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A framework for evaluating cloud computing services using AHP and TOPSIS approaches with interval valued spherical fuzzy sets

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Abstract

The interaction of multi criteria decision making for deciding optimal decision among the entirety of the likely other alternatives. The availability of numerous amount of cloud services make it challenging for decision makers to select a cloud service according to their non-functional requirements as a number of criteria has to be included during selection of cloud services. The amalgamation of analytic hierarchy process (AHP) and technique for order of preference by similarity to ideal solution (TOPSIS) has driven analysts to incorporate the blend with various augmentations of fuzzy sets. Extension of fuzzy set, the newly created 3-D spherical fuzzy set (SFS), is viable in dealing with vulnerability and evaluating expert decisions. In this paper, we have proposed general framework by combining AHP and TOPSIS methods under the dimensions of SFSs. SFAHP is employed to figure the importance of criteria and then these criteria weights used in IVSFTOPSIS (interval valued spherical fuzzy TOPSIS) to track down the ranking position of cloud service providers. This study addresses five different alternatives to six conflicting benchmarks by three decision makers. Sensitivity analysis is also conducted to highlight the reliability of proposed method.

Keywords Cloud computing · Service selection · Quality evaluation · Spherical fuzzy sets (SFS) · AHP · TOPSIS

1 Introduction

The quality of an individual cloud service plays a vital role in selecting the optimal cloud service for the user. Therefore, it is necessary to have a model to assess the quality of each alternative and provide a ranking of all available cloud service providers (CSPs) [1]. The ranking is depending upon multiple criteria from which we determine the quality of alternatives [2]. During the quality evaluation process, the uncertainties in available data make it difficult for the users to scrutinize the conflicting criteria and alternatives. Hence, to overcome the uncertainties and vagueness experienced by users, Zadeh [3] developed fuzzy logic theory as a viable alternative.

A fuzzy set $\tilde{A}$ assigns degree of membership to every element x in the interval [0,1]. It is significant in conditions when a suitable membership function for an element becomes hard to define [4]. This fuzzy set further extended with n-dimensional membership functions to decrease the vagueness in membership functions of ordinary fuzzy sets and defines the opinion of decision experts with more details. Intuitionstic Fuzzy Sets (IFS) proposed by Atanassov [5], assigns the degree of membership (μ) and non-membership (v) to every element x in a fuzzy set with the condition: $\mu + v \leq 1$. The extension of IFS i.e. IFS2 covers larger domain for membership and non membership parameters by satisfying these terms: $(\mu)^2 + (v)^2 \leq 1$ [6]. The additional dimension of IFS i.e. hesitancy degree, is calculated by: $\pi = (1 - (\mu)^2 + (v)^2)^{1/2}$. Neutrosophic Fuzzy Sets (NFS) presented by Smarandache [7], fulfill the need of independent hesitancy degree and it also decrease hesitation of ambiguous data. The membership functions of NFS are defined with truthiness (T), falsity (F) and indeterminacy (I) degrees, which satisfy the condition: $0 \leq T^2 + F^2 + I^2 \leq 3$, where $T, F, I \in [0, 1]$ [8]. Pythagorean Fuzzy Sets (PFS), developed by Yager [9] is defined with membership and non-membership degrees with the

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constraint that square sum of its degrees must be between 0 and 1.

Kutlu Gündoğdu and Kahraman [10] developed the concept of Spherical Fuzzy Sets (SFS) which is a synthesis of PFS and NFS because the theoretical concept of SFS combine larger domain approach from PFS and independency approach from NFS. In SFS hesitancy degree is derived independently by decision makers using linguistic evaluation scale with the following condition: $0 \leq (\mu)^2 + (\nu)^2 + (\pi)^2 \leq 1$ [11].

As a matter of fact, it possibly be infeasible to provide absolute values for membership and non-membership parameters of an element to a given set. Therefore, to make it happen Atanassov and Gargov [12] placed the concept of interval values set, where membership and non-membership values are in intervals rather than real numbers and also suitably describe multi criteria decision making (MCDM) problems in which parameters of elements cannot be delivered with precise numerical values [13]. Cloud Service selection and ranking problem comes in the category of MCDM problems because numerous number of factors and trade-offs need to be analyzed during evaluation process of MCDM problems [14]. In MCDM problems, best alternative is selected from available options by considering multiple criteria associated with alternatives. Various MCDM techniques i.e. AHP, MOORA, VIKOR, TOPSIS, WSM etc. have been proposed by academicians to handle MCDM problems [2].

The main objective of this paper is to enhance the integration of spherical fuzzy sets with MCDM technique i.e., AHP and TOPSIS to achieve more accurate ranking of cloud service providers. Spherical Fuzzy AHP is used to provide the weights to every criteria and then interval valued spherical fuzzy TOPSIS is applied to get the final ranking of the CSP_s. For experimental purpose, a case study of cloud service providers has been considered with six QoS (Quality of Services) criteria and five alternatives. To check the variations in outcome of proposed approach, a sensitive analysis is carried out by interchanging the weights of criteria one at a time.

Various fuzzy MCDM methods and their use in different application areas are discussed in related area section followed by preliminaries of spherical fuzzy sets and interval-valued spherical fuzzy sets (IVSFS). In the next sections, the details of extended methods i.e. AHP in spherical fuzzy environment and TOPSIS in interval-valued spherical fuzzy environment are discussed. Further, the results, sensitive analysis and comparison with basic approaches conducted in cloud computing environment are analysed. At the end of this paper, conclusion and future scope of the work are discussed.

2 Related work

There are many advancements in fuzzy set in the form of IFS, IFS2, NFS, PFS, SFS and researchers applied these fuzzy advancement form for solving different kind of MCDM problems as shown in Table 1. It shows that AHP and TOPSIS are the most commonly used MCDM approaches and have been applied in different application areas i.e. supplier selection, nurse selection, cloud provider selection, energy alternative selection, tourism attraction recommendation, transport project selection, 3D printer selection etc. [6, 13, 19, 23, 35]. AHP is a powerful yet simple method to assign subjective weights to evaluation criteria while TOPSIS is most commonly used MCDM technique because it uses scale method to mimic human choices that simultaneously find the best and worst solutions [13, 17]. These MCDM methods have been integrated with different types of fuzzy sets to solve selection and ranking problems. The main difference between different types of fuzzy sets is due to their constraint conditions in domain coverage of membership functions [4]. Among them, SFS is the latest generalized extension of fuzzy sets and the parameters of membership function in SFS, cover a larger domain. Büyüközkan et al. [16] has evaluated the cloud service providers under interval valued intuitionstic fuzzy environment by utilizing various quality attributes and selection criteria. To the best of our knowledge, the MCDM method TOPSIS with its fuzzy extension i.e. SFS was successfully used in previous studies with different application areas but has not been applied in cloud service selection application by any researcher. So in this paper, the proposed framework extends AHP-TOPSIS methods with spherical fuzzy number(SFN) as a novel hybrid method to improve the evaluation quality of cloud services. Here, we have applied AHP-TOPSIS with spherical fuzzy environment to find the suitable cloud service provider according to user requirement.

3 Spherical fuzzy sets (SFS)

Here, the basic concepts of SFS, interval valued spherical fuzzy sets (IVSFS) with their arithmatic, aggregation and defuzzification operations are defined.

3.1 Preliminaries: basic operations of SFS's

Definition 3.1.1 An SFS is described as [36]:

$$\tilde{A_s} = \{(u, (\mu_{\tilde{A_s}}(u), \nu_{\tilde{A_s}}(u), \pi_{\tilde{A_s}}(u)) \mid u \in U)\} \tag{1}$$

where $\mu_{\tilde{A_s}} : U \rightarrow [0, 1]$ is the membership degree, $\nu_{\tilde{A_s}}$:

Table 1 Literature of MCDM with various extensions of fuzzy set

Year	Author	Type of fuzzy set	MCDM approach	Application area
2020	[4]	IVFS	BWM, TOPSIS	Labours safety level
2020	[15]	IFS	DEMATEL, ANP	Big data analysis
2021	[6]	IFS	TOPSIS	Supplier selection, nurse selection
2018	[16]	Interval valued IFS (IVIFS)	AHP, COPRAS,VIKOR	Cloud provider selection
2020	[8]	Neutrosophic soft set	TOPSIS	Smart phone selection
2018	[1]	NFS	AHP	Cloud computing services
2018	[17]	Interval valued NFS (IVNFS)	AHP	Energy alternative selection
2019	[18]	IVNFS	TOPSIS	Hotel alternatives
2019	[19]	Picture fuzzy number	ANP, TODIM	Tourism attraction recommendation
2020	[20]	Probabilistic hesitant fuzzy	ORESTE	Selection of research topic
2020	[21]	PFS	AHP, TOPSIS, VIKOR	Risk assessment of self-driving vehicles
2019	[22]	PFS	AHP, TOPSIS	Green supplier selection
2021	[23]	Interval valued PFS	MULTIMOORA	Transport project selection
2022	[24]	Fuzzy	AHP, TOPSIS	Cloud services ranking prediction
2022	[25]	Hesitant fuzzy linguistic term set	Best-worst method	Supplier selection
2022	[26]	Intuitionistic fuzzy numbers	AHP. TOPSIS	Cloud service selection
2018	[10]	SFS	TOPSIS	Supplier selection problem
2019	[11]	SFS	VIKOR	Warehouse location selection
2019	[27]	Interval valued SFS	Aggregation operator	Investment policy selection
2019	[13]	Interval valued SFS	TOPSIS	3D printer selection
2021	[28]	Interval valued SFS	AHP	Public transportation development
2022	[29]	SFS	AHP, GRA	Industrialization performance evaluation
2022	[30]	SFS	COPRAS	Augmented reality application selection
2021	[31]	–	Delphi	Assessment indicators for cloud IaaS
2021	[32]	–	ANFIS	Cloud security evaluation
2021	[33]	–	Blockchain-based approaches	Privacy and security of cloud computing
2022	[34]	SFS	AHP, WASPAS	Turbine supplier selection

$U \rightarrow [0,1]$ is the non-membership degree, $\pi_{\tilde{A_s}} : U \rightarrow [0,1]$ is the hesitancy degree of u to $\tilde{A_s}$ such that

$$0 \le \mu^2_{\tilde{A_s}}(u) + v^2_{\tilde{A_s}}(u) + \pi^2_{\tilde{A_s}}(u) \le 1, \forall u \in U \tag{2}$$

Definition 3.1.2 Basic operations of SFS [35]:

$$\widetilde{A_s} \oplus \widetilde{B_s} = \left\{ \left(\mu^2_{\widetilde{A_s}} + \mu^2_{\widetilde{B_s}} - \mu^2_{\widetilde{A_s}} \mu^2_{\widetilde{B_s}} \right)^{1/2}, v_{\widetilde{A_s}} v_{\widetilde{B_s}}, \left(\left(1 - \mu^2_{\widetilde{B_s}} \right) \pi^2_{\widetilde{A_s}} + \left(1 - \mu^2_{\widetilde{A_s}} \right) \pi^2_{\widetilde{B_s}} - \left(\left(1 - \mu^2_{\widetilde{B_s}} \right) \pi^2_{\widetilde{A_s}} \left(\pi^2_{\widetilde{A_s}} \right) \pi^2_{\widetilde{B_s}} \right)^{1/2} \right) \right\} \tag{3}$$

$$\tilde{A_s} \otimes \tilde{B_s} = \left\{ \{ \mu_{\tilde{A_s}} \mu_{\tilde{B_s}}, (v^2_{\tilde{A_s}} + v^2_{\tilde{B_s}} - v^2_{\tilde{A_s}} v^2_{\tilde{B_s}})^{1/2}, ((1 - v^2_{\tilde{B_s}})\pi^2_{\tilde{A_s}} + (1 - v^2_{\tilde{A_s}})\pi^2_{\tilde{B_s}} - \pi^2_{\tilde{A_s}} \pi^2_{\tilde{B_s}})^{1/2} \right\} \tag{4}$$

$$\lambda.\tilde{A_s} = \left\{ (1 - (1 - \mu^2_{\tilde{A_s}})^{\lambda})^{1/2}, v^{\lambda}_{\tilde{A_s}}, ((1 - \mu^2_{\tilde{A_s}})^{\lambda} - (1 - \mu^2_{\tilde{A_s}} - \pi^2_{\tilde{A_s}})^{\lambda})^{1/2} \right\} \text{ for } \lambda \ge 0 \tag{5}$$

Definition 3.1.3 Single valued Spherical Weighted Arithmetic Mean (SWAM) with respect to $w = (w_1, w_2, ...w_n); w_i \in [0,1]; \sum_{i=1}^{n} w_i = 1$, is defined as [10]:

$$SWAM_w(\tilde{A}_{S1},.......\tilde{A}_{Sn}) = w_1\tilde{A}_{S1} + w_2\tilde{A}_{S2} + ... + w_n\tilde{A}_{Sn}$$
$$= \left\{ \left[1 - \Pi_{i=1}^{n}\left(1 - \mu^2_{\tilde{A}_{si}}\right)^{w_i} \right]^{1/2}, \Pi_{i=1}^{n} v^{w_i}_{\tilde{A}_{si}}, \left[\Pi_{i=1}^{n}\left(1 - \mu^2_{\tilde{A}_{si}}\right)^{w_i} - \Pi_{i=1}^{n}\left(1 - \mu^2_{\tilde{A}_{si}} - \pi^2_{\tilde{A}_{si}}\right)^{w_i} \right]^{1/2} \right\} \tag{6}$$

Definition 3.1.4 Score and accuracy functions are determined as [10]:

$$Score(\tilde{A_s}) = (\mu_{\tilde{A_s}} - \pi_{\tilde{A_s}})^2 - (v_{\tilde{A_s}} - \pi_{\tilde{A_s}})^2 \tag{7}$$

$$Accuracy(\tilde{A_s}) = \mu^2_{\tilde{A_s}} + v^2_{\tilde{A_s}} + \pi^2_{\tilde{A_s}} \tag{8}$$

3.2 Preliminaries: basic operations of IVSF

Definition 3.2.1 An Interval Valued Spherical Fuzzy Set $\tilde{A_s}$ of the universe of discourse is described as follows [13]:

$$\tilde{A_S} = \left\{ \mu, \left(\left[\mu^L_{\tilde{A_s}}(\mu), \mu^U_{\tilde{A_s}}(\mu) \right], \left[v^L_{\tilde{A_s}}(\mu), v^U_{\tilde{A_s}}(\mu) \right], \left[\pi^L_{\tilde{A_s}}(\mu), \pi^U_{\tilde{A_s}}(\mu) \right] \right) \mid \mu \in U \right\}$$

Definition 3.2.2 Let $\tilde{\alpha} = ([c,d],[e,f],[g,h])$, $\tilde{\alpha_1} = ([c_1,d_1],[e_1,f_1],[g_1,h_1])$ and $\tilde{\alpha_2} = ([c_2,d_2],[e_2,f_2],[g_2,h_2])$ be IVSFS then [35] [37]:

$$\tilde{\alpha}_1 \cup \tilde{\alpha}_2 = \left\{ \left[max\{c_1,c_2\}, max\{d_1,d_2\} \right], \left[min\{e_1,e_2\}, min\{f_1,f_2\} \right], \left[min\{g_1,g_2\}, min\{h_1,h_2\} \right] \right\} \tag{9}$$

$$\tilde{\alpha}_1 \cap \tilde{\alpha}_2 = \left\{ \left[min\{c_1,c_2\}, min\{d_1,d_2\} \right], \left[max\{e_1,e_2\}, max\{f_1,f_2\} \right], \left[min\{g_1,g_2\}, min\{h_1,h_2\} \right] \right\} \tag{10}$$

$$\tilde{\alpha}_1 \oplus \tilde{\alpha}_2 = \left\{ \left[\left((c_1)^2 + (c_2)^2 - (c_1)^2(c_2)^2 \right)^{1/2}, \left((d_1)^2 + (d_2)^2 - (d_1)^2(d_2)^2 \right)^{1/2} \right], \left[e_1e_2, f_1f_2 \right], \right. \tag{11}$$
$$\left. \left[\left((1-(c_2)^2)(g_1)^2 + (1-(c_1)^2)(g_2)^2 - (g_1)^2(g_2)^2 \right)^{1/2}, \left((1-(d_2)^2)(h_1)^2 + (1-(d_1)^2)(h_2)^2 - (h_1)^2(h_2)^2 \right)^{1/2} \right] \right\}$$

$$\tilde{\alpha}_1 \otimes \tilde{\alpha}_2 = \left\{ \left[c_1c_2, d_1d_2 \right], \left[\left((e_1)^2 + (e_2)^2 - (e_1)^2(e_2)^2 \right)^{1/2}, \left((f_1)^2 + (f_2)^2 - (f_1)^2(f_2)^2 \right)^{1/2} \right], \right. \tag{12}$$
$$\left. \left[\left((1-(e_2)^2)(g_1)^2 + (1-(e_1)^2)(g_2)^2 - (g_1)^2(g_2)^2 \right)^{1/2}, \left((1-(f_2)^2)(h_1)^2 + (1-(f_1)^2)(h_2)^2 - (h_1)^2(h_2)^2 \right)^{1/2} \right] \right\}$$

$$\lambda.\tilde{\alpha} = \left\{ \left[\left(1 - (1-c^2)^\lambda \right)^{1/2}, \left(1 - (1-d^2)^\lambda \right)^{1/2} \right], \left[e^\lambda, f^\lambda \right], \left[\left((1-c^2)^\lambda - (1-c^2-g^2)^\lambda \right)^{1/2}, \left((1-d^2)^\lambda - (1-d^2-h^2)^\lambda \right)^{1/2} \right] \right\} \tag{13}$$

Definition 3.2.3 Let $\tilde{\alpha_j} = ([c_j,d_j],[e_j,f_j],[g_j,h_j])$ be a collection of Interval-Valued Spherical Weighted Arithmetic Mean (IVSWAM) with respect to, $w_j = (w_1, w_2, ...w_n); w_j \in [0,1]; \sum_{j=1}^{n} w_j = 1$, IVSWAM is defined as [38]:

$$IVSWAM_w(\tilde{\alpha}_1, ...\tilde{\alpha}_n) = w_1\tilde{\alpha}_1 \oplus w_2\tilde{\alpha}_2 \oplus ..... \oplus w_n\tilde{\alpha}_n$$
$$= \left\{ \left[\left(1 - \Pi_{j=1}^{n}(1 - c_j{}^2)^{w_j}\right)^{1/2}, \left(1 - \Pi_{j=1}^{n}(1 - d_j{}^2)^{w_j}\right)^{1/2} \right], \right.$$
$$\left[\Pi_{j=1}^{n} e_j^{w_j}, \Pi_{j=1}^{n} f_j^{w_j} \right],$$
$$\left[\left(\Pi_{j=1}^{n}(1 - c_j^2)^{w_j} - \Pi_{j=1}^{n}(1 - c_j^2 - g_j^2)^{w_j} \right)^{1/2}, \right.$$
$$\left. \left. \left(\Pi_{j=1}^{n}(1 - d_j^2)^{w_j} - \Pi_{j=1}^{n}(1 - d_j^2 - h_j^2)^{w_j} \right)^{1/2} \right] \right\} \tag{14}$$

Definition 3.2.4 The score function of IVSFS number α is calculating as [38]:

$$Score(\alpha) = \frac{c^2 + d^2 - e^2 - f^2 - (g/2)^2 - (h/2)^2}{2} \tag{15}$$

4 Spherical fuzzy AHP (SFAHP)

AHP is one of the most accepted weighted factor scoring method, presented by Saaty [39] and has the capability to incorporate inherent inconsistencies during selection procedure. It is widely used with MCDM context related problems and assumes that an MCDM problem has discrete set of m alternatives x_i (i=1,2,…, m), which are assessed on n criteria c_j (j=1,2,…, n) with opinion of k decision makers [24]. Here, we extend AHP by combining it with spherical fuzzy set theory. The steps for applying the SFAHP are as follows:

(i) Decision maker (DM) weight calculation: weight to each DM is assigned according to the experience they have in field of cloud computing [29].

- Score value corresponding to spherical fuzzy preference scale represents the experience of each decison maker (DM) is calculated as follow:

$$Score(k) = (\mu_{\tilde{A_s}} - \pi_{\tilde{A_s}})^2 - (v_{\tilde{A_s}} - \pi_{\tilde{A_s}})^2 \tag{16}$$

- Normalization of DM's weight:

$$weight(k) = \frac{Score(k)}{\sum_{k=1}^{No.ofDM} Score(k)} \tag{17}$$

(ii) Establish spherical fuzzy pairwise comparison matrices: every expert used the weighting scale projected in Table 2 to represent the relation between attributes in their individual comparison matrices. The pairwise comparison matrix on n attributes can be represented in $(n \times n)$ matrix form in which every element i.e. $\tilde{C_{ij}} = (\mu_{\tilde{C}}(ij), v_{\tilde{C}}(ij), \pi_{\tilde{C}}(ij))$ is representing importance of attribute i over attribute j [40].

$$C = [c_{ij}]_{n*n} = \begin{array}{c} \\ C_1 \\ C_2 \\ \cdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} c_{11} & c_{12} & \ldots & c_{1n} \\ c_{21} & c_{22} & \ldots & c_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ c_{n1} & c_{n2} & \ldots & c_{nn} \end{bmatrix} \end{array}$$

(iii) Calculation of spherical fuzzy weighted pairwise comparison matrices [40]:

$$WC(k) = C(k) * weight(k) \tag{18}$$

where, $weight(k)$ is weight assigned to each DM using Eqs. 16, 17.

(iv) Calculate spherical fuzzy average weighted pairwise comparison matrix P [29]:

Table 2 Linguistic terms and spherical fuzzy preference scale

Numerical value	Linguistic terms	Spherical fuzzy numbers	Interval values spherical fuzzy numbers
9	Absolute more significant (AMS)	(0.9, 0.1, 0.1)	([0.85,0.95],[0.10,0.15],[0.05,0.15])
7	Very high significant (VHS)	(0.8, 0.2, 0.2)	([0.75,0.85],[0.15,0.20],[0.15,0.20])
5	High significant (HS)	(0.7, 0.3, 0.3)	([0.65,0.75],[0.20,0.25],[0.20,0.25])
3	Slightly more significant (SMS)	(0.6, 0.4, 0.4)	([0.55,0.65],[0.25,0.30],[0.25,0.30])
1	Equal significant (ES)	(0.5, 0.5, 0.5)	([0.50,0.55],[0.45,0.55],[0.30,0.40])
1/3	Slightly low significant (SLS)	(0.4, 0.6, 0.4)	([0.25,0.30],[0.55,0.65],[0.25,0.30])
1/5	Low significant (LS)	(0.3, 0.7, 0.3)	([0.20,0.25],[0.65,0.75],[0.20,0.25])
1/7	Very low significant (VLS)	(0.2, 0.8, 0.2)	([0.15,0.20],[0.75,0.85],[0.15,0.20])
1/9	Absolute low significant (ALS)	(0.1, 0.9, 0.1)	([0.10,0.15],[0.85,0.95],[0.05,0.15])

$$P = P(\mu(ij), v(ij), \pi(ij)) = \left(\frac{\sum_1^k WC(\mu(ij))}{3}, \frac{\sum_1^k WC(v(ij))}{3}, \frac{\sum_1^k WC(\pi(ij))}{3} \right) \quad (19)$$

(v) Evaluate consistency: the matrix P is converted to crisp value matrix for checking the consistency of the evaluation. This conversion is necessary because calculation of consistency ratio in AHP refers strictly to crisp valued pairwise comparison matrix (PCM) and still no confirmed method exists for fuzzy PCM consistency check. Therefore, matrix P is changed to crisp pairwise comparison martix, using $P = [p_{ij}] = [\frac{\mu_{ij}}{v_{ij}}]$ and then Saaty's basic consistency ratio method is used [24].

(vi) Calculate the weights of attributes:

- Calculate the geometric mean for each row using the following aggregration expression of SFS [29]:

$$p^i = \left(\prod_{j=1}^{n} p_{ij} \right)^{1/n} \quad (20)$$

- Compute the priority of each row $F(p^i)$ using prioritization function proposed by Iman Mohamad [40] as follows:

$$F(p^i) = \mu(1 - v)(1 - \pi) \quad (21)$$

- Find the priority vector $W = [w_1, w_2, ...wn]$, where

$$w_i = \frac{F(p^i)}{\sum_{i=1}^{n} F(p^i)} \quad (22)$$

5 IVSF-TOPSIS

TOPSIS is an generally utilized outranking approach presented by Ching-Lai Hwang and Yoon in [14] and effectively applied in MCDM selection problems. It choose the best solution which exist at minimum distance from positive ideal sloution and maximum from negative ideal solution [10]. Here, we carried out the procedure of TOPSIS in interval valued spherical fuzzy environment and steps to perform the IVSF-TOPSIS are as follows:

(i) Construct the individual decision Matrix for all DM's using the weighting scale projected in Table 2. A desicion matrix elements indicates the assessments of all alternatives regarding each criteria.

(ii) Combine the decision matrix from every DM using IVSWAM operator presented in Eq. (14). Let $C_j(X_i) = ([\mu^L_{ij}(\mu), \mu^U_{ij}(\mu)], [v^L_{ij}(\mu), v^U_{ij}(\mu)], [\pi^L_{ij}(\mu), \pi^U_{ij}(\mu)])$ represent the value of alternative $X_i(i = 1, 2, 3.....m)$ corresponding to criteria $C_j(j = 1, 2, ...n)$. Then, an aggregated interval valued spherical fuzzy decision matrix $D = (C_j(X_i))_{m\times n}$ is constructed in this manner [13]:

$$D = \left(C_j(X_i)\right)_{m\times n} = \begin{bmatrix} ([\mu^L_{11}, \mu^U_{11}], [v^L_{11}, v^U_{11}], [\pi^L_{11}, \pi^U_{11}]) \ldots & ([\mu^L_{1n}, \mu^U_{1n}], [v^L_{1n}, v^U_{1n}], [\pi^L_{1n}, \pi^U_{1n}]) \\ ([\mu^L_{22}, \mu^U_{22}], [v^L_{22}, v^U_{22}], [\pi^L_{22}, \pi^U_{22}]) \ldots & ([\mu^L_{2n}, \mu^U_{2n}], [v^L_{2n}, v^U_{2n}], [\pi^L_{2n}, \pi^U_{2n}]) \\ \vdots & \\ ([\mu^L_{m1}, \mu^U_{m1}], [v^L_{m1}, v^U_{m1}], [\pi^L_{m1}, \pi^U_{m1}]) \ldots & ([\mu^L_{mn}, \mu^U_{mn}], [v^L_{mn}, v^U_{mn}], [\pi^L_{mn}, \pi^U_{mn}]) \end{bmatrix}$$

(iii) Calculate criteria weights using SFAHP method given in Sect. 4.

(iv) Aggregated weighted interval valued spherical fuzzy decision matrix is produced by multiplying criteria weights and aggregated decision matrix using Eq. (13) and demonstrated as [13]:

$$D = \left(C_j(X_{iw})\right)_{m\times n} = \begin{bmatrix} \left([\mu^L_{11w}(\mu), \mu^U_{11w}(\mu)], [v^L_{11w}(\mu), v^U_{11w}(\mu)], [\pi^L_{11w}(\mu), \pi^U_{11w}(\mu)]\right) \dots & \left([\mu^L_{1nw}(\mu), \mu^U_{1nw}(\mu)], [v^L_{1nw}(\mu), v^U_{1nw}(\mu)], [\pi^L_{1nw}(\mu), \pi^U_{1nw}(\mu)]\right) \\ \left([\mu^L_{22w}(\mu), \mu^U_{22w}(\mu)], [v^L_{22w}(\mu), v^U_{22w}(\mu)], [\pi^L_{22w}(\mu), \pi^U_{22w}(\mu)]\right) \dots & \left([\mu^L_{2nw}(\mu), \mu^U_{2nw}(\mu)], [v^L_{2nw}(\mu), v^U_{2nw}(\mu)], [\pi^L_{2nw}(\mu), \pi^U_{2nw}(\mu)]\right) \\ \vdots & \\ \left([\mu^L_{m1w}(\mu), \mu^U_{m1w}(\mu)], [v^L_{m1w}(\mu), v^U_{m1w}(\mu)], [\pi^L_{m1w}(\mu), \pi^U_{m1w}(\mu)]\right) \dots & \left([\mu^L_{mnw}(\mu), \mu^U_{mnw}(\mu)], [v^L_{mnw}(\mu), v^U_{mnw}(\mu)], [\pi^L_{mnw}(\mu), \pi^U_{mnw}(\mu)]\right) \end{bmatrix}$$

(v) Determine the score for each alternative by defuzzification of decision matrix D:

$$S(C_j(X_{iw})) = \frac{(\mu^L_{ijw}(\mu))^2 + (\mu^U_{ijw}(\mu))^2 - (v^L_{ijw}(\mu))^2 - (v^U_{ijw}(\mu))^2 - \left(\frac{\pi^L_{ijw}(\mu)}{2}\right)^2 - \left(\frac{\pi^L_{ijw}(\mu)}{2}\right)^2}{2} \tag{23}$$

(vi) Find Interval Valued Spherical Fuzzy Positive Ideal Solution (IVSF-PIS) and Interval Valued Spherical Fuzzy Negative Ideal Solution (IVSF-NIS) based on score value calculated in step (v). The IVSF-PIS is as follows [37]:

$$X^+ = \left\{ C_j, max_i < S(C_j(X_{iw})) > \middle| j = 1, 2.....n \right\} \tag{24}$$

or

$$\begin{aligned} X^+ = \{ & \langle C_1, ([\mu_1^{L^+}, \mu_1^{U^+}], [v_1^{L^+}, v_1^{U^+}], [\pi_1^{L^+}, \pi_1^{U^+}])\rangle, \\ & \langle C_2, ([\mu_2^{L^+}, \mu_2^{U^+}], [v_2^{L^+}, v_2^{U^+}], [\pi_2^{L^+}, \pi_2^{U^+}])\rangle, \\ & \dots\dots\dots\dots \langle C_n, ([\mu_n^{L^+}, \mu_n^{U^+}], [v_n^{L^+}, v_n^{U^+}], [\pi_n^{L^+}, \pi_n^{U^+}])\rangle\} \end{aligned} \tag{25}$$

The IVSF-NIS is as follows [37]:

$$X^- = \left\{ C_j, min_i < S(C_j(X_{iw})) > \middle| j = 1, 2.....n \right\} \tag{26}$$

or

$$\begin{aligned} X^- = \{ & \langle C_1, ([\mu_1^{L^-}, \mu_1^{U^-}], [v_1^{L^-}, v_1^{U^-}], [\pi_1^{L^-}, \pi_1^{U^-}])\rangle, \\ & \langle C_2, ([\mu_2^{L^-}, \mu_2^{U^-}], [v_2^{L^-}, v_2^{U^-}], [\pi_2^{L^-}, \pi_2^{U^-}])\rangle, \\ & \dots\dots\dots\dots \langle C_n, ([\mu_n^{L^-}, \mu_n^{U^-}], [v_n^{L^-}, v_n^{U^-}], [\pi_n^{L^-}, \pi_n^{U^-}])\rangle\} \end{aligned} \tag{27}$$

(vii) Determine the distance measure of alternative X_i with IVSF-PIS and IVSF-NIS respectively by using the distance formula from [41]. The distance with IVSF-PIS is as follows:

$$\begin{aligned} d(X_i, X_j^+) = \frac{1}{4n}\sum_{j=1}^{n}\Bigg(& \left| (\mu_{ij}^L)^2 - (\mu_j^+)^2 \right| \\ & \left| (v_{ij}^U)^2 - (v_j^+)^2 \right| + \left| (\pi_{ij}^L)^2 - (\pi_j^+)^2 \right| \end{aligned} \tag{28}$$

The distance with IVSF-NIS is as follows:

$$\begin{aligned} d(X_i, X_j^-) = \frac{1}{4n}\sum_{j=1}^{n}\Bigg(& \left| (\mu_{ij}^L)^2 - (\mu_j^-)^2 \right| \\ & + \left| (\mu_{ij}^U)^2 - (\mu_j^-)^2 \right| + \left| (v_{ij}^L)^2 - (v_j^-)^2 \right| + \\ & \left| (v_{ij}^U)^2 - (v_j^-)^2 \right| + \left| (\pi_{ij}^L)^2 - (\pi_j^-)^2 \right| \\ & + \left| (\pi_{ij}^U)^2 - (\pi_j^-)^2 \right| \Bigg) \forall i \end{aligned} \tag{29}$$

Table 3 Weights to decision makers

Decision makers	Experience	Score value	Weight
DM_1	3 Years	0.04	0.071428571
DM_2	5 Years	0.16	0.285714286
DM_3	7 Years	0.36	0.642857143

(viii) Determine the closeness ratio for each alternative as follows:

$$Closeness\,Ratio_i = \frac{d(X_{ij}, X_j^-)}{d(X_{ij}, X_j^-) + d(X_{ij}, X_j^+)} \tag{30}$$

(ix) Ranking of alternatives: find the best alternative by arranging alternatives in decreasing order of their closeness ratio [18].

$$A_{TOPSIS} = \{A_i = max_i Closeness\,Ratio_i\} \tag{31}$$

6 Experimental results

To show the utilization of introduced approach, we have considered a cloud service selection problem with five available cloud service providers (CSP_s) (CSP_1,CSP_2, CSP_3, CSP_4, CSP_5). Due to the availability of various CSPs, this approach is going to help cloud users in selection of suitable cloud service according to their non-functional requirements. The criteria used for evaluating cloud services are Response Time (CR_1),Availability (CR_2),Throughput (CR_3), Performance (CR_4), Reliability (CR_5), and Latency (CR_6) [2]. A group of three decision makers (DM_1, DM_2, DM_3), having deviating experience in field of cloud computing is formed to help in the evaluation process of finding the best CSP. In this process, SF-AHP method is used to derive the weights of criteria and decision makers and ranking is derived using IVSF-TOPSIS.

6.1 SF-AHP

The steps of solution procedure of SF-AHP are demonstrated as follows:

(i) Decision makers weight calculation: the weights of DM according to their experiences are calculated using Eqs. (16), (17) and result is tabulated in Table 3.

Table 4 Pairwise comparison matrix by decision makers

Decision makers	Criteria	CR1	CR2	CR3	CR4	CR5	CR6
DM1	CR1	ES	LS	SMS	HS	SLS	SMS
	CR2	HS	ES	HS	SMS	ES	HS
	CR3	SLS	LS	ES	LS	SLS	SMS
	CR4	LS	SLS	HS	ES	SLS	SMS
	CR5	SMS	ES	SMS	SMS	ES	VHS
	CR6	SLS	LS	SLS	SLS	VLS	ES
DM2	CR1	ES	SLS	SLS	SLS	SMS	HS
	CR2	SMS	ES	HS	HS	SLS	HS
	CR3	SMS	LS	ES	LS	LS	SMS
	CR4	SMS	LS	HS	ES	SLS	SLS
	CR5	SLS	SMS	HS	SMS	ES	SMS
	CR6	LS	LS	SLS	SMS	SLS	ES
DM3	CR1	ES	SMS	HS	HS	SLS	HS
	CR2	SLS	ES	SMS	HS	SLS	SMS
	CR3	LS	SLS	ES	SMS	LS	ES
	CR4	LS	LS	SLS	ES	VHS	SMS
	CR5	SMS	HS	HS	VLS	ES	HS
	CR6	LS	SLS	ES	SLS	LS	ES

Table 5 Average weighted pairwise comparison matrix

Criteria	CR1	CR2	CR3	CR4	CR5	CR6
CR1	[0.167,0.167,0.167]	[0.131,0.202,0.112]	[0.205,0.129,0.124]	[0.226,0.107,0.102]	[0.138,0.195,0.133]	[0.212,0.121,0.121]
CR2	[0.202,0.131,0.112]	[0.167,0.167,0.167]	[0.224,0.110,0.110]	[0.212,0.121,0.121]	[0.145,0.188,0.145]	[0.224,0.110,0.110]
CR3	[0.129,0.205,0.124]	[0.110,0.224,0.110]	[0.167,0.167,0.167]	[0.129,0.205,0.110]	[0.121,0.212,0.121]	[0.190,0.143,0.143]
CR4	[0.107,0.226,0.102]	[0.121,0.212,0.121]	[0.205,0.129,0.110]	[0.167,0.167,0.167]	[0.171,0.162,0.114]	[0.195,0.138,0.133]
CR5	[0.195,0.138,0.133]	[0.188,0.145,0.145]	[0.212,0.121,0.121]	[0.162,0.171,0.114]	[0.167,0.167,0.167]	[0.252,0.081,0.081]
CR6	[0.121,0.212,0.121]	[0.110,0.224,0.110]	[0.143,0.190,0.143]	[0.138,0.195,0.133]	[0.081,0.252,0.081]	[0.167,0.167,0.167]

Table 6 Geometric mean for each row

Critria	μ	v	π
Response time	0.175860178	0.149165568	0.12507054
Availability	0.193196592	0.134724419	0.125705025
Throughput	0.13824029	0.190200382	0.127489315
Performance	0.156797198	0.168593605	0.122971557
Reliability	0.193809326	0.133390106	0.123946732
Latency	0.123451985	0.204984793	0.122732077

Table 7 Prioritization function and weights

Critria	Prioritization function $F(p^i)$	Weights
Response time	0.130913853	0.181242211
Availability	0.146154399	0.202341814
Throughput	0.097674896	0.135224911
Performance	0.114331351	0.158284754
Reliability	0.147139348	0.203705416
Latency	0.086100518	0.119200894

Table 8 Decision matrix by DMs

DMs	CSPs	CR1	CR2	CR3	CR4	CR5	CR6
DM1	CSP1	SMS	VHS	HS	LS	VHS	LS
	CSP2	ALS	HS	HS	LS	HS	LS
	CSP3	VHS	VHS	VHS	AMS	AMS	AMS
	CSP4	VHS	SMS	SLS	HS	ALS	HS
	CSP5	HS	SMS	SMS	ES	HS	VLS
DM2	CSP1	HS	AMS	ES	LS	SMS	ALS
	CSP2	HS	HS	VHS	ES	HS	SMS
	CSP3	AMS	VHS	SMS	AMS	VHS	VHS
	CSP4	AMS	ES	VLS	AMS	AHS	VHS
	CSP5	VHS	SMS	VLS	AMS	SLS	LS
DM3	CSP1	HS	HS	HS	VHS	VHS	HS
	CSP2	ES	HS	HS	ES	HS	SLS
	CSP3	AMS	VHS	ALS	VHS	VHS	VHS
	CSP4	LS	SMS	ES	LS	SMS	LS
	CSP5	HS	HS	SMS	LS	SMS	LS

Table 9 Weighted interval valued spherical fuzzy decision matrix

CSPs	CR1	CR2	CR3	CR4	CR5	CR6
CSP1	([0.273,0.333], [0.767,0.795], [0.120,0.161])	([0.382,0.469], [0.689,0.728], [0.097,0.159])	([0.263,0.319], [0.029,0.036], [0.097,0.139])	([0.203,0.251], [0.068,0.081], [0.083,0.117])	([0.386,0.471], [0.032,0.042], [0.098,0.156])	([0.147,0.181], [0.056,0.066], [0.075,0.102])
CSP2	([0.151,0.177], [0.922,0.947],[0.087,0.132])	([0.324,0.392], [0.722,0.755], [0.114,0.161])	([0.272,0.331], [0.026,0.033], [0.094,0.136])	([0.142,0.163], [0.090,0.106], [0.106,0.145])	([0.325,0.394], [0.041,0.051], [0.114,0.162])	([0.091,0.113], [0.069,0.080], [0.080,0.100])
CSP3	([0.405,0.509], [0.691,0.733],[0.075,0.160])	([0.392,0.478], [0.681,0.722], [0.095,0.155])	([0.270,0.333], [0.035,0.043], [0.072,0.119])	([0.408,0.524], [0.018,0.026], [0.053,0.162])	([0.452,0.573], [0.024,0.034], [0.063,0.173])	([0.353,0.456], [0.014,0.020], [0.051,0.145])
CSP4	([0.330,0.409], [0.761,0.797],[0.087,0.144])	([0.263,0.320], [0.762,0.791], [0.134,0.177])	([0.130,0.149], [0.072,0.085], [0.104,0.138])	([0.264,0.327], [0.042,0.052], [0.093,0.139])	([0.184,0.228], [0.108,0.125], [0.080,0.119])	([0.221,0.271], [0.033,0.040], [0.084,0.119])
CSP5	([0.313,0.380], [0.744,0.776],[0.107,0.154])	([0.284,0.346], [0.746,0.776], [0.127,0.170])	([0.211,0.259], [0.037,0.044], [0.107,0.141])	([0.211,0.253], [0.071,0.087], [0.119,0.173])	([0.299,0.363], [0.047,0.057], [0.120,0.164])	([0.065,0.083], [0.081,0.093], [0.067,0.085])

Table 10 Score function values

CSPs	Response time	Availability	Throughput	Performance	Reliability	Latency
CSP1	− 0.52185431	− 0.323824611	0.080802661	0.043973649	0.179760455	0.021423944
CSP2	− 0.849073722	− 0.421268382	0.08756679	0.0096496	0.123385299	0.002889772
CSP3	− 0.299535281	− 0.305572323	0.087993101	0.216570952	0.261052265	0.163136899
CSP4	− 0.472739118	− 0.522952017	0.009576839	0.082677721	0.026808099	0.057432835
CSP5	− 0.46098586	− 0.484545429	0.050160817	0.042361295	0.102877649	− 0.003504874

(ii) Pairwise comparison matrix collected from DM's is presented in Table 4.

(iii) Spherical fuzzy weighted pairwise comparison matrix is calculated for each DM using Eq. (18).

(iv) Average weighted pairwise comparison matrix (P) is determined utilizing Eq. (19) and result is tabulated in Table 5.

(v) Consistency of weighted pairwise comparison matrix (P) is calculated using Saaty's eigenvalue method. The obtained consistency value is = 0.091474 which is less than 0.1.

(vi) Determine the weights of attributes: geometric mean for each row is calculated utilizing Eq. (20) and result is shown in Table 6. Now find the priority of each row using prioritization function in Eq. (21) and then compute the priority of criteria utilizing Eq. (22). The result of prioritization function and criteria weights is shown in Table 7.

6.2 IVSF-TOPSIS

The solution steps using IVSF-TOPSIS are performed as demonstrated below:

(i) Decision matrix from all DM are gathered using interval valued linguistic preference scale as shown in Table 2. All decision matrices are presented in Table 8.

(ii) These matrices are combined using IVSWAM operator in Eq. (14) based on priority of decision makers.

(iii) Calculate criteria weights using SFAHP: criteria weights are given in Table 7.

Table 11 Positive and negative ideal solutions

	CR1	CR2	CR3	CR4	CR5	CR6
IVSF-PIS	([0.405,0.509],[0.691,0.733],[0.075,0.160])	([0.392,0.478],[0.681,0.722],[0.095,0.155])	([0.270,0.333],[0.035,0.043],[0.072,0.119])	([0.408,0.524],[0.018,0.026],[0.053,0.162])	([0.452,0.573],[0.024,0.034],[0.063,0.173])	([0.353,0.456],[0.014,0.020],[0.051,0.145])
IVSF-NIS	([0.151,0.177],[0.922,0.947],[0.087,0.132])	([0.263,0.320],[0.762,0.792],[0.134,0.177])	([0.130,0.149],[0.072,0.085],[0.104,0.138])	([0.142,0.163],[0.090,0.106],[0.106,0.145])	([0.184,0.228],[0.108,0.125],[0.080,0.119])	([0.065,0.083],[0.081,0.093],[0.067,0.086])

(iv) Determine the aggregated weighted interval valued spherical fuzzy decision matrix (D) utilizing Eq. (13) and results are presented in Table 9.

(v) Score function value for every CSP utilizing Eq. (23) and the results are tabulated in Table 10.

(vi) Identify the IVSF-PIS and IVSF-NIS using Eqs. (24–27) respectively based on score value. The results are presented in Table 11.

(vii) Calculate distance of each CSP from IVSF-PIS and IVSF-NIS utilizing Eqs. (28), (29) respectively and solution is presented in Table 12.

(viii) & (ix) Calculate closeness ratio using Eq. (30) and final ranking using closeness ratio is presented in Table 13.

6.3 Sensitivity analysis

To check the dynamic impact on the ranking of alternatives, sensitivity analysis is performed by exchanging weights of criteria with each other [26]. As there are six criteria, so sensitivity analysis is performed with 15 cases of weights alterations. Results of sensitivity analysis are consistent despite of slightly changes in ranking results as shown in Fig. 1. For example, by exchanging the weights of criteria reliability (C5) and latency (C6) would affect the results but doesn't affect the best alternative rank. So the sensitivity analysis concludes the robustness and validity of the proposed approach.

6.4 Comparison with other approaches

To check the robustness of proposed approach, we have compared the obtained results with some other variations of TOPSIS i.e. Single valued SFTOPSIS [10] method and observed the variation in ranking of CSPs. The obtained ranking results are shown in Table 14. In single valued SFTOPSIS, best CSP is CSP_3 and ranking order is $CSP_3 > CSP_1 > CSP_5 > CSP_2 > CSP_4$. The proposed approach also find CSP_3 as best alternative and ranking order is $CSP_3 > CSP_1 > CSP_5 > CSP_4 > CSP_2$. The minor variation in ranking result is due to the difference in aggregation operator of both approaches. The sensitivity analysis also proved the consistency in ranking results of proposed approach.

Table 12 Distance of CSPs from IVSF-PIS and IVSF-NIS

Distance	CSP1	CSP2	CSP3	CSP4	CSP5
Distance between CSPs and IVSF-PIS	0.056217	0.100351	0.000000	0.081645	0.075875
Distance between CSPs and IVSF-NIS	0.070079	0.025170	0.124612	0.043322	0.050430

Table 13 Closeness ratio and ranking

Distance	CSP1	CSP2	CSP3	CSP4	CSP5
Closeness ratio	0.554879377	0.200522218	1	0.346670605	0.399272603
Ranking	2	5	1	4	3

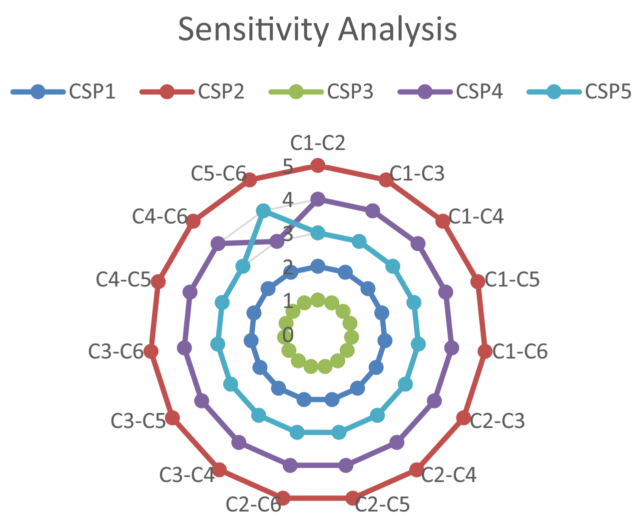

Fig. 1 Results of sensitivity analysis

7 Conclusion

In this paper, we have proposed a hybrid approach by integrating spherical fuzzy AHP with interval valued spherical fuzzy TOPSIS for solving the cloud service ranking problem and this approach also enrich the area of addressing multi criteria problems. Here, we have considered the six important criteria from non-functional requirements of cloud users. These illustrated criteria in this study are: response time, availability, throughput, performance, reliability, latency and the values of these criteria taken from DM in linguistic terms. SF-AHP method is applied to these criteria for obtaining their weights where it brings out that DM prioritised reliability as the most effective measure during the selection of cloud service. Later, the work is done on an interval valued weighted spherical decision matrix obtained by multiplying criteria weights with decision matrix. Furthermore, the procedure and measures of IVSF-TOPSIS is applied on interval valued weighted spherical decision matrix to attain the final ranking of CSP. The closeness ration for each alternative is presented in Table 13 and final ranking of CSPs indicates the result as: $CSP_3 > CSP_1 > CSP_5 > CSP_4 > CSP_2$. Hence, the proposed novel approach of SFAHP-IVSFTOPSIS indicates CSP_3 as the best alternative as shown in Table 14. Comparative analysis is performed with single valued spherical fuzzy AHP-TOPSIS method and CSP_3 remains the best alternative in both approaches. The sensitivity analysis is conducted to prove the stability of proposed approach and reacts all alterations in criteria weights by enduring the same alternative as the best. Further research refers to the adoption of proposed approach for ranking and selection problem in domains of business and engineering.

Table 14 Comparison with single valued TOPSIS

Alternatives	Fuzzy-TOPSIS		SF-TOPSIS		Porposed approach	
CSPs	Closeness ratio	Ranking	Closeness ratio	Ranking	Closeness ratio	Ranking
CSP1	0.588317652	2	0.481308329	2	0.554879377	2
CSP2	0.642596831	1	0.290667916	4	0.200522218	5
CSP3	0.528648684	3	0.987958839	1	1	1
CSP4	0.228296078	5	0.259787969	5	0.346670605	4
CSP5	0.384549922	4	0.29237814	3	0.399272603	3

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Data Availability The datasets analysed during the current study are available in the [github] repository, [https://qwsdata.github.io/] and all the data generated during this are included in this paper.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Consent for publication All authors whose names appear on the submission approved the version to be published; and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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