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Spherical Fuzzy BW-AHP Strategy and its Applications in Renewable Energy

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ABSTRACT: The current work proposes a new hybrid decision-making method called the Spherical Fuzzy Best Worst Analytic Hierarchy Process (SFBWAHP). The fuzzy AHP technique calculates the weights of elements using advanced relationships among selections, transactions, and feedback of criteria and alternatives. However, the potency and utility of this methodology have been reduced due to the large number of pairwise comparisons and difficulties in understanding the comparison method for experts. SF-BWAHP exploits the Fuzzy Best-Worst technique to overcome the demerits mentioned above. A special feature of the proposed method is that it requires less information for comparisons. Numerous reliable results are obtained from various consistent comparisons, making it easier for experts to make decisions. Lastly, the Bhakra Nangal hydroelectric power plant is used as a case study to illustrate the stability and support of this technology.

Keywords: Fuzzy best-worst method, fuzzy AHP method, spherical fuzzy set, hydropower plant, climate change.

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1. Introduction

Hydropower has emerged as a crucial and sustainable source of renewable energy, playing a pivotal role in meeting the world's growing energy demands while minimizing environmental impacts. The efficiency of a hydroelectric power plant is a vital aspect that determines how effectively it converts the potential energy stored in water into electrical energy. This efficiency encompasses various technical, economic, and environmental factors that contribute to the overall performance and viability of the power generation process. Hydropower plants harness the kinetic and potential energy of flowing water to generate electricity, primarily through the use of turbines and generators. The efficiency of a hydroelectric power plant is a complex interplay of several components, each contributing to the overall conversion process. Here, we delve into the key aspects that define the efficiency of a hydro power plant. The core objective of a hydro power plant is to convert the energy of falling water into mechanical and then electrical energy. This conversion efficiency depends on the design of the plant, the type of turbines used (e.g., Francis, Pelton, Kaplan), and the head (the vertical distance the water falls) and flow rate of the water. Modern turbine designs, advanced materials, and precise engineering techniques have significantly improved the overall conversion efficiency [1]. Energy losses occur at various stages of the power generation process. These include hydraulic losses due to friction and turbulence in pipelines and penstocks, as well as losses in mechanical transmission systems such as gears and bearings. Minimizing these losses is crucial to optimizing the efficiency of the plant [2]. The environmental impact of a hydro power plant can affect its efficiency. Proper consideration of ecological factors, fish migration routes, sediment transport, and water quality maintenance are essential for ensuring minimal disruption to the ecosystem surrounding the plant. Implementing environmentally friendly technologies, such as fish-friendly turbines and fish passages, can help strike a balance between energy production and ecological preservation [3]. Regular maintenance and timely repairs of equipment are critical to sustaining efficiency. Neglecting maintenance can lead to operational inefficiencies, higher downtime, and increased wear and tear on machinery. Implementing predictive maintenance techniques and using high-quality materials can extend the lifespan of the equipment and maintain optimal efficiency [3]. The efficiency of a hydro power plant also influences its economic viability. Higher efficiency translates to increased energy output per unit of input, thereby enhancing the plant's revenue generation potential. Moreover, greater efficiency can contribute to lower operational and maintenance costs, improving the overall return on investment [4]. Advancements in materials science, turbine design, automation, and control systems continue to enhance the efficiency of hydro power plants. Innovative technologies, such as adjustable speed drives and smart grid integration, enable better synchronization with fluctuating energy demands and supply [3]. The sustainability of hydro power depends on maintaining efficiency while addressing potential environmental and social concerns. Respecting downstream water rights, ensuring local communities' participation, and adopting environmentally sound practices are essential components of sustainable hydropower development [5]. In conclusion, the efficiency of a hydro power plant plays a pivotal role in optimizing energy conversion, minimizing losses, and ensuring long-term sustainability. Advances in technology, proper management of resources, and a commitment to environmental stewardship collectively contribute to the successful operation of efficient hydroelectric power plants. As the world continues to prioritize renewable energy sources, further research and innovation will likely drive continuous improvements in the efficiency and effectiveness of these power plants. Optimal energy policies, guided by the identification of key challenges, can facilitate the expansion of renewable energy sources. Recognizing the vital role of fostering entrepreneurship within the renewable energy sector, this study investigates the impediments to entrepreneurial development in Pakistan's renewable energy landscape. Consequently, our research introduces a systematic methodology for prioritizing these obstacles based on their significance. The study was conducted in two phases. Firstly, a comprehensive review of the existing literature and expert interviews were conducted to pinpoint potential hurdles. Secondly, the Spherical Fuzzy Analytic Hierarchy Process (SFAHP) methodology was employed to refine and categorize these challenges. Ultimately, twelve barriers were identified and subsequently classified into four distinct categories. Finally, PF-AHP was employed to assign weights and ranks to these barriers [6]. Implementing effective energy policies that acknowledge and address key obstacles can significantly streamline the development of solar energy systems. Pakistan has encountered numerous challenges that have hindered the growth of solar energy to a satisfactory level. To address these issues, it is essential to first identify the barriers obstructing the adoption of solar energy. Therefore, this study endeavours to discover and rank the impediments to solar power expansion in Pakistan, employing an innovative approach known as the spherical fuzzy analytical hierarchy process. The findings of the study indicate that the category of economic obstacles (21.46%) holds the highest significance among major categories. Conversely, when assessing the global ranking of sub-obstacles, budget constraints (4.68%), lack of access to credit/capital (4.52%), political instability (4.51%), high investment risk and operation cost (4.42%), and partnership issues (4.37%) emerge as the five most critical sub-obstacles, surpassing the remaining twenty-one obstacles across various categories. Furthermore, the study offers recommendations for overcoming these obstacles, carrying substantial policy implications for government officials, researchers, and industry practitioners in the solar sector within the country. It also provides valuable insights for the development of strategies aimed at the seamless deployment of solar energy solutions in Pakistan [7]. In response to the pressing issue of climate change, organizations worldwide are formulating strategies to curb carbon emissions through the advancement of clean energy technologies and energy-efficient devices. In this context, progress in the realm of green energy in Pakistan has been relatively limited over the past two decades. Specifically, there has been a shortage of representation and utilization of renewable sources, particularly biomass feedstock supplies such as agricultural residue, forest residue, municipal waste, and animal waste, for the transition towards green energy. This study employs the Low Emissions Analysis Platform (LEAP) software to analyse the trajectory of green energy transition in Pakistan. It does so by incorporating biomass feedstock into ongoing and sustainable energy scenarios spanning from 2022 to 2050. The results reveal a significant increase in bioelectricity production, rising from 18.73 Terawatt-Hours (TWHs) in the ongoing scenario to an impressive 265.20 TWhs in the biomass-based sustainable energy scenario by 2050. Furthermore, the establishment of biomass plants is poised to contribute to a substantial reduction in CO2 emissions. Emissions are projected to decline from 138.47 million metric tonnes in the current scenario to a mere 8.71 million metric tonnes in the sustainable energy scenario by 2050. This research provides essential data and valuable insights, empowering policymakers and stakeholders to pivot towards the development of renewable and sustainable energy systems in Pakistan [8]. In the present study, the review of literature and preliminary is discussed in section 2 and 3 respectively, the proposed method is presented in section 4, section 5 presents the methodology of the study, results and discussion are discussed in section 6, and advantages and disadvantages are presented in section 7 and 8 respectively and last section 9 presents the conclusion of the study.

2. Review of Literature

Since 1960, Multi-Criteria Decision Making (MCDM) finds its vast application in various fields. Several MCDM methods are available, such as Analytic Hierarchy Process (AHP) [9], Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [10], VIekriterijumsko KOmpromisno Rangiranje (VIKOR) [11], Best Worst Method (BWM) [12]. BWM is a well-known MCDM method for measuring, prioritizing, ranking, and evaluating decision options initiated by Jafar Rezai in 2015 [12]. This method depends on two vectors of pairwise comparisons to calculate weights. Firstly, the decision-maker selects two criteria from all the selected criteria as the worst and best criteria. Comparisons are then made in pairs between the best and worst criteria with the other criteria. Here, in BWM, a scale of 1 to 9 is used to perform the pairwise reference comparisons. In recent times, various researchers have shown much interest in the BWM method in fuzzy domains [13, 14, 15, 16, 17]. Moreover, AHP developed by Saaty has a common problem in that the pairwise comparison methods usually lack consistency [18]. BWM has overcome the demerits of AHP by only performing reference comparisons. Hence, BWM increases the overall consistency of the problem more efficiently than AHP.

Following Zadeh's introduction of the idea of fuzzy sets [19], research has been conducted to expand fuzzy sets to type-2 fuzzy sets [20], intuitionistic fuzzy sets [21], hesitant fuzzy sets [22], Pythagorean fuzzy sets [23], and neutrosophic sets [24]. Another critical notion introduced by Kutlu Gündoğdu and Kahraman in 2019 was the spherical fuzzy set [25]. The degree of hesitation associated with decision-makers in these fuzzy sets may be determined separately, given that the membership and non-membership degrees adhere to the following constraint:

$$o \leq \mu^2_{\tilde{C}}(\eta) + \nu^2_{\tilde{C}}(\eta) + \pi^2_{\tilde{C}}(\eta) \leq 1, \forall\ \eta \in V. \tag{1}$$

Here, $\mu^2_{\tilde{C}}(\eta), \nu^2_{\tilde{C}}(\eta), \pi^2_{\tilde{C}}(\eta)$ are the degrees of membership, non-membership, and hesitancy of each η , respectively. On the surface of the sphere, relation (1) reduces to

$$\mu^2_{\tilde{C}}(\eta) + \nu^2_{\tilde{C}}(\eta) + \pi^2_{\tilde{C}}(\eta) = 1, \forall\ \eta \in V. \tag{2}$$

Here, for reliability analysis of performance in hydropower plants, a model for decision-making is designed based on spherical fuzzy sets. This decision model bridges BWM and AHP with spherical fuzzy sets.

The main objective of the study is the development of an MCDM technique combining spherical fuzzy sets. The study depends mainly on two ways, namely spherical fuzzy AHP as well as spherical fuzzy BWM. The criteria weights are obtained utilizing spherical fuzzy BWM, while spherical fuzzy AHP generates the weights of alternatives (or indicators). BWM is utilized to address various shortcomings of AHP, such as AHP has more comparisons than BWM. Furthermore, the BWM integer scale is utilized in comparing more closely to human perceptions and knowledge for making the evaluation process much easier. Finally, as redundant comparisons are removed, BWM works well in maintaining the consistency of pairwise comparisons. This enhances the dependability of the BWM's results over those of the AHP. Also, spherical length is wholly dissimilar from existing spaces due to its nonlinear relevance to the amendment of the equivalent fuzzy membership degrees. Some studies on the power production efficiency of Hydro-Power Plants (HPPs) show that the climate change and sustainability factors in vulnerable conditions are never utilized [26, 27, 28, 29]. This research aimed to improve a decision-support model for assessing HPPs performance, creating a climate-informed tool for future adaptation planning.

Furthermore, the effect of alternatives is partly enclosed in the process of decision-making based on their relevance concerning the climate-changing parameter, and control of climate-changing parameters is evaluated using their capacity to modify the characteristics which may be utilized to rank various power plants supporting the climate change vulnerability. The originality of this work consists in using the fuzzy BWM in a completely innovative way to identify the best and worst criteria. In fuzzy AHP, to select a criterion, we need a pairwise comparison with each criterion. Further, we apply our proposed method to check the effect of climate change globally as climate change has appeared as the most significant developmental challenge for humanity. Obtaining the impact of climate change is another specialty of this work. Rezaei Presented the famous MCDM technique known as the BWM [12]. Its accuracy, ease of use, and reduced computational complexity make it more competitive than other MCDM techniques. In recent times, the BWM method has been developed using Fuzzy sets. From the birth of standard Fuzzy sets, various developments have been done in this direction. Fuzzy BWM is utilized in solving various real-world decision problems. Moslem et al. [30] used fuzzy BWMM for finding driver behaviour factors based on roadsafety. Dong et al. [31] used triangular fuzzy BWM in proposing four programming models for various decisions. Amiri et al. [32] worked on sustainability in Supply Chain Management (SCM) using the fuzzy BWM.

Trapezoidal fuzzy BWM [5] is the generalized and improved version of the triangular fuzzy BWM [13]. Wan et al. [33] developed the generalized interval-valued trapezoidal fuzzy (GITrF) best-worst methodused for three different problems as transportation mode selection, car selection, and lastly supplier selection. Yucesan and Gul [34] developed the neutrosophic BWM to deal with a case study for the implant industry. Liao et al. [developed the Hesitant Fuzzy BWM (HFBWM) and applied it in evaluating hospital performance. Li et al. [36] grounded the BWM and Probabilistic Hesitant Fuzzy Elements (PHFEs) to solve the problem of choosing the best investment company. BWM, when extended using intuitionistic fuzzy sets, is commonly applied to handle uncertainty in MCDM [37] and the method is used in evaluating overseas talent in China. Mahdiraji et al. [38] developed the BWM-TODIM in intervalvalued intuitionistic fuzzy envionment and employed it to find ways for implementing industry 4.0. The hierarchy of extension of BWM with the help of various fuzzy sets is illustrated in Figure 1.

Recently BWM is applied in varied real-world issues besides the fuzzy sets. Kieu et al. [39] utilized the spherical fuzzy with AHP to select locations for distributing the perishable agricultural products. Unal and Temur [40] used the combination of spherical fuzzy and AHP in prioritizing the criteria affecting sustainable supplier selection. This study proposes a novel approach, referred to as Spherical Fuzzy BWM

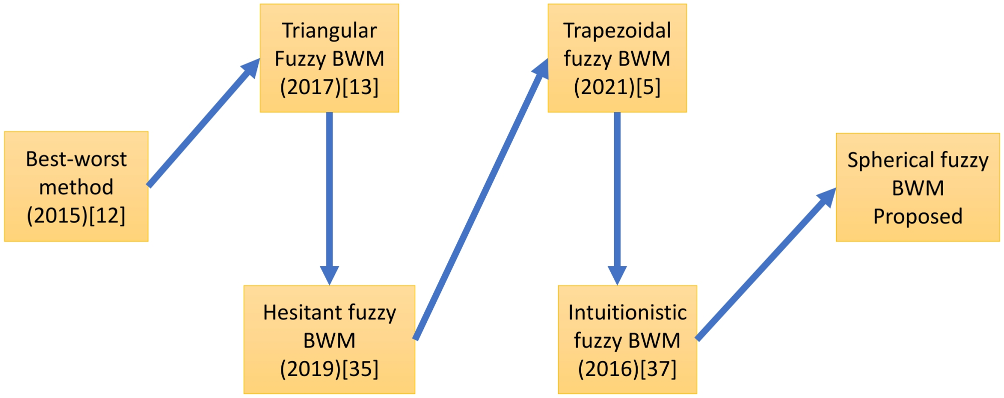

Figure 1. Extensions of BWM

(SFBWM), to determine the weights of criteria. Also, this study proposes a hybrid MCDM technique. This hybrid technique combines the proposed SF-BWM and existing Spherical Fuzzy AHP (SFAHP). In this study, SFAHP is used to determine the weights of the set of alternatives. An application of this approach is to analyze the efficiency of hydroelectric power plants.

3. Mathematics-Preliminaries

Let V_1 be a universe of discourse. Two arbitratry spherical fuzzy sets are defined as follows [25]:

$$\begin{aligned}\tilde{C}_s = \Bigg\{ & \left(\eta, \mu_{\tilde{C}_s}(\eta), \nu_{\tilde{C}_s}(\eta), \pi_{\tilde{C}_s}(\eta)\right) \Bigg| \\ & \mu_{\tilde{C}_s}(\eta), \nu_{\tilde{C}_s}(\eta), \pi_{\tilde{C}_s}(\eta) :\rightarrow (0,1) \cup \{0,1\}, \\ & 0 \leq \mu^2_{\tilde{C}_s}(\eta) + \nu^2_{\tilde{C}_s}(\eta) + \pi^2_{\tilde{C}_s}(\eta) \leq 1, \quad \eta \in V_1 \Bigg\}\end{aligned}$$

$$\begin{aligned}\tilde{D}_s = \Bigg\{ & \left(\gamma, \mu_{\tilde{D}_s}(\gamma), \nu_{\tilde{D}_s}(\gamma), \pi_{\tilde{D}_s}(\gamma)\right) \Bigg| \\ & \mu_{\tilde{D}_s}(\gamma), \nu_{\tilde{D}_s}(\gamma), \pi_{\tilde{D}_s}(\gamma) :\rightarrow (0,1) \cup \{0,1\}, \\ & 0 \leq \mu^2_{\tilde{D}_s}(\gamma) + \nu^2_{\tilde{D}_s}(\gamma) + \pi^2_{\tilde{D}_s}(\gamma) \leq 1, \quad \gamma \in V_1 \Bigg\}\end{aligned}$$

$$\tilde{C}_s \oplus \tilde{D}_s = \left\{ \sqrt{\mu^2_{\tilde{C}_s} + \mu^2_{\tilde{D}_s} - \mu^2_{\tilde{C}_s}\mu^2_{\tilde{D}_s}},\ \nu_{\tilde{C}_s}\nu_{\tilde{D}_s},\ \sqrt{(1-\mu^2_{\tilde{D}_s})\pi^2_{\tilde{C}_s} + (1-\mu^2_{\tilde{C}_s})\pi^2_{\tilde{D}_s} - \pi^2_{\tilde{C}_s}\pi^2_{\tilde{D}_s}} \right\}$$

$$\tilde{C}_s \otimes \tilde{D}_s = \left\{ \mu_{\tilde{C}_s}\mu_{\tilde{D}_s},\ \sqrt{\nu^2_{\tilde{C}_s} + \nu^2_{\tilde{D}_s} - \nu^2_{\tilde{C}_s}\nu^2_{\tilde{D}_s}},\ \sqrt{(1-\nu^2_{\tilde{D}_s})\pi^2_{\tilde{C}_s} + (1-\nu^2_{\tilde{C}_s})\pi^2_{\tilde{D}_s} - \pi^2_{\tilde{C}_s}\pi^2_{\tilde{D}_s}} \right\}$$

$$\lambda\tilde{C}_s = \left\{\sqrt{1-\left(1-\mu^2_{\tilde{C}_s}\right)^{\lambda}},\ \nu_{\tilde{C}_s},\ \sqrt{\left(1-\mu^2_{\tilde{C}_s}\right)^{\lambda}-\left(1-\mu^2_{\tilde{C}_s}-\pi^2_{\tilde{C}_s}\right)^{\lambda}}\right\},\quad \lambda>0$$

$$\tilde{C}_s^{\lambda} = \left\{\mu^{\lambda}_{\tilde{C}_s},\ \sqrt{1-\left(1-\nu^2_{\tilde{C}_s}\right)^{\lambda}},\ \sqrt{\left(1-\nu^2_{\tilde{C}_s}\right)^{\lambda}-\left(1-\nu^2_{\tilde{C}_s}-\pi^2_{\tilde{C}_s}\right)^{\lambda}}\right\},\quad \lambda>0$$

4. Spherical Fuzzy Best Worst AHP (SFBWAHP) Strategy

In the current section, we explain the development of the process, SFBWAHP. The proposed method, namely SFBWAHP, has two phases, namely phase 1 and phase 2.

Phase 1 is explained in seven steps, and similarly, phase 2 is explained in five steps. Using phase 1, the choice of the best, as well as worst criteria is done. In the next phase, the choice of the most critical Indicator is done. Figure 2 represents the proposed technique.

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- **Stage-1 : Defining the Criteria**:
  First, select a set of decision criteria. Let $S = s_1, s_2, ..., s_n\ and\ X = y_1, y_2, ..., y_n$ indicate the set of criteria as well as alternatives, respectively. The performances of each alternative are a function of the group of the element of S. Therefore, $PV(y_i) = f_i(s_1, s_2, ..., s_n), i = 1, 2, ..., m.$

- **Stage-2 : Selection of the Best and the Worst Criteria**:
  Here, the best and worst criteria are selected using various surveys like literature, expert, media survey, etc. Let S_B and S_W be the best as well as worst criteria respectively. Then $S_B, S_W \in S$.

- **Stage-3 : Pair-wise Judgement Matrix**:
  In stage-3, the pairwise comparison is done, which is explained in two steps: 4.1 and 4.2. Criteria pairwise comparisons are completed using Linguistic terms. Table I represents each Linguistic term into spherical fuzzy numbers.

Table 1: **Linguistic Term into Spherical Fuzzy**

Linguistic Term	Score Index (SI)	Spherical Fuzzy Number
Equally Importance (EI)	1	(0.5, 0.4, 0.4)
Slightly More Importance (SMI)	3	(0.6, 0.4, 0.3)
High Importance (HI)	5	(0.7, 0.3, 0.2)
Very High Importance (VHI)	7	(0.8, 0.2, 0.1)
Absolutely More Importance (AMI)	9	(0.9, 0.1, 0.0)
Absolutely Low Importance (ALI)	$\frac{1}{9}$	(0.1, 0.9, 0.0)
Very Low Importance(VLI)	$\frac{1}{7}$	(0.2, 0.8, 0.1)
Low Importance (LI)	$\frac{1}{5}$	(0.3, 0.7, 0.2)
Slightly Low Importance (SLI)	$\frac{1}{3}$	(0.4, 0.6, 0.3)

- **Stage-3.1 : Judgement for Best criterion**:
  Here, the judgment of each criterion of set S is done with the help of the best criterion and is shown in TABLE II. In the table, $\tilde{x}_{Bi}, i = 1, 2, ..., n$ takes one of the spherical fuzzy numbers from TABLE I, also $\tilde{x}_{BB} = (0.5, 0.4, 0.4)$.

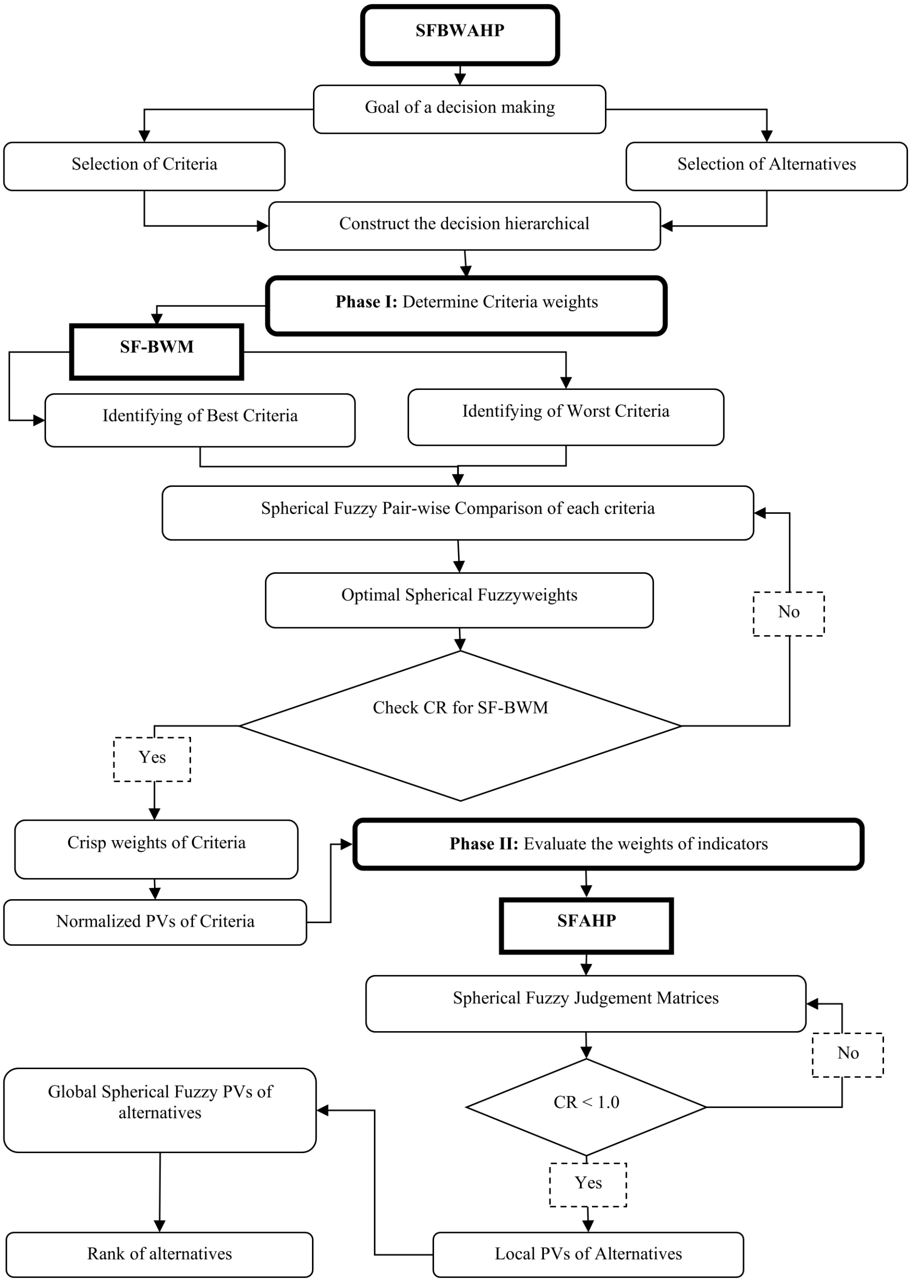

Figure 2. Flow chart of the proposed SFBWAHP

Table 2: **Pairwise Comparison Concerning the Best Criterion**

	s_1	s_2	$\cdots$ s_n
S_B	$\tilde{x}_{B1}$	$\tilde{x}_{B2}$	$\cdots$ $\tilde{x}_{Bn}$

- **Stage-3.2 : Judgement of Criterion to the worst Criterion** :
  Comparison is made with the worst criterion by every S criterion, represented in Table 3I. In the table,$\tilde{x}_{Bi}, i = 1, 2, ..., n$ keeps any one of the spherical fuzzy numbers from Table 2, also $\tilde{x}_{BB} = (0.5, 0.4, 0.4)$.

Table 3: **Pairwise judgement of worst criteria to collection of each criterion**

	S_w
S_1	$\tilde{x}_{1w}$
S_2	$\tilde{x}_{2w}$
$\vdots$	$\vdots$
S_n	$\tilde{x}_{nw}$

- **Stage-4 : Optimal Priority Value (PV)** :
  In this case, the determination of the optimal PV is done. Let $w_1, w_2, ..., w_n$ be the PV of criteria $s_1, s_2, ..., s_n$,respectively. Assume that $w_1, w_2, ..., w_n$ are decision variables of the optimization tools. Here ,w_B as well, be taken as the PVs or weights of the criteria and s_w respectively.
  For optimal PV, two ratios $\frac{w_B}{w_i}$ and $\frac{w_i}{w_w}, i = 1, 2, ..., n$ satisfy $\frac{w_B}{w_i} - \tilde{x}_{Bi} = 0$ and $\frac{w_i}{w_w} - \tilde{x}_{iw} = 0, i = 1, 2, ..., n$ and feasible $\forall i = 1, 2, \ldots, n$ it should find the minimum of maximum gaps $\forall i = 1, 2, \ldots, n$. All the PVs in SFBWMAHP are Spherical Fuzzy Sets (SFS s). We take $\tilde{w_i} = (\mu_{w_i}, \nu_{w_i}, \pi_{w_i}), \forall i = 1, 2, \ldots, n$ for selection of suitable indicator optimally. Hence, the mathematical problem of optimization can be presented

$$\min \left\{ \max_i \left| \frac{\tilde{w}_B}{\tilde{w}_i} - \tilde{x}_{Bi} \right| \cdot \left| \frac{\tilde{w}_i}{\tilde{w}_w} - \tilde{x}_{iw} \right| \right\}$$

subject to

$$\sum_{i=1}^{n} R_{\tilde{w}_i} = 1,$$

$$0 \le \mu_{wi}^2 + \nu_{wi}^2 + \pi_{wi}^2 \le 1, \quad i = 1, 2, \ldots, n,$$

$$\mu_{wi}, \nu_{wi}, \pi_{wi} \le 0, \quad i = 1, 2, \ldots, n, \tag{3}$$

where, $\tilde{w_i} = (\mu_{wi}, \nu_{wi}, \pi_{wi}), \tilde{w}_B = (\mu_{wB}, \nu_{wB}, \pi_{wB}),$ and $\tilde{x}_{wi} = (\mu_{x_{wi}}, \nu_{x_{wi}}, \pi_{x_{wi}})$.
Now, we convert the mathematical problem of optimization (3) into a nonlinear equation. The nonlinear optimization form is presented as

$$\begin{aligned}
&\min \tilde{\zeta} \\
&\text{subject to} \\
&\left| \frac{\tilde{w}_B}{\tilde{w}_i} - \tilde{x}_{Bi} \right| \leq \tilde{\zeta}, \\
&\left| \frac{\tilde{w}_i}{\tilde{w}_w} - \tilde{x}_{iw} \right| \leq \tilde{\zeta}, \\
&\sum_{i=1}^{n} R_{\tilde{w}_i} = 1, \\
&0 \leq \mu_{wi}^2 + \nu_{wi}^2 + \pi_{wi}^2 \leq 1, \quad i = 1, 2, \ldots, n, \\
&\mu_{wi}, \nu_{wi}, \pi_{wi} \geq 0, \quad i = 1, 2, \ldots, n, \qquad (4) \\
&\text{where} \quad \tilde{\zeta} = (\mu_\zeta, \nu_\zeta, \pi_\zeta).
\end{aligned}$$

Suppose $\zeta = (\lambda, \lambda, \lambda)$, $\lambda \leq min(\mu_\zeta, \nu_\zeta, \pi_\zeta)$.
Thus, Eq. (4) reduces to

$$\begin{aligned}
&\min(\lambda, \lambda, \lambda) \\
&\text{subject to} \\
&\left\{ \left| \frac{(\mu_{\tilde{w}_B}, \nu_{\tilde{w}_B}, \pi_{\tilde{w}_B})}{(\mu_{\tilde{w}_i}, \nu_{\tilde{w}_i}, \pi_{\tilde{w}_i})} - (\mu_{\tilde{x}_i}, \nu_{\tilde{x}_i}, \pi_{\tilde{x}_i}) \right| \leq (\lambda, \lambda, \lambda) \right\} \\
&\left\{ \left| \frac{(\mu_{\tilde{w}_i}, \nu_{\tilde{w}_i}, \pi_{\tilde{w}_i})}{(\mu_{\tilde{w}_w}, \nu_{\tilde{w}_w}, \pi_{\tilde{w}_w})} - (\mu_{\tilde{x}_{\overline{w}_i}}, \nu_{\tilde{x}_{\overline{w}_i}}, \pi_{\tilde{x}_{\overline{w}_i}}) \right| \leq (\lambda, \lambda, \lambda) \right\} \\
&\sum_{i=1}^{n} R_{\tilde{w}_i} = 1, \qquad (5) \\
&0 \leq \mu_{wi}^2 + \nu_{wi}^2 + \pi_{wi}^2 \leq 1, \quad i = 1, 2, \ldots, n, \\
&\mu_{wi}, \nu_{wi}, \pi_{wi} \geq 0, \quad i = 1, 2, \ldots, n.
\end{aligned}$$

Solving (5), we obtain the optimal PVs $\tilde{w}_1^*, \tilde{w}_2^*, ..., \tilde{w}_n^*$, where $\tilde{w}^* = (\mu_{\tilde{w}_i^*}, \nu_{\tilde{w}_i^*}, \pi_{\tilde{w}_i^*}), i = 1, 2, ..., n$ of the criteria $s_1, s_2, ..., s_n$, respectively.

- **Stage-5 :Checking the CR (Consistency ratio)**:
  In spherical fuzzy BWM, pairwise comparison is a consistent matrix $\tilde{x}_{Bi} \times \tilde{x}_{iW} - \tilde{x}_{BW} = 0$. if $\tilde{x}_{Bi} \times \tilde{x}_{iW} - \tilde{x}_{BW} \neq 0$ then, the matrix of pairwise judgment is inconsistent. When $\tilde{x}_{BW}$ being equal to $\tilde{x}_{Bi}$ and $\tilde{x}_{iW}$ then, the inequality will reach the largest, which outputs ζ. Consider the existence of the most significant inequality, according to the relation

$$\frac{\tilde{W}_B}{\tilde{W}_i} \times \frac{\tilde{W}_i}{\tilde{W}_w} - \frac{\tilde{W}_B}{\tilde{W}_w} = 0$$

$\tilde{W}_i$ can be obtained as ,

$$(\tilde{x}_{Bi} - \zeta) \times (\tilde{x}_{iW} - \zeta) - (\tilde{x}_{BW} - \zeta) = 0 \qquad (6)$$

As for the maximum spherical fuzzy, it is inconsistent, so $\tilde{x}_{BW} = \tilde{x}_{iW} = \tilde{x}_{iW}$ then the equation reduces to

$$\zeta^2 - (1 + 2\tilde{x}_{BW})\zeta + (\tilde{x}_{BW}^2 - \tilde{x}_{BW}) = 0 \tag{7}$$

Here $\zeta = (\mu_{\tilde{\zeta}}, \nu_{\tilde{\zeta}}, \pi_{\tilde{\zeta}})$ is an SFS and $\tilde{x}_{BW} = (\mu_{BW}, \nu_{BW}, \pi_{BW})$.

The maximum spherical fuzzy number $\tilde{x}_{BW} = (\mu_{BW}, \nu_{BW}, \pi_{BW}) = (0.9, 0.1, 0.0)$.
So $\mu_{BW} = 0.9, \nu_{BW} = 0.1, \pi_{BW} = 0.0$. So, $\max(\mu_{BW}, \nu_{BW}, \pi_{BW})$ cannot exceed the value 0.9.The Consistency Index (CI) using Eq. (7) for SFS is 2.83. Using the same procedure, we have the CI for SFS. Table 4 represents the value of SFS CI.

Table 4: **Consistency Index of SFS**

Consistency Index (CI)	**Value**
(0.5, 0.4, 0.4)	2.11
(0.6, 0.4, 0.3)	2.30
(0.7, 0.3, 0.2)	2.48
(0.8, 0.2, 0.1)	2.66
(0.9, 0.1, 0.0)	2.83

- **Stage-6 : Crisp Priority Value** :
  Finally, we alter optimal spherical fuzzy PV $\tilde{w}_1^*, \tilde{w}_2^*, ..., \tilde{w}_n^*$, into a crisp value with the help of the formula (8).

$$S(\tilde{W_i^*}) = \sqrt{\left\{|100[(3\mu_{wi^*} - \frac{\pi_{wi^*}}{2}) - (\frac{\nu_{wi^*}}{2} - \pi_{wi^*})]|\right\}},$$
$$i = 1, 2, ..., n \tag{8}$$

- **Stage-7 : Normalized Weights**:
  PVs of criteria in the normalized form are measured by the formula (9).

$$\tilde{W_i}^{*S} = \frac{S(\tilde{W_i^*})}{\sum_1^n S(\tilde{W_i^*})} \qquad i = 1, 2, ..., n \tag{9}$$

- **Phase 2**
  Here, SFAHP is used for global PVs of indicators. To determine global PVs, the PVs of criteria from phase-1 are used. The proposed SFAHP technique consists of 5 stages. The respective stages are given as follows:

- **Stage-1 : Matrix of Spherical Fuzzy Judgment**:
  In stage 1, construction of the spherical fuzzy judgment matrices with the help of Table. 1 of alternatives using each criterion is done. To check the consistency of the spherical fuzzy judgment matrix, conversion of score indices (SI) of spherical fuzzy judgment is done. The SI and 1/SI is calculated using formulae (10) and (11). It is seen that when the conversion of score indices is done, then the pairwise judgment matrix looks similar to the matrix of the ordinary crisp pairwise judgment of AHP. Thus, the CR of the pairwise judgment matrix is measured by the normal AHP process.

$$SI = \sqrt{\{|100 \times [(\mu_{A_s} - \pi_{A_s})^2 - (\nu_{A_s} - \pi_{A_s})^2]\,|\}} \tag{10}$$

$$\frac{1}{SI} = \frac{1}{\sqrt{\{|100 \times [(\mu_{A_s} - \pi_{A_s})^2 - (\nu_{A_s} - \pi_{A_s})^2]\,|\}}} \tag{11}$$

- **Stage-2**: Local PVs
  Local PVs of alternatives are calculated using the SWAN operator that is represented by formula (12).

$$(SphericalWeightedArithmaticMean)SWAM_W(A_{S1}, A_{S2}, ..., A_{Sn}) = w_1 A_{S1} + w_2 A_{S2} + ... + w_n A_{Sn} =$$

$$\left\langle \sqrt{\left[1 - \prod_{i=1}^{n}(1 - \mu^2_{A_{Si}})^{w_i}\right]}, (\nu^2_{A_{Si}})^{w_i}, \sqrt{\left[(1 - \mu^2_{A_{Si}})^{w_i} - (1 - \mu^2_{A_{Si}} - \pi^2_{A_s})^{w_i}\right]} \right\rangle, \forall i \qquad \text{where } w = \frac{1}{n} \tag{12}$$

- **Stage-3 :Global Fuzzy PVs** :
  Global PVs are used in two ways: an utterly fuzzy approach and a partially fuzzy approach. Both of these cases use the spherical fuzzy multiplication given by the formula (13). The fuzzy AHP PVs for each indicator are calculated using Formulae (14) and (15), yielding fully fuzzy and partially fuzzy results, respectively.

$$\tilde{A}_{S_i} = \tilde{w}_j^{*S}\, \tilde{A}_{S_i} = \left\langle \sqrt{1 - (1 - \mu^2_{\tilde{A}_s})^{w_i}},\ (\nu_{\tilde{A}_s})^{w_i},\ \sqrt{(1 - \mu^2_{\tilde{A}_s})^{w_i} - (1 - \mu^2_{\tilde{A}_s} - \pi^2_{\tilde{A}_s})^{w_i}} \right\rangle \tag{13}$$

$$\begin{aligned} &\prod_{j=1}^{n} \tilde{A}_{S_{ij}} \\ &= \tilde{A}_{S_{i1}} \otimes \tilde{A}_{S_{i2}} \otimes \cdots \otimes \tilde{A}_{S_{in}}, \quad \forall i \\ &\tilde{A}_{S_{i1}} \otimes \tilde{A}_{S_{i2}} \\ &= \left\langle \mu_{\tilde{A}_{S_{i1}}}\, \mu_{\tilde{A}_{S_{i2}}},\ \sqrt{\nu^2_{\tilde{A}_{S_{i1}}} + \nu^2_{\tilde{A}_{S_{i2}}} - \nu^2_{\tilde{A}_{S_{i1}}}\, \nu^2_{\tilde{A}_{S_{i2}}}},\ \sqrt{(1 - \nu^2_{\tilde{A}_{S_{i1}}})\pi^2_{\tilde{A}_{S_{i1}}} + (1 - \nu^2_{\tilde{A}_{S_{i2}}})\pi^2_{\tilde{A}_{S_{i2}}} - \pi^2_{\tilde{A}_{S_{i1}}}\, \pi^2_{\tilde{A}_{S_{i2}}}} \right\rangle \end{aligned} \tag{14}$$

$$\tilde{F} = \sum_{i=1}^{n} \tilde{A}_{S_{ij}} = \tilde{A}_{S_{i1}} \oplus \tilde{A_{S_{i2}}} \oplus ... \oplus \tilde{A}_{S_{in}} \tag{15}$$

$$\begin{aligned} &\tilde{A}_{S_{i1}} \oplus \tilde{A}_{S_{i2}} \\ &= \left\langle \sqrt{\mu^2_{\tilde{A}_{S_{i1}}} + \mu^2_{\tilde{A}_{S_{i2}}} - \mu^2_{\tilde{A}_{S_{i1}}}\, \mu^2_{\tilde{A}_{S_{i2}}}}, \nu_{\tilde{A}_{S_{i1}}}\, \nu_{\tilde{A}_{S_{i2}}}, \sqrt{(1 - \mu^2_{\tilde{A}_{S_{i1}}})\pi^2_{\tilde{A}_{S_{i1}}} + (1 - \mu^2_{\tilde{A}_{S_{i2}}})\pi^2_{\tilde{A}_{S_{i2}}} - \pi^2_{\tilde{A}_{S_{i1}}}\, \pi^2_{\tilde{A}_{S_{i2}}}} \right\rangle, \forall i \end{aligned}$$

The final score is calculated by formula (15).

- **Stage-4 : Global Defuzzified PVs** :
  Finally, defuzzification of PVs of each indicator is done by formula (8).

- **Stage-5 :Rank** :
  Finally, normalized PVs and rank are calculated using formula (9).

5. Methodology

The main objective here is to develop a new hybrid MCDM method, namely SF-BWAHP in spherical fuzzy set environments. Firstly, SFBWM is applied for selecting the best and the worst criteria. Then, SFAHP, is used to find essential indicators. This study is divided into five parts: Real-life decision-making problem, Application of SF-BWAHP, case study, development of the index, and validation of the model.

5.1. Real-life decision-making problem

Environmental change is one of the unprecedented challenges of the 21st century. Hydroelectric power is the most essential and inexhaustible source of low-carbon fuel, producing just over 15% of the world's total electrical energy. Hydropower generates energy from water, and the adjustment of the characteristic water yen due to environmental changes affected the age of the power. In territories where the water bodies will diminish because of environmental changes, new hydropower plants can be set up, keeping in mind the alternatives that can increase the proficiency of the plant. In this way, the environmental change is a test for hydropower and a chance for advancement and improving the world.

5.2. Application of SFBWAHP MCDM

5.2.1. ***Application of SFWBM.*** Firstly, the best and the worst criteria are selected as per the data gathered. From that point, the pair wise comparison is finished by best rules available in Table 5. Essentially; another pairwise investigation is finished by most exceedingly awful models with every ground, which appears in Table 6. After developing a pairwise examination network, we define the dynamic improvement issue, and condition (3) addresses this numerical plan. In this case, s_1, s_2 and s_3 are the criteria denoting Temperature, Precipitation and Evapo-transpiration and y_1, y_2, y_3, y_4, y_5 and y_6 are the alternatives representing Efficiency of turbine, Factor of utilization, Rate of discharge, Hydraulic head, Capacity factor and Capacity of storage respectively.

Table 5: **Membership, Non-membership, and Hesitancy Values**

	s_1	s_2	s_3
s_1 (best criteria)	(0.5, 0.4, 0.4)	(0.7, 0.3, 0.2)	(0.8, 0.2, 0.1)

Table 6: **Membership, Non-membership, and Hesitancy Values for Worst Criteria**

	s_3 (worst criteria)
s_1	(0.8, 0.2, 0.1)
s_2	(0.6, 0.4, 0.3)
s_3	(0.5, 0.4, 0.4)

$$\min(\lambda, \lambda, \lambda)$$

Subject to

$$\left(\begin{array}{lcll}
\left|\frac{(\mu_{\tilde{W}_B},\nu_{\tilde{W}_B},\pi_{\tilde{W}_B})}{(\mu_{\tilde{W}_1},\nu_{\tilde{W}_1},\pi_{\tilde{W}_1})}\right. & - & (\mu_{\tilde{x}_{B1}},\nu_{\tilde{x}_{B1}},\pi_{\tilde{x}_{B1}})| & \leq (\lambda,\lambda,\lambda) \\
\left|\frac{(\mu_{\tilde{W}_B},\nu_{\tilde{W}_B},\pi_{\tilde{W}_B})}{(\mu_{\tilde{W}_2},\nu_{\tilde{W}_2},\pi_{\tilde{W}_2})}\right. & - & (\mu_{\tilde{x}_{B2}},\nu_{\tilde{x}_{B2}},\pi_{\tilde{x}_{B2}})| & \leq (\lambda,\lambda,\lambda) \\
\left|\frac{(\mu_{\tilde{W}_B},\nu_{\tilde{W}_B},\pi_{\tilde{W}_B})}{(\mu_{\tilde{W}_3},\nu_{\tilde{W}_3},\pi_{\tilde{W}_3})}\right. & - & (\mu_{\tilde{x}_{B3}},\nu_{\tilde{x}_{B3}},\pi_{\tilde{x}_{B3}})| & \leq (\lambda,\lambda,\lambda) \\
\left|\frac{(\mu_{\tilde{W}_B},\nu_{\tilde{W}_B},\pi_{\tilde{W}_B})}{(\mu_{\tilde{W}_4},\nu_{\tilde{W}_4},\pi_{\tilde{W}_4})}\right. & - & (\mu_{\tilde{x}_{B4}},\nu_{\tilde{x}_{B4}},\pi_{\tilde{x}_{B4}})| & \leq (\lambda,\lambda,\lambda) \\
\left|\frac{(\mu_{\tilde{W}_1},\nu_{\tilde{W}_1},\pi_{\tilde{W}_1})}{(\mu_{\tilde{W}_w},\nu_{\tilde{W}_w},\pi_{\tilde{W}_w})}\right. & - & (\mu_{\tilde{x}_{W1}},\nu_{\tilde{x}_{W1}},\pi_{\tilde{x}_{W1}})| & \leq (\lambda,\lambda,\lambda) \\
\left|\frac{(\mu_{\tilde{W}_2},\nu_{\tilde{W}_2},\pi_{\tilde{W}_2})}{(\mu_{\tilde{W}_w},\nu_{\tilde{W}_w},\pi_{\tilde{W}_w})}\right. & - & (\mu_{\tilde{x}_{W2}},\nu_{\tilde{x}_{W2}},\pi_{\tilde{x}_{W2}})| & \leq (\lambda,\lambda,\lambda) \\
\left|\frac{(\mu_{\tilde{W}_3},\nu_{\tilde{W}_3},\pi_{\tilde{W}_3})}{(\mu_{\tilde{W}_w},\nu_{\tilde{W}_w},\pi_{\tilde{W}_w})}\right. & - & (\mu_{\tilde{x}_{W3}},\nu_{\tilde{x}_{W3}},\pi_{\tilde{x}_{W3}})| & \leq (\lambda,\lambda,\lambda) \\
\left|\frac{(\mu_{\tilde{W}_4},\nu_{\tilde{W}_4},\pi_{\tilde{W}_4})}{(\mu_{\tilde{W}_w},\nu_{\tilde{W}_w},\pi_{\tilde{W}_w})}\right. & - & (\mu_{\tilde{x}_{W4}},\nu_{\tilde{x}_{W4}},\pi_{\tilde{x}_{W4}})| & \leq (\lambda,\lambda,\lambda)
\end{array}\right) \tag{16}$$

$$\sum_{i=1}^{n} R(\tilde{W}_i) = 1$$

$$0 \leq \mu_{\tilde{w}_i}^2 + \nu_{\tilde{w}_i}^2 + \pi_{\tilde{w}_i}^2 \leq 1, \quad \forall i = 1, 2, 3, 4$$

$$\mu_{\tilde{w}_i}^2 + \nu_{\tilde{w}_i}^2 + \pi_{\tilde{w}_i}^2 \geq 0, \ i = 1, 2, ..., n$$

Problem (16) is a nonlinear optimization problem. We consider the application of SFAHP.

5.2.2. ***Application of SFAHP***. In this study, SFAHP is utilized to evaluate the local PV of each alternative concerning each criterion. Therefore, an alternative to each standard requires pair-wise judgment. Tables 7, 8, and 9 show the pairwise assessment of the alternatives concerning the criteria s_1, s_2 and s_3 respectively.

$$\min \ \lambda$$

$$\text{Subject to} \quad \left.\begin{array}{l}
(\mu_{\tilde{W}_B} - 0.7\pi_{\tilde{W}_2} \leq \lambda\pi_{\tilde{W}_2}) \ , \ (\mu_{\tilde{W}_B} - 0.7\pi_{\tilde{W}_2} \geq \ -\lambda\pi_{\tilde{W}_2}) \\
(\nu_{\tilde{W}_B} - 0.3\nu_{\tilde{W}_2} \leq \lambda\nu_{\tilde{W}_2}) \ , \ (\nu_{\tilde{W}_B} - 0.3\nu_{\tilde{W}_2} \geq \ -\lambda\nu_{\tilde{W}_2}) \\
(\pi_{\tilde{W}_B} - 0.2\mu_{\tilde{W}_2} \leq \lambda\mu_{\tilde{W}_2}) \ , \ (\pi_{\tilde{W}_B} - 0.2\mu_{\tilde{W}_2} \geq \ -\lambda\mu_{\tilde{W}_2}) \\
(\mu_{\tilde{W}_B} - 0.8\pi_{\tilde{W}_3} \leq \lambda\pi_{\tilde{W}_2}) \ , \ (\mu_{\tilde{W}_B} - 0.8\pi_{\tilde{W}_3} \geq \ -\lambda\pi_{\tilde{W}_3}) \\
(\nu_{\tilde{W}_B} - 0.2\nu_{\tilde{W}_3} \leq \lambda\nu_{\tilde{W}_3}) \ , \ (\nu_{\tilde{W}_B} - 0.2\nu_{\tilde{W}_3} \geq \ -\lambda\nu_{\tilde{W}_3}) \\
(\pi_{\tilde{W}_B} - 0.1\mu_{\tilde{W}_3} \leq \lambda\mu_{\tilde{W}_3}) \ , \ (\pi_{\tilde{W}_B} - 0.1\mu_{\tilde{W}_3} \geq \ -\lambda\mu_{\tilde{W}_3}) \\
(\mu_{\tilde{W}_2} - 0.6\pi_{\tilde{W}_w} \leq \lambda\pi_{\tilde{W}_w}) \ , \ (\mu_{\tilde{W}_2} - 0.6\pi_{\tilde{W}_w} \geq \ -\lambda\pi_{\tilde{W}_w}) \\
(\nu_{\tilde{W}_2} - 0.4\nu_{\tilde{W}_w} \leq \lambda\nu_{\tilde{W}_w}) \ , \ (\nu_{\tilde{W}_2} - 0.4\nu_{\tilde{W}_w} \geq \ -\lambda\nu_{\tilde{W}_w}) \\
(\pi_{\tilde{W}_2} - 0.3\mu_{\tilde{W}_w} \leq \lambda\mu_{\tilde{W}_w}) \ , \ (\pi_{\tilde{W}_2} - 0.3\mu_{\tilde{W}_w} \geq \ -\lambda\mu_{\tilde{W}_w})
\end{array}\right\}$$

$$\begin{array}{l}
\displaystyle\sum_{i=1}^{4} \frac{\tilde{\mu}_{W_i} + \tilde{\nu}_{W_i} + \tilde{\pi}_{W_i}}{3} = 1 \\
0 \leq \tilde{\mu}_{W_i}^2 + \tilde{\nu}_{W_i}^2 + \tilde{\pi}_{W_i}^2 \leq 1, \forall i = 1, 2, 3. \\
\tilde{\mu}_{W_i}, \tilde{\nu}_{W_i}, \tilde{\pi}_{W_i} \geq 0, i = 1, 2, 3 \\
\lambda \geq 0
\end{array} \tag{17}$$

Table 7: **Pairwise judgment table of alternatives caused by S_1.**

	y_1	y_2	y_3	y_4	y_5	y_6
y_1	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)	(0.7, 0.3, 0.2)	(0.7, 0.3, 0.2)	(0.6, 0.4, 0.3)	(0.8, 0.2, 0.1)
y_2	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)	(0.7, 0.3, 0.2)	(0.6, 0.4, 0.3)	(0.6, 0.4, 0.3)	(0.7, 0.3, 0.2)
y_3	(0.3, 0.7, 0.2)	(0.3, 0.7, 0.2)	(0.5, 0.4, 0.4)	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)
y_4	(0.3, 0.7, 0.2)	(0.4, 0.6, 0.3)	(0.6, 0.4, 0.3)	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)	(0.7, 0.3, 0.2)
y_5	(0.4, 0.6, 0.3)	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)
y_6	(0.2, 0.8, 0.1)	(0.3, 0.7, 0.2)	(0.4, 0.6, 0.3)	(0.3, 0.7, 0.2)	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)

Table 8: **Pairwise judgment table of alternatives caused by S_2.**

	y_1	y_2	y_3	y_4	y_5	y_6
y_1	(0.5, 0.4, 0.4)	(0.5, 0.4, 0.4)	(0.7, 0.3, 0.2)	(0.6, 0.4, 0.3)	(0.9, 0.1, 0.0)	(0.6, 0.4, 0.3)
y_2	(0.5, 0.4, 0.4)	(0.5, 0.4, 0.4)	(0.7, 0.3, 0.2)	(0.8, 0.2, 0.1)	(0.8, 0.2, 0.1)	(0.7, 0.3, 0.2)
y_3	(0.3, 0.7, 0.2)	(0.3, 0.7, 0.2)	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)	(0.7, 0.3, 0.2)	(0.6, 0.4, 0.3)
y_4	(0.4, 0.6, 0.3)	(0.2, 0.8, 0.1)	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)	(0.5, 0.4, 0.4)
y_5	(0.1, 0.9, 0.0)	(0.2, 0.8, 0.1)	(0.3, 0.7, 0.2)	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)	(0.4, 0.6, 0.3)
y_6	(0.4, 0.6, 0.3)	(0.3, 0.7, 0.2)	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)	(0.5, 0.4, 0.4)

Table 9: **Pairwise judgment table of alternatives caused by S_3.**

	y_1	y_2	y_3	y_4	y_5	y_6
y_1	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)	(0.8, 0.2, 0.1)	(0.7, 0.3, 0.2)	(0.9, 0.1, 0.0)	(0.8, 0.2, 0.1)
y_2	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)	(0.6, 0.4, 0.3)	(0.6, 0.4, 0.3)	(0.8, 0.2, 0.1)	(0.7, 0.3, 0.2)
y_3	(0.2, 0.8, 0.1)	(0.4, 0.6, 0.3)	(0.5, 0.4, 0.4)	(0.4, 0.6, 0.3)	(0.7, 0.3, 0.2)	(0.4, 0.6, 0.3)
y_4	(0.3, 0.7, 0.2)	(0.4, 0.6, 0.3)	(0.6, 0.4, 0.3)	(0.5, 0.4, 0.4)	(0.8, 0.2, 0.1)	(0.6, 0.4, 0.3)
y_5	(0.1, 0.9, 0.0)	(0.2, 0.8, 0.1)	(0.3, 0.7, 0.2)	(0.2, 0.8, 0.1)	(0.5, 0.4, 0.4)	(0.3, 0.7, 0.2)
y_6	(0.2, 0.8, 0.1)	(0.3, 0.7, 0.2)	(0.6, 0.4, 0.3)	(0.4, 0.6, 0.3)	(0.7, 0.3, 0.2)	(0.5, 0.4, 0.4)

5.3. Case study

The Bhakra Nangal Dam is the second tallest dam in Asia in the provinces of Punjab and Himachal Pradesh. This is India's most amazing straight gravity dam, staggering at about 207.26 meters to 168.35 km. Bakla Nang Dam is 518.25 (1700 ft) long and about 9.1 m (30 ft) wide. There are 10 hydro generators on either side. Japan's Hitachi rose to introduce Sumitomo, Hitachi, and Ann Ritz restrictions, giving generators to generate power. It is a significant dam of all dams in Asian countries. Therefore, we pondered this in a situational analysis to analyze the impact of environmental changes on hydropower plants. Table 10 displays standardized information in Bhakra Nangal Hydroelectric Power Project (Global Energy Observatory)[41].

Table 10: **Data of the Magnitude value of alternatives**.

Indicator	**Data in normalization form**
Efficiency turbine (in %)	0.008229
The factor of utilization (in %)	0.007588
Rate of discharge (in cu mech)	0.84372
Hydraulic head (in meter)	0.011014
Capacity factor (in %)	0.009756
Capacity of storage (in cubic meters)	0.119693

5.4. Development of index

The index was developed to represent efficiency according to several indicators. The index can be equivalent to several other investigative decision functions. This study defines an index I (Equation (18)) that is proportional to the efficiency of HPP. This index constitutes the weighted sum of each metric.

$$I = \frac{\sum_{i=1}^{6} w_i y_i}{\sum_{i=1}^{6} w_i} \tag{18}$$

Where y_i indicates i-th indicator, as well as w_i, denotes the PV of the i-th indicator.

5.5. Validation of the model

This section is divided into scenario analysis and sensitivity analysis to validate our proposed model. All these subdivisions are described below.

5.5.1. ***Analysis of scenario.*** In this study, scenario analysis is performed with possible HPP efficiencies and non-possible HPP efficiencies. The conditions are formed by expanding and diminishing the initial two most significant parameters. An increment or decrement of the standardized value of every parameter from 1% to 15% is likely for this situation. This condition, which increases or decreases the normalized value of each parameter from 15% to 100%, is called an unlikely scenario.

5.5.2. ***Analysis of sensitivity.*** The sensitivity analysis of the provided MCDM method is evaluated using the secondary reference size. The values of some well-defined indicators remain unchanged. Therefore, if the ranking of indicators is changed it is to be assumed that the technology is sensitive and vice versa. This type of sensitivity investigation was provided by Hamby (1994) [42].

6. Result and discussion

The results obtained in this investigation can be divided into three parts: using MCDM based on the method used the results of using scenario research, and the sensitivity test. The results are again divided into four parts: MCDM tool results, comparative studies, scenario analysis results, and sensitivity survey results. MCDM results are described in three subsections.

6.1. Result obtained from MCDM

Here, we select three criteria and six indicators. Then we propose a method, namely SFBWAHP. Here we study the result from MCDM into three sub-sections: Result obtained from SFBWM, Result using SFAHP, and Result utilizing SFBWAHP.

6.1.1. ***Result obtained from SFBWM.*** Solving Eq. (17), the optimal spherical fuzzy priority values (PVs) of three criteria are obtained. Table 11 represents these PVs of criteria in optimal spherical fuzzy PVs, the defuzzified criteria PVs and the normalized spherical fuzzy PVs form. According to the result, the temperature is the most crucial criterion.

Table 11: **PVS of criteria**

	Optimal spherical fuzzy PVs	**Defuzzify the criteria PVs**	**Normalize spherical fuzzy PVs**
s_1	(0.713, 0.639, 0.287)	19.96	0.689
s_2	(0.210, 0.340, 0.308)	4.565	0.158
s_3	(0.163, 0.248, 0.091)	4.438	0.153
λ	(0.131, 0.131, 0.131)	–	–

$$CI = 2.83$$

$$CR = \frac{0.131}{2.83} = 0.0463 \to 0$$

6.1.2. ***Result from SFAHP.*** Table 12 shows the local weights of alternatives in spherical fuzzy weights and the DE fuzzified criteria weights form.

Table 12: Local PVs of indicators

	s_1		s_2		s_3	
	Spherical fuzzy PVs	**Defuzzified criteria PVs**	**Spherical fuzzy PVs**	**Defuzzified criteria PVs**	**Spherical fuzzy PVs**	**Defuzzified criteria PVs**
y_1	(0.668, 0.324, 0.253)	18.761	(0.685, 0.303, 0.267)	19.184	(0.757, 0.240, 0.190)	21.756
y_2	(0.602, 0.389, 0.285)	16.611	(0.695, 0.288, 0.238)	19.648	(0.631, 0.363, 0.269)	17.573
y_3	(0.454, 0.516, 0.321)	11.997	(0.537, 0.459, 0.283)	14.691	(0.474, 0.524, 0.287)	12.776
y_4	(0.546, 0.448, 0.293)	14.893	(0.458, 0.514, 0.326)	12.082	(0.581, 0.419, 0.275)	16.038
y_5	(0.476, 0.490, 0.340)	12.557	(0.349, 0.646, 0.270)	9.1169	(0.301, 0.695, 0.227)	7.7873
y_6	(0.367, 0.619, 0.279)	9.5955	(0.465, 0.503, 0.331)	12.282	(0.499, 0.503, 0.276)	13.582
CR	$0.68 < 1$		$0.61 < 1$		$0.95 < 1$	

6.1.3. ***Result from Final of SFBWMAHP.*** In this study, global PVs are determined by two approaches, namely, an utterly fuzzy approach and a partially fuzzy approach. The PVs and ranking obtained from completely fuzzy and partly fuzzy techniques are described below in Tables 13 and 14. According to the cases, the efficiency of turbine has the most significant effect on HPP efficiency. The current study's results are also supported by some existing studies [26, 27].

Table 13: **Final PVs and ranking obtained from a completely fuzzy approach**

	Spherical fuzzy PVs	**Defuzzification of the criteria PVs**	**Normalize spherical fuzzy PVs**	**Rank**
y_1	(0.017, 0.977, 0.116)	3.7292	0.196	1
y_2	(0.062, 0.955, 0.118)	3.3635	0.176	3
y_3	(0.058, 0.920, 0.206)	2.4370	0.128	6
y_4	(0.027, 0.972, 0.122)	3.6383	0.191	2
y_5	(0.042, 0.930, 0.204)	2.6003	0.136	5
y_6	(0.053, 0.952, 0.134)	3.2983	0.173	4

Table 14: **Final PVs and ranking obtained from partially fuzzy approach**

	Spherical fuzzy PVs	Defuzzified the criteria PVs	Normalize spherical fuzzy PVs	Rank
y_1	(0.687, 0.306, 0.612)	16.934	0.197	1
y_2	(0.611, 0.396, 0.554)	15.159	0.177	3
y_3	(0.494, 0.488, 0.463)	12.325	0.144	5
y_4	(0.630, 0.308, 0.547)	15.688	0.183	2
y_5	(0.446, 0.498, 0.431)	11.077	0.129	6
y_6	(0.590, 0.314, 0.524)	14.621	0.170	4

6.2. Comparative study

Table 15 highlights the values as well as the ranking order for the given alternatives. From Table 15, it is seen that the proposed tool demonstrates better performance according to the other techniques. Again, this table shows that the optimal alternative is y_1, i.e., efficiency of turbine for all the approaches but these approaches have different computational steps. In feature the result is compared by some aggression operators like Schweizer-Sklar (SS) aggregation operator based on CmPFS (cubic m-polar fuzzy set) [43] and linear Diophantine fuzzy sine-trigonometric aggregation operations [44].

Table 15: **Results obtained from a comparative study**

	Proposed method (completely fuzzy)	Proposed method (partially fuzzy)	SFAHP (complete fuzzy)	SFAHP (partial fuzzy)	Fuzzy AHP
y_1	0.196	0.197	0.206	0.204	0.331
y_2	0.176	0.177	0.183	0.175	0.330
y_3	0.128	0.144	0.131	0.142	0.111
y_4	0.191	0.183	0.201	0.181	0.117
y_5	0.136	0.129	0.135	0.128	0.046
y_6	0.173	0.170	0.144	0.169	0.033

6.3. Result from scenario analysis

The scenario analysis is divided into two stages, namely likely and unlikely scenarios. The normalized value of the most important parameter increases or decreases within the range 1%–15% and 15%–100%, which are referred to as the likely and unlikely scenarios, respectively. The likely scenario is divided into six parts, namely +5%, +10%, +15%, −5%, −10% and −15%. The unlikely scenario is divided into six parts, namely +20%, +50%, +100%, −20%, −50% and −100%. Here the + and − signs represent increases and decreases of the most significant indicator, respectively. Table 16 shows that for the likely scenario the index value is highest in Scenario C when the efficiency of turbine is raised by 15%, and lowest in Scenario F.

Table 16: **Result obtained from the analysis of scenario**.

Likely scenario	Different scenario	Change of percentage of most significant factors	Value of index
	Scenario A	5%	0.171289
	Scenario B	10%	0.171398
	Scenario C	15%	0.171506
	Scenario D	−5%	0.171072
	Scenario E	−10%	0.170964
	Scenario F	−15%	0.170855
Normal scenario	–	–	0.171181
Unlikely scenario	Scenario A	20%	0.171615
	Scenario B	50%	0.172266
	Scenario C	100%	0.173350
	Scenario D	−20%	0.170747
	Scenario E	−50%	0.170096
	Scenario F	−100%	0.169011

6.4. Result from sensitivity analysis

A sensitivity analysis is recommended to check the sensitivity of the proposed model according to the input indicator. If PV matches the sensitivity of the indicator, the result is confirmed. The result shows that the Efficiency of turbine (y_1) is the most sensitive parameter with swing2 value 56.8% . It Is also observed that the two least sensitive parameters are Capacity factor (y_5) with swing2 value 9.8%. Using SensIt 1.40 Academic Version software analyze the sensitivity of the parameters. Fig. 3 shows the results of the sensitivity test.

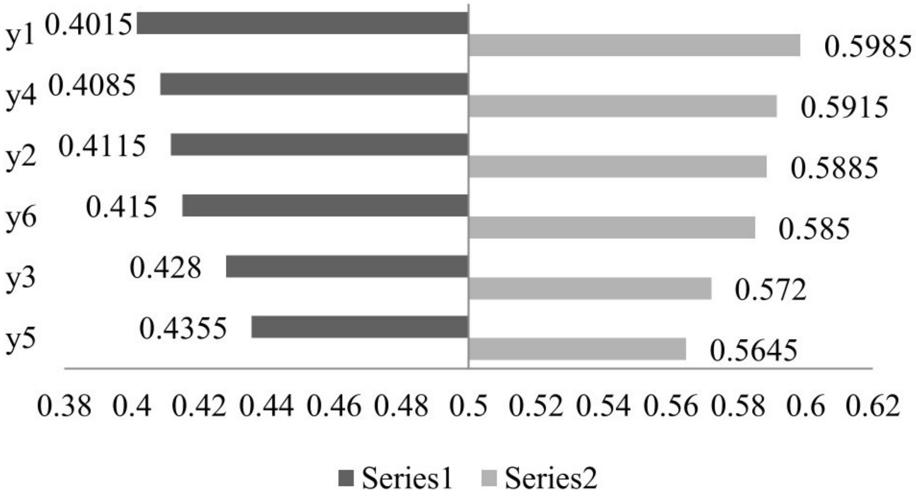

Figure 1: *
Figure 3: Result from the sensitivity analysis

7. Advantage of the study

The advantages of the proposed method are: The proposed approach allows decision-makers to make relative comparisons between alternatives, which can be more intuitive and less complex than assigning numerical values to criteria. The proposed method is relatively simple to understand and use compared to some other MCDM methods, making it accessible to a wide range of decision-makers, including those without a deep background in mathematics or statistics. This method is effective at handling situations where there is asymmetric information or varying degrees of importance among criteria. It allows decision-makers to express their preferences for criteria in a straightforward manner. The method provides a transparent way to identify the best and worst alternatives, which can be helpful in explaining the decision-making process to stakeholders and ensuring accountability. This approach is robust in the sense that it can handle different types of data (qualitative or quantitative) and doesn't require strict assumptions about data distribution.

8. Disadvantage of this study

While the proposed Method offers several advantages for MCDM, it also comes with some disadvantages and limitations. Here are some of the drawbacks associated with the approach: The proposed approach does not explicitly incorporate weight information for criteria, which can be a disadvantage in cases where certain criteria are significantly more important than others. This can lead to less accurate or less relevant results if all criteria are treated equally. This approach may struggle to handle situations where there are ties or equal preferences for some criteria or alternatives. Resolving ties can be challenging in the absence of explicit weighting information. The proposed approach is better suited to small- to moderate-sized decision problems with a limited number of alternatives and criteria. As the number of alternatives and criteria increases, the method's complexity can become a drawback. Like other MCDM methods, SBWM relies on subjective input from decision-makers. Different individuals or groups may provide different rankings based on their perspectives and preferences, potentially leading to inconsistency.

9. Conclusion

This study develops an innovative MCDM strategy by combining spherical fuzzy set, BWM and AHP, namely SF-BWAHP. After that, this hybridized strategy is used to find the most significant indicator responsible for the performance efficiency of any HPP. The results point to the " efficiency of turbine " as an intrinsic alternative observed by the technique compared to that obtained by previous studies. Criteria weightage is obtained by spherical fuzzy BWM, and alternatives local weightage is obtained by SFBWAHP. As the BWM method only has the capability of finding the criteria weightage but not the alternatives, the AHP technique is utilized to determine the weights of the alternatives.

MCDM methods can be used to evaluate the efficiency of a hydro power plant by considering various features or criteria. The scope of features to assess the efficiency of a hydro power plant using MCDM methods can include:

This is a fundamental criterion and involves evaluating the plant's ability to convert the potential energy of water into electrical power efficiently. Assess the environmental sustainability of the plant, including its impact on aquatic ecosystems, water quality, and greenhouse gas emissions. Consider the costs associated with constructing and operating the hydro power plant and weigh them against the benefits in terms of power generation and revenue. Evaluate the plant's ability to operate consistently and provide power when needed, considering factors like maintenance, downtime, and grid integration. Analyze the availability and sustainability of the water resources that feed the hydro power plant. This includes considering factors like seasonal variations in water flow. Assess the efficiency of the plant's equipment and technology, including turbines, generators, and control systems. Evaluate the plant's ability to adapt to changing climate conditions, such as variations in precipitation and temperature. Consider the plant's impact on local communities, including employment opportunities, land use, and cultural considerations. Ensure that the plant complies with all relevant environmental and safety regulations. If the hydro power plant includes energy storage solutions (e.g., pumped hydro storage), assess their efficiency and effectiveness in grid balancing and energy storage. Evaluate how well the hydro power plant integrates with the existing electrical grid and its contribution to grid stability and reliability. Assess the efficiency of the plant's maintenance and operation practices to minimize downtime and maximize power generation. Consider the expected lifetime of the hydro power plant and the durability of its infrastructure. Evaluate safety measures and protocols in place to protect workers, the public, and the environment. Assess the potential for expanding the plant's capacity or integrating additional renewable energy sources. Consider the efficiency of transmitting the generated energy from the plant to end-users or the grid. Evaluate the sustainable management of water resources, including water conservation practices and ecological considerations. Assess the visual impact of the plant on the surrounding landscape and its integration into the natural environment. Analyze the economic benefits the hydro power plant brings to the local economy, including job creation and increased tourism. Consider the engagement of the local community and stakeholders in the decision-making process and addressing their concerns.

Each of these features can be assigned weights or priorities based on the specific context and goals of the assessment, and MCDM methods can be used to quantitatively evaluate the efficiency of the hydro power plant in relation to these criteria.

Declarations

Ethical approval

This article contains no studies performed by the authors involving human participants or animals.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Informed Consent

Informed consent was not applicable as no human participants were involved in the study.

10. Abbreviations

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BWM	Best–Worst Method
CI	Consistency Index
CR	Consistency Ratio
Fuzzy AHP	Fuzzy Analytic Hierarchy Process
Fuzzy BWM	Fuzzy Best–Worst Method
HFBWM	Hesitant Fuzzy Best Worst Method
HFWs	Hesitant Fuzzy Weights
HPP	Hydropower Plant
HPPs	Hydropower Plants
MCDM	Multi-Criteria Decision Making
PHFE	Probabilistic Hesitant Fuzzy Elements
PV	Priority Value
PVs	Priority Values
s_1	Temperature
s_2	Precipitation
s_3	Evapo-transpiration
SCM	Supply Chain Management
SF-BWAHP	Spherical Fuzzy Best Worst Analytic Hierarchy Process
SFS	Spherical Fuzzy Sets
SI	Score Index
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
VIKOR	VIšekriterijumsko KOmpromisno Rangiranje
y_1	Efficiency of turbine
y_2	The factor of utilization
y_3	Rate of discharge
y_4	Hydraulic head
y_5	Capacity factor
y_6	Capacity of storage

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