and rnak the alternatives such as AHP, TOPSIS, VIKOR, and EDAS methods. These methods can be applied to different crietria and alternatievs in the future directions. Extended number of crietria in the future durections can be considered to obtain accure and reliable results. Other extensions of neutrosophic sets can be used to dela with uncertainty and vgaue information in the future directions.

Acknowledgment

This work was supported by the Research on Sponge Design of Coal Mine Waste Land Landscape under the Dual Carbon Goal, Project No. 2022AH051550. The university-level key scientific research project "Research on the Application Design of the Fifth Facade Space of Public Buildings from the Perspective of Sponge - A Case Study of Huainan Xinhua Bookstore", Project No.: 2022XJZD008.

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