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Selection of Optimal Sites for New Airport in Urban Areas: An Intuitionistic Fuzzy-based Decision Making Study

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ABSTRACT

Airports play an important part in elevating regional communication, resulting in better economic value and enhanced accessibility. Choosing the best location for building a new airport involves considering multiple, interrelated, and complex criteria, including economic activity, population density, land availability, geographic suitability, strategic importance, and accessibility. A decision-making framework has been proposed, involving criteria and suitable regions for establishing a new airport station in urban areas, utilizing Multi-Criteria Decision-Making (MCDM) procedures. The Fuzzy Analytic Hierarchy Process (AHP) is employed to determine the objective balance for the evaluation criteria, and the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is used to rate the alternative locations. Intuitionistic Fuzzy Sets are incorporated into the model to support uncertainty and inaccuracy in the experts' judgments. A comparative analysis is also conducted to ensure the stability and feasibility of the final output. The proposed model aims to assist urban researchers, policymakers, and aviation authorities in making detailed, data-driven decisions for the development of national infrastructure.

1. Introduction

The aeronautics sector has observed an exponential growth in the last few years, which is being driven by the earnings of the middle-class families, escalated travel in business class and the air com-

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munication system in every region has been elevated through different government initiatives such as UDAN [1]. The existing airport infrastructure has been under enormous pressure due to this air surge, especially in metropolitan regions. Thus, it leads to delays, logistics strain and overcrowding. To manage these problems and support broader national integration and sustainable growth in various areas, as well as identify and develop new airport locations in emerging cities and towns, is now a strategic necessity. The standardized methods of decision-making often face problems amalgamating subjectivity and uncertainty inherent in the researcher's evaluation, especially when dealing with incomplete data and linguistic variables. To overcome this challenge, adopt an approach of Multi-Criteria Decision-Making (MCDM) that combines the advantages of fuzzy set theory with recognised techniques of MCDM, allowing human reasoning to be modelled more accurately and ambiguity to be handled through judgment.

1.1 Multi-Criteria Decision Making

Multi-Criteria Decision Analysis (MCDA) [2] or Multi-Criteria Decision Making (MCDM) [3] is considered one of the decision-making processes that selects the best option from several alternatives during the selection process. MCDM methods are applicable in various fields, including management [4], engineering [5], finance [6], public policy [7] and ecological planning [8], where decisions involve multiple stakeholders and options. This process of decision-making helps by producing a proper structure that enhances translucency, objectivity, and consistency in the decision-making process.

In this process of solving problems, the desired outcomes are expected while considering various factors. It initially involves real-world issues that incorporate choosing between different options, including environmental factors, time, quality and cost. This process provides decision-makers with an organised structure to determine alternatives, examine the outputs of different options, and ultimately reach a conclusion through the weighted diversification of alternatives. In this case, both qualitative and quantitative methods are integrated with stakeholder preferences, ensuring more transparent and smoother methods across various fields, including engineering, business and environmental and public interest projects.

TOPSIS, AHP, and ELECTRE are some convenient methods that provide an approach for making the best possible decisions. Various other processes have been developed, including fuzzy-based methods to tackle conflicting situations and imperfections, as well as data-driven models that utilise machine learning and big data analytics. Additionally, MCDM methods and multiple approaches are connected through Hybrid approaches that complete the project's aims and objectives. Accurate and practical answers to contemporary issues can be resolved through decision-making strategies based on the needs of the modern day, which are to be addressed and reassessed using MCDM, along with various AI techniques, such as IoT and big data.

1.2 Site Selection using MCDM

Site selection involves evaluating more than one alternative against a set of complex conditions. It is a strategic decision-making process that incorporates various domains, such as infrastructure growth, facility location and urban planning, which involves the construction of an airport and selecting the most appropriate site. The selection of location involves different diversified factors, including land availability, environmental conditions, economic feasibility, accessibility, and social influence. These conditions are multi-directional as well as significant in the context of stakeholder priorities and decision-making procedures that are highly complex.

Efficient tools and techniques have evolved to solve problems by providing a planned structure to assess, select, and rank the best alternatives through Multi-Criteria Decision-Making (MCDM) methods. MCDM procedures help decision-makers incorporate both qualitative judgments, such as political feasibility or environmental sensitivity, and quantitative data, such as cost, population and distance, into the research work.

MCDM is exclusively used in its fuzzy form to help experts comprehensively contemplate all related conditions, reflecting researchers' knowledge under uncertainty, and making more vigorous, justifiable, and transparent decisions for site selection. In the context of large-scale infrastructure, such as airports, the rigour of the technique supports sustainable growth, long-term operational efficiency and maximises the use of resources.

1.3 Fuzzy Set Theory

Fuzzy set theory [9] establishes the conception of a set by permitting elements to have degrees of membership ranging between 0 and 1. Instead of allocating a strict yes or no, it permits us to express the quantity of an element that belongs to a set. This can be illustrated through an example: instead of considering a site as either suitable or not suitable for a communication depot, fuzzy logic allows us to contemplate that a site is suitable to a degree of 0.75, which reflects the reality that most site selection research falls into grey areas. This method is much closer to the processes by which researchers and stakeholders genuinely think, speak, and assess complex, multidimensional issues.

The advantages of the Fuzzy Set Theory fall into its capacity to bridge the space between qualitative judgment and quantitative data. At a vast rate, the problems with decision-making involve choosing an area for a communication depot or an airport. Decision-makers may most of the time depend on the opinions of experts, environmental assessments and feedback from stakeholders. Thus, including all of that incorporates inherently unclear and prejudiced data. Subjective evaluations can be structurally organised, compared and processed through the involvement of fuzzy logic in decision-making techniques, resulting in more transparent and precise decision-making.

1.4 MCDM with Fuzzy Set Theory

Different criteria applicable in decision-making are not quantifiable in crisp numerical expressions. However, they are rather expressed in linguistic and subjective forms, which include "moderate environmental impact", "low cost", or "high accessibility". Fuzzy Set Theory is combined with basic MCDM procedures, resulting in Fuzzy MCDM [10, 11], which has been introduced to address the challenges encountered during qualitative evaluations that incorporate indeterminacy and uncertainty. The authenticity and pliability of decision-making procedures can be enhanced by incorporating uncertain, unclear, or partial information.

The MCDM, integrated with fuzzy logic, supports connecting the space between qualitative reasoning and quantitative analysis. It enhances the precision of decision-making frameworks, particularly in complex, high-stakes applications, such as selecting a location for a communication depot, where decision-making conditions may involve researchers' opinions, stakeholder inputs and socio-environmental influences that cannot be precisely quantified.

1.5 Structure of this paper

This section of the thesis explains the structure within which the thesis is framed. The introduction to the thesis, as described in Section 1, provides an overview of the entire thesis. Section 2 of the thesis explains the literature summary of the entire thesis. Section 3 has the preliminaries of the mathematical tools used in this thesis. Section 4 includes the proposed MCDM methodologies. Section 5 defines the conditions or criteria required for the site selection of a new airport in India. Different advantageous and disadvantageous explanations regarding the proposed site for a new airport in India have been accumulated in Section 6. Section 7 provides a detailed discussion of the model formulation and data collection. However, Section 8 provides numerical illustrations, in which the weights of the criteria and the rankings of alternatives are considered. Finally, Section 9 provides a smooth conclusion to the research study, outlining the scope of future research.

2. Literature Survey of this study

This section presents a literature survey for the research project. Firstly, we discuss the strategy for site selection for a New Airport in India, then study the background of Fuzzy numbers with applications. Finally, we surveyed MCDM methods and two used decision-making methods, AHP and TOPSIS processes.

2.1 *Background on Site Selection*

The selection of a location [12] is a crucial step in structuring and developing infrastructure, as well as commercial, public service and industrial facilities. The decision-making techniques have far-reaching applications for social influence, economic viability, functional efficacy and environmental sustainability, encompassing areas such as communication depots, schools, hospitals, manufacturing plants and the construction of airports [1, 13]. A nicely maintained location can precisely decrease the cost, enhance the availability of services, ensure the expansion of future support and long-term improvement can be ensured. In contrast, an appallingly chosen location can lead to operational deficiencies, increased transportation time, logistical challenges, regulatory issues and even public opposition.

The selection of the location is a technical challenge as well as a participatory and strategic technique in advanced urban and communication planning [14]. It needs alliances among planners, environmental scientists, engineers, government officials and the general public [15, 16]. Thus, utilising advanced decision-making methods such as Fuzzy MCDM enhances the capacity to make balanced, scientifically sound and inclusive decisions that connect the long-term aims of sustainability with immediate functional requirements. A brief review of site selection in different fields is presented in Table 1.

2.2 *Literature on Mathematical Tools*

Lotfi A. Zadeh [21] introduced the theory of fuzzy sets in 1965, which revolutionised the idea of classical set theory by including the condition of partial membership. In a crisp set or traditional set, the element either remains present or is absent from the set. However, there is a range of 0 and 1 in the degree of membership for fuzzy sets [22, 23]. The vagueness, uncertainty and imprecision can be handled through a robust mathematical structure that has been applied in various real-life issues.

2.2.1 *Fuzzy Sets*

Mathematically, Zadeh [21] has consistently worked on linguistic variables and human reasoning problems at the basic level. The further expansions of classical set theory characterise partial degrees of membership between 0 and 1. Thus, it would become evident in modelling that vagueness, imprecision, and uncertainty are present in real-life applications. The latest studies emphasise the growing importance of fuzzy sets [24, 25] in hybrid models, particularly when integrated with neural networks or neuro-fuzzy systems and evolving algorithms, which facilitate self-learning in dynamic en-

Table 1
Some recent studies on the background of site selection

Author	Year	Methodology	Application Area
[14] Ballis, A.	2003	Analysis of multi-criteria	Selection of airport sites in Island.
[17] Sólnes, J. et al.	2006	Socio-economic and environmental evaluation	Selection of domestic airport sites on different parameters.
[12] Alves, C. et al.	2020	Objective decision-making framework	Site selection of regional airport locations.
[15] Erkan, T. E. et al.	2020	AHP and ROC methods with GIS technology	Site selection of Airport in Libya.
[16] Russu, A.	2021	Multiple-criteria decision analysis	Selection of new Lisbon Airport.
[18] Chandra, S. et al.	2024	AHP	Selection of suitable dam construction in India.
[19] Fadli, O. et al.	2024	VIMM and TOPSIS techniques	Selecting of locations for optimal wind farm.
[20] Hisoğlu, S. et al.	2025	GIS and MCDM methods	Selection of electric vehicle charging stations using solar-energy-assisted.
This research	2025	AHP and TOPSIS methods	Airport sites in India.

vironments. Fuzzy sets and fuzzy numbers [26] are utilised in various numerical fields to capture the uncertainty and vagueness of systems.

2.2.2 *Intuitionistic Fuzzy Numbers*

A robust for the uncertainty model has been offered through extended traditional fuzzy numbers including hesitation $(\pi = 1 - \mu - \nu)$, non-membership (ν) and membership (μ) in Intuitionistic Fuzzy Numbers (IFNs) [23, 26] introduced on the basis of Intuitionistic Fuzzy Sets by Atanassov [27] in the year 1986. IFN has the ability to track evaluations in human hesitations, so it has been applied in expert systems, pattern recognition and decision-making, which are commonly in trapezoidal and triangular forms. Modern research has focused on balancing and instructing IFNs through precise operations and refined scores that consider the stability between belief, disbelief and uncertainty. Moreover, the initiation of triangular and trapezoidal IFNs has boosted computational efficiency in real-world problems. Hybrid structures combine IFNs with VIKOR [28], TOPSIS [29] and DEMATEL [30, 31] procedures, elevating multi-criteria decision-making [32] in the inspection of varying or incomplete data. Noteworthy scientists have explored entropy-based techniques to compute uncertainty within IFNs and proper distance and correlation methods have been applied to enhance assembly and organisational tasks.

2.3 *Literature on MCDM methodology*

The literature review of the MCDM method [33] typically encompasses a wide range of studies, methodologies, and implementations across different domains. In the context of Chandra, S. et al. [18] literature review of the implementation of the Analytic Hierarchy Process (AHP) has been presented.

According to Qian, J. et al. [34], the viability of industrial projects using the AHP procedure has been assessed. However, Mandal, S. et al. [29] describes the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) procedure and its upgraded method. It can be concluded from Thuannadee, S. [35] that their research project, which evaluates the inter-company comparison method as a multi-criteria analysis model, represents a significant procedure by updating TOPSIS to tackle the problem. Some recent studies on AHP and TOPSIS are listed in Table 2 to provide a more detailed understanding of the implementation of these methodologies.

Table 2
Recent studies on AHP and TOPSIS methodologies

Author	Year	Uncertainty	Application Area
[36] Karasan, A. et al.	2018	Intuitionistic fuzzy set	Prioritizing production master plan in a manufacturing hub.
[37] Akargöl, İ. et al.	2024	Pythagorean fuzzy set	Choosing the best optimal e-learning platform in a university.
[38] Cebi, S. et al.	2024	Pythagorean fuzzy set	Determination of industry 5.0 projects.
[39] Cüvelek, G. et al.	2024	Fuzzy set	Measurement of performance of products in commerce.
[40] Haktanır, E. et al.	2024	Intuitionistic Z-numbers	Selection of hydrogen storage technology in industry.
[29] Mandal, S. et al.	2024	Interval valued intuitionistic fuzzy set	Selection of Ph.D supervisor for guidance.
[41] Tran, N. et al.	2024	Triangular fuzzy set	Selection of Robotics in industrial areas.
[42] Panchal, D. et al.	2025	Intuitionistic fuzzy set	Determine the optimal supporting system in the Sugar mill industries.
This study	2025	Intuitionistic fuzzy set	Airport site selection.

3. Preliminaries of Mathematical Tools

A crisp set is a classical concept in set theory where an element either belongs to the set or does not—membership is binary and clearly defined (i.e., 0 or 1). In contrast, a fuzzy set [21] allows partial membership, meaning each element can belong to the set to a certain degree, represented by a membership value between 0 and 1. This flexibility makes fuzzy sets ideal for modeling vague or imprecise concepts, such as "tall person" or "high temperature." Besides fuzzy numbers [43, 44], other types of uncertain numbers include interval numbers (where values lie within a range), probabilistic numbers (based on probability distributions), and intuitionistic fuzzy numbers (which include degrees of membership, non-membership, and hesitation). These tools help represent uncertainty in real-world decision-making problems.

3.1 *Fuzzy set*

Lotfi A. Zadeh [21] introduced the Fuzzy set in 1965. A feature that describes a fuzzy set, not like a crisp set, is the Membership function (MF). The demonstrative, customised and empirical outlook incorporates a fuzzy set. Linguistic variables are internalized in terms of linguistic and grouped in a universal set of phonemes and constitute MF. In order to decrease intricacy, the fuzzy set obliterates the excruciating limits that differentiate the non-members and the pair members. Every element is in a set and has its values of membership.

3.2 Intuitionistic fuzzy set

There are many extensions of the fuzzy set, one of them is the Intuitionistic fuzzy set [29]. Krassimir T. Atanassov [27] introduced the IFS, an extension of fuzzy sets, in 1986. In the Intuitionistic fuzzy set [45], we considered the degree of membership and non-membership of each element of that set. The graphical representation of IFN is shown in Figure 1. Furthermore, the representation of IFN in discrete form is depicted in Figure 2.

Definition 1. *An Intuitionistic fuzzy set (IFS) [29] $\tilde{\mathscr{A}}$ on the universe of discourse $\mathscr{U}$ is defined as,*

$$\tilde{\mathscr{A}} = \{\langle \zeta; \mu_{\tilde{\mathscr{A}}}(\zeta), \nu_{\tilde{\mathscr{A}}}(\zeta)\rangle : \zeta \in \mathscr{U}\} \tag{1}$$

where $0 \leq \mu_{\tilde{\mathscr{A}}}(\zeta) + \nu_{\tilde{\mathscr{A}}}(\zeta) \leq 1$.

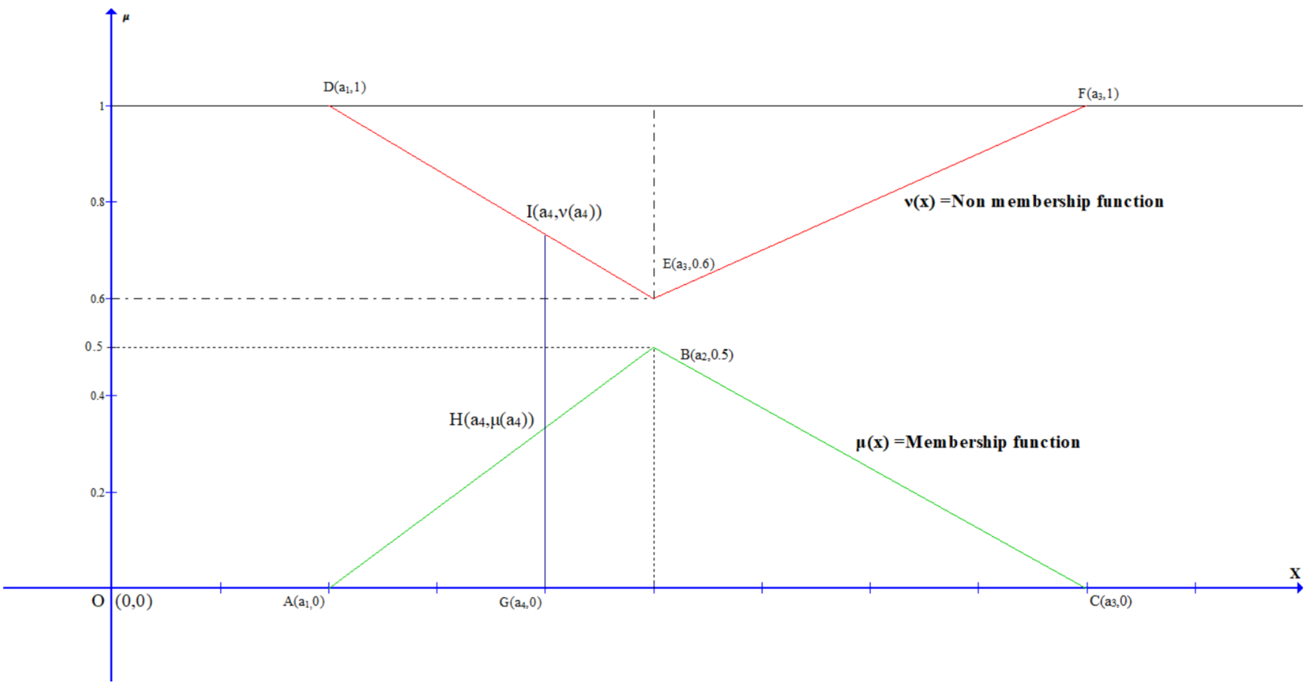

Fig. 1. Graphical representation of Intuitionistic fuzzy set (IFS)

Here, $\mu_{\tilde{\mathscr{A}}}(\zeta) : \mathscr{U} \to [0,1]$ represents the degree of membership and $\nu_{\tilde{\mathscr{A}}}(\zeta) : \mathscr{U} \to [0,1]$ denotes the degree of non-membership of an element ζ to the set $\tilde{\mathscr{A}}$. Now, the degree of hesitation of an element ζ to the set $\tilde{\mathscr{A}}$ is defined as, $\pi_{\tilde{\mathscr{A}}}(\zeta) = 1 - \mu_{\tilde{\mathscr{A}}}(\zeta) - \nu_{\tilde{\mathscr{A}}}(\zeta)$.

The intuitionistic fuzzy set is further divided into two types: the first one is the Type I Intuitionistic fuzzy set (IFS) and the second one is the Type II Intuitionistic fuzzy set (IFS). For a Type I Intuitionistic fuzzy set $\tilde{\mathscr{A}}$ degree of membership $\mu_{\tilde{\mathscr{A}}}(\zeta)$ and degree of non membership $\nu_{\tilde{\mathscr{A}}}(\zeta)$ both belongs to the set $[0,1]$ and give crisp values. It also satisfies the relation $0 \leq \mu_{\tilde{\mathscr{A}}}(\zeta) + \nu_{\tilde{\mathscr{A}}}(\zeta) \leq 1$. The Type II Intuitionistic Fuzzy Set is an extension of the Type I Intuitionistic Fuzzy Set. For a Type II Intuitionistic Fuzzy Set, both the membership and the non-membership functions take fuzzy values.

Definition 2. *An Intuitionistic Fuzzy Set (IFS) $\tilde{\mathscr{A}}$ defined on the set of real numbers $(\mathbb{R})$ is said to be an Intuitionistic Fuzzy Number [46] if its membership $(\mu_{\tilde{\mathscr{A}}})$ and non-membership $(\nu_{\tilde{\mathscr{A}}})$ functions satisfy the following four properties*

(i) $\tilde{\mathscr{A}}$ is a normalized fuzzy set that means there exists $\zeta \in \mathbb{R}$ such that $\mu_{\tilde{\mathscr{A}}}(\zeta) = 1$ and $\nu_{\tilde{\mathscr{A}}}(\zeta) = 0$.

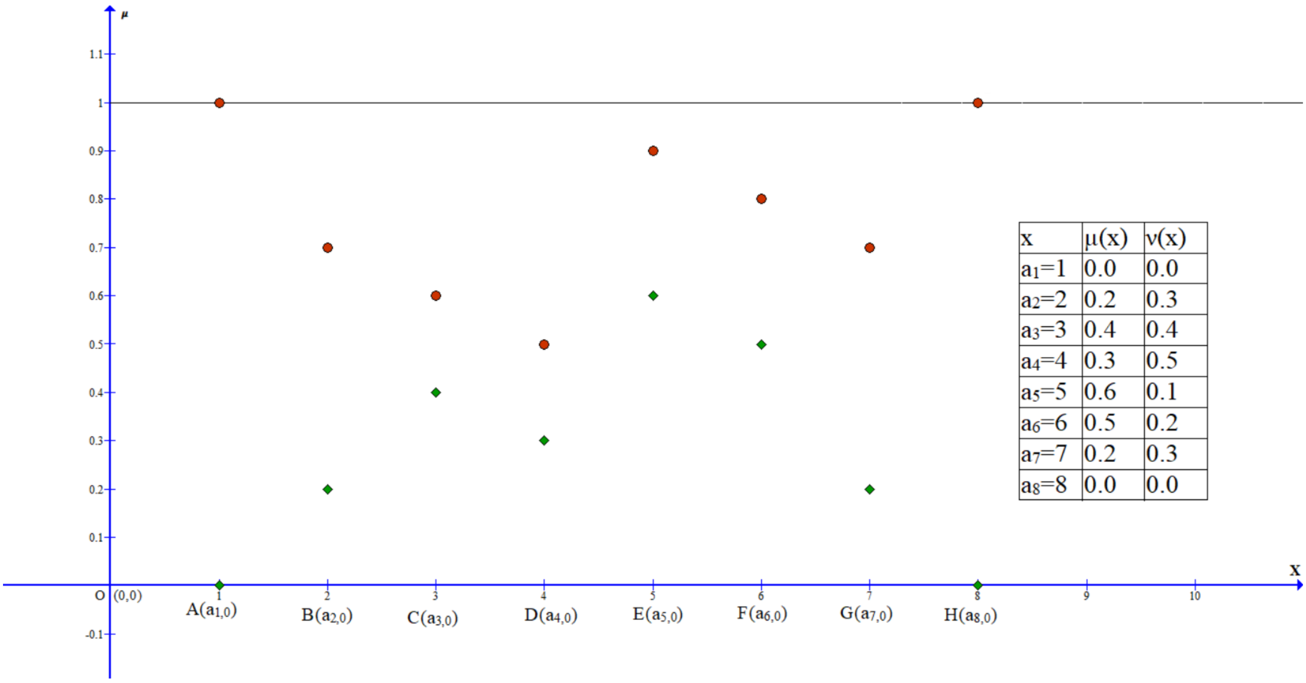

Fig. 2. Structural view of the discrete IFS

(ii) *$\tilde{\mathscr{A}}$ is a convex fuzzy set i.e,* $\mu_{\tilde{\mathscr{A}}}(\lambda\zeta_1 + (1-\lambda)\zeta_2) \geq \min\{\mu_{\tilde{\mathscr{A}}}(\zeta_1), \mu_{\tilde{\mathscr{A}}}(\zeta_2)\}$ *and* $\nu_{\tilde{\mathscr{A}}}(\lambda\zeta_1 + (1-\lambda)\zeta_2) \leq \min\{\nu_{\tilde{\mathscr{A}}}(\zeta_1), \nu_{\tilde{\mathscr{A}}}(\zeta_2)\}$; $\forall \zeta_1, \zeta_2 \in \tilde{\mathscr{A}}$ *and* $\lambda \in [0,1]$.

(iii) *$\tilde{\mathscr{A}}$ must have a bounded support.*

(iv) *The membership function $\mu_{\tilde{\mathscr{A}}}$ and $\nu_{\tilde{\mathscr{A}}}$ are piecewise continuous.*

Example 1. *Let $\tilde{\mathscr{B}}$ represent student's ratings (ζ) about a particular lecture of History, where rating 1 means Poor, rating 3 means Average and rating 5 means Excellent. Then the Intuitionistic Fuzzy Number $\tilde{\mathscr{B}}$ can be represented as,*

$$\tilde{\mathscr{B}} = \{< 1; 0.3, 0.6 >, < 3; 0.5, 0.2 >, < 5; 0.7, 0.1 >\}$$

Definition 3. ***Hesitation Membership Function:***
Consider $\tilde{\mathscr{A}}$ be an Intuitionistic Fuzzy Set (IFS) defined on $\mathbb{R}$. Then the Hesitation Membership Function (HMF) of IFS $\tilde{\mathscr{A}}$ is denoted by $\pi_{\tilde{\mathscr{A}}}$ and evaluated by

$$\pi_{\tilde{\mathscr{A}}} = 1 - \mu_{\tilde{\mathscr{A}}} - \nu_{\tilde{\mathscr{A}}} \tag{2}$$

where $\mu_{\tilde{\mathscr{A}}}$ and $\nu_{\tilde{\mathscr{A}}}$ are membership and non-membership functions of the IFS $\tilde{\mathscr{A}}$.

3.3 Properties of IFNs

In 1986, a mathematician named Atanassov introduced Intuitionistic Fuzzy Sets, broadening the idea of classical fuzzy sets through incorporating a degree of membership $(\mu_{\tilde{\mathscr{A}}})$, a degree of non-membership $(\nu_{\tilde{\mathscr{A}}})$ and a hesitation margin $(\pi_{\tilde{\mathscr{A}}})$. Let A be an IFS which is defined on a universe X, then for each element $x \in X$, it is symbolized by a triple:

$$\begin{aligned} \tilde{\mathscr{A}}(x) &= \langle x; \mu_{\tilde{\mathscr{A}}}(x), \nu_{\tilde{\mathscr{A}}}(x)\rangle \\ &= \langle \mu_{\tilde{\mathscr{A}}}(x), \nu_{\tilde{\mathscr{A}}}(x)\rangle \end{aligned} \tag{3}$$

where

- $\mu_{\tilde{\mathscr{A}}}(x) \in [0,1]$ is the **degree of membership** of x in $\tilde{\mathscr{A}}$,
- $\nu_{\tilde{\mathscr{A}}}(x) \in [0,1]$ is the **degree of non-membership** of x in $\tilde{\mathscr{A}}$,
- $\pi_{\tilde{\mathscr{A}}}(x) = 1 - \mu_{\tilde{\mathscr{A}}}(x) - \nu_{\tilde{\mathscr{A}}}(x)$ is the **hesitation degree** (or indeterminacy).

The significant properties of the intuitionistic fuzzy sets are as follows:

1. **Boundedness of Membership and Non-membership:**

$$0 \le \mu_{\tilde{\mathscr{A}}}(x) + \nu_{\tilde{\mathscr{A}}}(x) \le 1 \tag{4}$$

   This ensures that the hesitation margin $\pi_{\tilde{\mathscr{A}}}(x)$ is always non-negative.

2. **Hesitation Margin (Indeterminacy):**

$$\pi_{\tilde{\mathscr{A}}}(x) = 1 - \mu_{\tilde{\mathscr{A}}}(x) - \nu_{\tilde{\mathscr{A}}}(x) \tag{5}$$

   It reflects the lack of knowledge or uncertainty about whether x belongs to $\tilde{\mathscr{A}}$.

3. **Classical Fuzzy Set as a Special Case:**
   If $\nu_{\tilde{\mathscr{A}}}(x) = 0$, then the IFS reduces to a classical fuzzy set.

4. **Classical Set as a Special Case:**
   If $\mu_{\tilde{\mathscr{A}}}(x) = 1$ and $\nu_{\tilde{\mathscr{A}}}(x) = 0$ simultaneously, then the IFS reduces to a classical set.

5. **Operations on IFSs:**
   - Complement: $\tilde{\mathscr{A}}^c(x) = \langle \nu_{\tilde{\mathscr{A}}}(x), \mu_{\tilde{\mathscr{A}}}(x) \rangle$,
   - Union: $(\tilde{\mathscr{A}} \cup \tilde{\mathscr{B}})(x) = \langle \max(\mu_{\tilde{\mathscr{A}}}(x), \mu_{\tilde{\mathscr{B}}}(x)), \min(\nu_{\tilde{\mathscr{A}}}(x), \nu_{\tilde{\mathscr{B}}}(x)) \rangle$,
   - Intersection: $(\tilde{\mathscr{A}} \cap \tilde{\mathscr{B}})(x) = \langle \min(\mu_{\tilde{\mathscr{A}}}(x), \mu_{\tilde{\mathscr{B}}}(x)), \max(\nu_{\tilde{\mathscr{A}}}(x), \nu_{\tilde{\mathscr{B}}}(x)) \rangle$.

6. **Inclusion Relation:** $\tilde{\mathscr{A}} \subseteq \tilde{\mathscr{B}}$ if and only if:

$$\mu_{\tilde{\mathscr{A}}}(x) \le \mu_{\tilde{\mathscr{B}}}(x), \quad \nu_{\tilde{\mathscr{A}}}(x) \ge \nu_{\tilde{\mathscr{B}}}(x), \quad \forall x \in X \tag{6}$$

7. **Equality of IFSs:** Two IFSs $\tilde{\mathscr{A}}$ and $\tilde{\mathscr{B}}$ are equal if:

$$\mu_{\tilde{\mathscr{A}}}(x) = \mu_{\tilde{\mathscr{B}}}(x), \quad \nu_{\tilde{\mathscr{A}}}(x) = \nu_{\tilde{\mathscr{B}}}(x), \quad \forall x \in X \tag{7}$$

8. **Support and Core:**
   - Support: Supp$(\tilde{\mathscr{A}}) = \{x \in X \mid \mu_{\tilde{\mathscr{A}}}(x) > 0$ or $\nu_{\tilde{\mathscr{A}}}(x) < 1\}$,
   - Core: Core$(\tilde{\mathscr{A}}) = \{x \in X \mid \mu_{\tilde{\mathscr{A}}}(x) = 1$ and $\nu_{\tilde{\mathscr{A}}}(x) = 0\}$.

9. **Convexity:** An IFS $\tilde{\mathscr{A}}$ is convex if for any $x, y \in X$ and $\lambda \in [0,1]$,

$$\begin{cases} \mu_{\tilde{\mathscr{A}}}(\lambda x + (1-\lambda)y) & \ge \min\{\mu_{\tilde{\mathscr{A}}}(x), \mu_{\tilde{\mathscr{A}}}(y)\} \\ \nu_{\tilde{\mathscr{A}}}(\lambda x + (1-\lambda)y) & \le \max\{\nu_{\tilde{\mathscr{A}}}(x), \nu_{\tilde{\mathscr{A}}}(y)\} \end{cases} \tag{8}$$

3.4 Arithmetic operation on IFNs

In this section, we will discuss the arithmetic operations of Intuitionistic Fuzzy Numbers [29, 47]. Some basic arithmetic operations like addition, scalar multiplication, multiplication and power of IFNs [48] are discussed as follows:

Here, we have taken, $\tilde{\mathscr{P}} = \{(r; \mu_{\tilde{\mathscr{P}}}(r), \nu_{\tilde{\mathscr{P}}}(r)) : r \in \mathbb{R}\}$ and $\tilde{\mathscr{Q}} = \{(s; \mu_{\tilde{\mathscr{Q}}}(s), \nu_{\tilde{\mathscr{Q}}}(s)) : s \in \mathbb{R}\}$ are two IFNs define on $\mathbb{R}$. Then, some popular arithmetic operations on IFNs [25] described as

i) Addition of two IFNs:
The addition of the above described two IFNs $\tilde{\mathscr{P}}$ and $\tilde{\mathscr{Q}}$ is define as,

$$\begin{aligned} \tilde{\mathscr{P}} \oplus \tilde{\mathscr{Q}} &= \Big\{((r+s); \mu_{\tilde{\mathscr{P}}} \oplus \tilde{\mathscr{Q}}, \nu_{\tilde{\mathscr{P}}} \oplus \tilde{\mathscr{Q}})\Big\} \\ &= \{((r+s); \mu_{\tilde{\mathscr{P}}} + \mu_{\tilde{\mathscr{Q}}} - \mu_{\tilde{\mathscr{P}}}\mu_{\tilde{\mathscr{Q}}}, \nu_{\tilde{\mathscr{P}}}\nu_{\tilde{\mathscr{Q}}})\} \end{aligned} \tag{9}$$

ii) Scalar Multiplication of IFNs:
If σ is the positive real number $(\delta \in \mathbb{R}^+)$. Then, the scalar multiplication (σ) of IFN $\tilde{\mathscr{P}}$ is

$$\begin{aligned} \sigma.\tilde{\mathscr{P}} = \sigma \times \tilde{\mathscr{P}} &= \{(\sigma r; \mu_{\sigma.\tilde{\mathscr{P}}}, \nu_{\sigma.\tilde{\mathscr{P}}})\} \\ &= \{(\sigma r; 1 - (1 - \mu_{\tilde{\mathscr{P}}})^\sigma, (\nu_{\tilde{\mathscr{H}}})^\sigma)\} \end{aligned} \tag{10}$$

iii) Multiplication of two IFNs:
The multiplication of two IFNs $\tilde{\mathscr{P}}$ and $\tilde{\mathscr{Q}}$ is denote as

$$\begin{aligned} \tilde{\mathscr{P}} \otimes \tilde{\mathscr{Q}} &= \Big\{(rs; \mu_{\tilde{\mathscr{P}}} \otimes \tilde{\mathscr{Q}}, \nu_{\tilde{\mathscr{P}}} \otimes \tilde{\mathscr{Q}})\Big\} \\ &= \{(rs; \mu_{\tilde{\mathscr{P}}}\mu_{\tilde{\mathscr{Q}}}, \nu_{\tilde{\mathscr{P}}} + \nu_{\tilde{\mathscr{Q}}} - \nu_{\tilde{\mathscr{P}}}\nu_{\tilde{\mathscr{Q}}})\} \end{aligned} \tag{11}$$

iv) Power of IFN:
Consider δ be a natural number $(\delta \in \mathbb{N})$. Then the scalar power (δ) of IFN $\tilde{\mathscr{P}}$ is

$$\begin{aligned} \tilde{\mathscr{P}}^\delta &= \Big\{(r^\delta; \mu_{\tilde{\mathscr{P}}^\delta}, \nu_{\tilde{\mathscr{P}}^\delta})\Big\} \\ &= \Big\{(r^\delta; (\mu_{\tilde{\mathscr{P}}})^\delta, 1 - (1 - \nu_{\tilde{\mathscr{P}}})^\delta)\Big\} \end{aligned} \tag{12}$$

3.5 De-i-fuzzification method on IFN

De-i-fuzzification [26, 49] is the technique of converting an Intuitionistic Fuzzy Number (IFN) into a crisp (actual) value, similar to defuzzification in classical fuzzy set theory. The aim is to deduce a representative scalar value for decision analysis, ranking, or comparing.

An Intuitionistic Fuzzy Number (IFN) is characterised by:

1. A membership function $\mu(x)$,
2. A non-membership function $\nu(x)$,
3. And a hesitation degree $\pi(x) = 1 - \mu(x) - \nu(x)$.

Common De-i-fuzzification Methods:

1. **Score Function Method** One of the most widely used techniques. Let $A = \langle \mu_{\tilde{\mathscr{A}}}(x), \nu_{\tilde{\mathscr{A}}}(x) \rangle$ be an IFN. The score function $S(\tilde{\mathscr{A}})$ is defined as:

$$S(\tilde{\mathscr{A}}) = \mu_{\tilde{\mathscr{A}}}(x)^2 - \nu_{\tilde{\mathscr{A}}}(x)^2 \tag{13}$$

- The higher the score, the better (more preferable) the alternative.
- Simple and easy for ranking purposes.

2. **Accuracy Function Method** Adds precision when two IFNs have the same score.

$$H(\tilde{\mathscr{A}}) = \mu_{\tilde{\mathscr{A}}}(x)^2 - \nu_{\tilde{\mathscr{A}}}(x)^2 + \pi_{\tilde{\mathscr{A}}}(x)^2 \tag{14}$$

where $\pi_{\tilde{\mathscr{A}}}(x)$ be the Hesitation Membership Function of $\tilde{\mathscr{A}}$. This gives information about the "certainty level" (how much we know).

3. **Combined Score-Accuracy Function** To use both score and accuracy, a lexicographic or weighted approach is used:

$$C(\tilde{\mathscr{A}}) = w_1 \cdot S(\tilde{\mathscr{A}}) + w_2 \cdot H(\tilde{\mathscr{A}}) \tag{15}$$

with $w_1 + w_2 = 1$, typically $w_1 > w_2$.

4. **Expected Value Method** For intuitionistic fuzzy numbers defined over intervals (e.g., triangular or trapezoidal IFNs), an **expected value function** can be used. For example, for a triangular IFN:

Let $\tilde{\mathscr{A}} = (\tilde{a}, \tilde{\mu}, \tilde{\nu})$, where:

- $\tilde{a} = (a_1, a_2, a_3)$ triangular number,
- $\tilde{\mu} = (\mu_1, \mu_2, \mu_3)$,
- $\tilde{\nu} = (\nu_1, \nu_2, \nu_3)$.

Then, a general **expected value index** is:

$$E(\tilde{\mathscr{A}}) = \frac{1}{3} \sum_{i=1}^{3} [\mu_i \cdot a_i + (1 - \nu_i) \cdot a_i] \tag{16}$$

It combines the positive impact of membership and the complement of non-membership.

4. Proposed MCDM Methodologies

A set of procedures used to assess and choose the best alternative from a set of options that depend on more than one and mostly contrasting, criteria is known as Multi-Criteria Decision-Making (MCDM) [32]. During the planning of the infrastructure, a thorough evaluation is necessary that encompasses various issues, such as selecting a suitable site for aeronautics. These are the factors that decision-makers or researchers must consider, encompassing a wide range of elements such as technical, economic, social and environmental considerations that may not always be mutually exclusive or quantifiable. A proper structure needs to be provided by MCDM that supports a rational and transparent comparison of various alternatives by providing significance to each and every condition and integrating their results. These methods decrease subjectivity and enhance the quality of decisions, making the technique much more defensible and consistent.

4.1 *Fuzzy Analytic Hierarchy Process (AHP) Method*

Thomas L. Saaty [50] developed a decision-making tool that frames the difficult decisions into a hierarchical structure and is managed jointly compared to develop balanced weights of conditions known as AHP or Analytic Hierarchy Process [51]. It depends on various comparisons of numbers that may or may not always reveal the unclear or uncertain character of real-life findings, and it is highly effective in influencing judgments of the human world. In practical applications, choosing a location for a communication centre involves making decisions based on information obtained through objective opinions from multiple researchers. The accuracy required by conventional AHP can lead to irregularity or a lack of consequential data. The constraints have been addressed through the Fuzzy AHP technique by amalgamating the traditional AHP structure with fuzzy set theory.

The fuzzy AHP technique provides a hierarchical framework that builds upon the traditional AHP. However, elevates its effectiveness by permitting greater feasibility and realism in exploring alternatives. This technique also supports the consistency verification system of AHP, ensuring that the analysts' judgments are logically coherent. Fuzzy AHP is individually significant as it allows the researcher's judgment to be included even when the exact information is limiting or, at the time, evaluating conditions are objective in nature. The ultimate fuzzy weights provide a more accurate and feasible input for future investigations and rating, particularly when mixed with procedures such as Fuzzy TOPSIS. It can be concluded that Fuzzy AHP provides an efficient and realistic decision-making system for comparative issues in uncertain situations. The step-wise AHP methodology is shown through the flowchart in Figure 3.

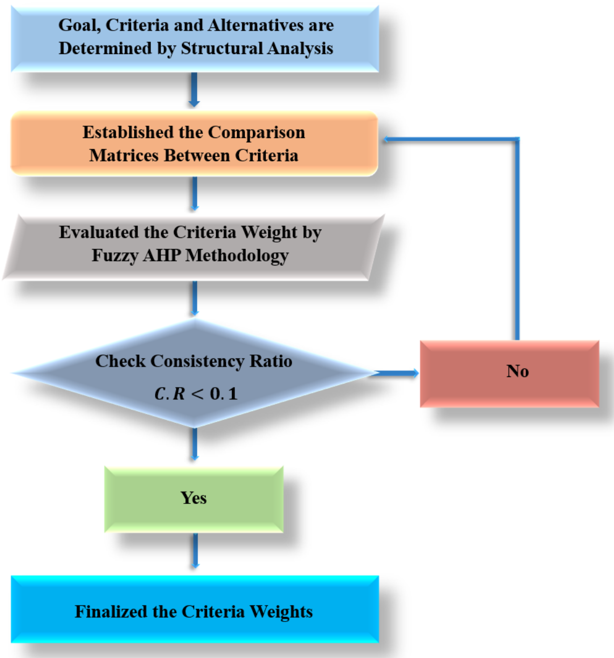

Fig. 3. Structural flowchart of the AHP method

Let us consider C number of criteria $(q, r = 1, 2, \ldots, C)$ are taken to formulate the model. Further, D number of decision makers $(k = 1, 2, \ldots, D)$ are associated with the data collection for this study. The comprehensive process for AHP methodology in an intuitionistic fuzzy environment is presented as follows:

Step 1: Construct the comparison matrix $(\tilde{\mathcal{I}}_k)$ in terms of Intuitionistic Fuzzy Number (IFN):
The decision-makers (DMs) are given opinions based on their experiences on the criteria related to the other criteria in the form of a comparison matrix. There is D number of comparison matrices built with linguistic terms by Table 5 and transformed into intuitionistic fuzzy numbers (IFS) by the same table. If the k^{th} DM given rating of q^{th} criteria based on r^{th} criteria is $\left(\tilde{\mathcal{E}}_{qr}\right)_k$

then the k^{th} comparison matrix is $\tilde{\mathcal{I}}_k$ of formed as

$$\tilde{\mathcal{I}}_k = \begin{bmatrix} \left(\tilde{\mathcal{E}}_{11}\right)_k & \left(\tilde{\mathcal{E}}_{12}\right)_k & \dots & \left(\tilde{\mathcal{E}}_{1r}\right)_k & \dots & \left(\tilde{\mathcal{E}}_{1C}\right)_k \\ \left(\tilde{\mathcal{E}}_{21}\right)_k & \left(\tilde{\mathcal{E}}_{22}\right)_k & \dots & \left(\tilde{\mathcal{E}}_{2r}\right)_k & \dots & \left(\tilde{\mathcal{E}}_{2C}\right)_k \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \left(\tilde{\mathcal{E}}_{q1}\right)_k & \left(\tilde{\mathcal{E}}_{q2}\right)_k & \dots & \left(\tilde{\mathcal{E}}_{qr}\right)_k & \dots & \left(\tilde{\mathcal{E}}_{qC}\right)_k \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \left(\tilde{\mathcal{E}}_{C1}\right)_k & \left(\tilde{\mathcal{E}}_{C2}\right)_k & \dots & \left(\tilde{\mathcal{E}}_{Cr}\right)_k & \dots & \left(\tilde{\mathcal{E}}_{CC}\right)_k \end{bmatrix}_{C\times C} \tag{17}$$

Now, the Equation (17) can be also described as,

$$\tilde{\mathcal{I}}_k = \left[\left(\tilde{\mathcal{E}}_{qr}\right)_k\right]_{C\times C} = \left[\left\{\left(\mu_{\tilde{\mathcal{E}}_{qr}}\right)_k, \left(\nu_{\tilde{\mathcal{E}}_{qr}}\right)_k\right\}\right]_{C\times C} \tag{18}$$

where $q, r = 1, 2, \dots, C$ and $k = 1, 2, \dots, D$.

The input $\tilde{\mathcal{E}}_{qr}$ represents the k^{th} decision maker's opinion about q^{th} criteria based on r^{th} criteria and it is given as

$$\left(\tilde{\mathcal{E}}_{qr}\right)_k = \left\{\left(\mu_{\tilde{\mathcal{E}}_{qr}}\right)_k, \left(\nu_{\tilde{\mathcal{E}}_{qr}}\right)_k\right\} \tag{19}$$

Step 2: Aggregating Comparison Matrix $(\tilde{\mathcal{I}}^{\mathscr{A}})$**:**
Aggregate the D numbers of the comparison matrices into a single comparison matrix by Equation (20), as follows

$$\begin{aligned} \tilde{\mathcal{E}}_{qr} &= \left\{\mu_{\tilde{\mathcal{E}}_{qr}}, \nu_{\tilde{\mathcal{E}}_{qr}}\right\} \\ &= \left\{\frac{\sum_{k=1}^{D}\left(\mu_{\tilde{\mathcal{E}}_{qr}}\right)_k}{D}, \frac{\sum_{k=1}^{D}\left(\nu_{\tilde{\mathcal{E}}_{qr}}\right)_k}{D}\right\} \end{aligned} \tag{20}$$

Then, the aggregated comparison matrix $(\tilde{\mathcal{I}}^{\mathscr{A}})$ is

$$\tilde{\mathcal{I}}^{\mathscr{A}} = \left[\tilde{\mathcal{E}}_{qr}\right]_{C\times C} = \left[\left\{\mu_{\tilde{\mathcal{E}}_{qr}}, \nu_{\tilde{\mathcal{E}}_{qr}}\right\}\right]_{C\times C} \tag{21}$$

where $q, r = 1, 2, \dots, C$ and $k = 1, 2, \dots, D$.

Step 3: De-i-fuzzified the Aggregated Comparison Matrix $(\mathcal{I})$**:**
Now, determine the de-i-fuzzified aggregated comparison matrix $(\mathcal{I})$ by de-i-fuzzifying every entry of the aggregated comparison matrix $(\tilde{\mathcal{I}}^{\mathscr{A}})$ using Equation (13). The de-i-fuzzified aggregated comparison matrix $(\mathcal{I})$ is described as follows

$$\mathcal{I} = [\mathcal{E}_{qr}]_{C\times C} \tag{22}$$

where $\mathcal{I}_{qr}$ is the de-fuzzification value corresponding to the IFNs $\tilde{\mathcal{E}}_{qr}$ with $q, r = 1, 2, \dots, C$.

Step 4: Normalized Comparison Matrix $(\mathcal{I}^n)$**:**
Further, we evaluate the normalized comparison matrix $(\mathcal{I}^n)$ from the de-i-fuzzified aggregated comparison matrix $(\mathcal{I})$. The qr^{th} entry of the normalized comparison matrix $(\mathcal{I}^n)$ is determined as

$$\mathcal{E}^n_{qr} = \frac{\mathcal{E}_{qr} - \mathcal{E}^{worst}{}_r}{\mathcal{E}^{best}{}_r - \mathcal{E}^{worst}{}_r} \tag{23}$$

and here

$$\begin{cases} \mathcal{E}^{best}{}_r = \max\limits_{q=1,2,\dots,C} \mathcal{E}_{qr} \\ \mathcal{E}^{worst}{}_r = \min\limits_{q=1,2,\dots,C} \mathcal{E}_{qr} \end{cases}$$

Step 5: Calculate criteria weight $(\mathscr{W}_q)$**:**
Then the weight of the criteria is determined from the normalized comparison matrix $(\mathcal{I}^n)$ and denoted by $\mathscr{W}_q$. The criteria weight is evaluated as follows:

$$\mathscr{W}_q = \frac{\left(\prod_{r=1}^{C} \mathcal{E}_{qr}^n\right)^{\frac{1}{C}}}{\sum_{q=1}^{C}\left\{\left(\prod_{r=1}^{C} \mathcal{E}_{qr}^n\right)^{\frac{1}{C}}\right\}} \tag{24}$$

where $q = 1, 2, \ldots, C$.

Step 6: Evaluate factor weight:
Further, we check the consistency of the comparison matrix $(\tilde{\mathcal{I}}_k)$. Now, we calculate the weighted comparison matrix $(\mathscr{W}\mathscr{C})$ from the normalized comparison matrix $(\mathcal{I}^n)$ shown in Equation (23) and using the weight of the criteria $(\mathscr{W}_q)$ calculated using Equation (24). The weighted comparison matrix $(\mathscr{W}\mathscr{C})$ evaluated as follows:

$$\mathscr{W}\mathscr{C} = [\mathscr{W}\mathscr{C}_{qr}]_{C\times C} = \mathscr{W}_q \times \mathcal{I}^n = \left[\mathscr{W}_q \times \mathcal{E}_{qr}^n\right]_{C\times C} \tag{25}$$

where $q, r = 1, 2, \ldots, C$.

Step 7: Weighted sum of each factor of the weighted comparison matrix $(\mathscr{W}\mathscr{C})$**:**
Evaluate the weighted sum $(\mathscr{W}\mathscr{S}_q)$ of each factor q from the weighted comparison matrix $(\mathscr{W}\mathscr{C})$ by Equation (26), as follows:

$$\mathscr{W}\mathscr{S}_q = \frac{\left(\sum_{r=1}^{C} \mathscr{W}\mathscr{C}_{qr}\right)}{\mathscr{W}_q} \tag{26}$$

where $q = 1, 2, \ldots, C$ and C be the number of criteria.

Step 8: Determine the maximum eigenvalue (λ_{max})**:**
Calculate the maximum eigenvalue $(\lambda_{\max})$ of the above comparison matrix as follows:

$$\lambda_{\max} = \frac{\sum_{q=1}^{C} \mathscr{W}\mathscr{S}_q}{C} \tag{27}$$

where $q = 1, 2, \ldots, C$.

Step 9: Evaluate the consistency index $(C.I.)$**:**
The consistency index (CI) of the comparison matrix is determined as follows,

$$CI = \frac{\lambda_{\max} - C}{C - 1} \tag{28}$$

Step 10: Determine the consistency ratio $(C.R.)$**:**
Finally, the consistency ratio (CR) value is evaluated as,

$$CR = \frac{CI}{RI} \tag{29}$$

where RI is the Random Index $(R.I.)$ of the comparison matrix given by Thomas L. Saaty [**SAATY19909**] based on the size of the matrix.

The Random Index (R.I.) is proposed by Thomas L. Saaty [**SAATY19909**] shown in Table 3 for various sizes of comparison matrix.

The calculated value of the Consistency Ratio (CR) must be ≤ 0.1; otherwise, the comparison matrix will be inconsistent and it has to be rectified and reconstructed again. If the comparison matrix is consistent, then the criteria weights evaluated by Equation (24) are considered as optimal weights of the system.

Table 3
Random Index (R.I.) is proposed by Thomas L. Saaty

Λ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57	1.59

4.2 Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Methodology

The most popular technique of Multi-Criteria Decision-Making (MCDM) methods used for rating and selecting the optimal option from a set of alternatives is the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [29]. It was originally developed by Ching–Lai Hwang and Yoon in 1981. Further, updated in 1993 and applied in various fields of applications. The basic principle of this method is to select the best option that is the farthest from the negative ideal solution (NIS) and the closest to the positive ideal solution (PIS). NIS is the hypothetical option that has the worst production values for all conditions. In contrast, PIS has the best performance values under all conditions. This pairwise comparison depends on a weighted evaluation construct on nearness to perfect criteria.

These fuzzy inputs are utilized to build a fuzzy decision matrix, which is standardized and balanced with the use of fuzzy arithmetic. After balancing, the fuzzy decision matrix is constructed with a fuzzy negative ideal solution (FNIS) and a fuzzy positive ideal solution (FPIS) are recognised for every condition. The length of each option from FNIS and FPIS is then planned utilizing a fuzzy distance metric, such as the vertex method.

After calculating the lengths, a closeness coefficient (CC) is calculated for every option, representing the relevant proximity to a definite solution. The option with the highest proximity coefficient determines the best and most advantageous alternative. This technique permits for a more human-centric, adjustable, and preferred process of decision-making, particularly at the time of evaluations, that includes subjectivity and uncertainty. The graphical flowchart of the TOPSIS methodology is presented in Figure 4.

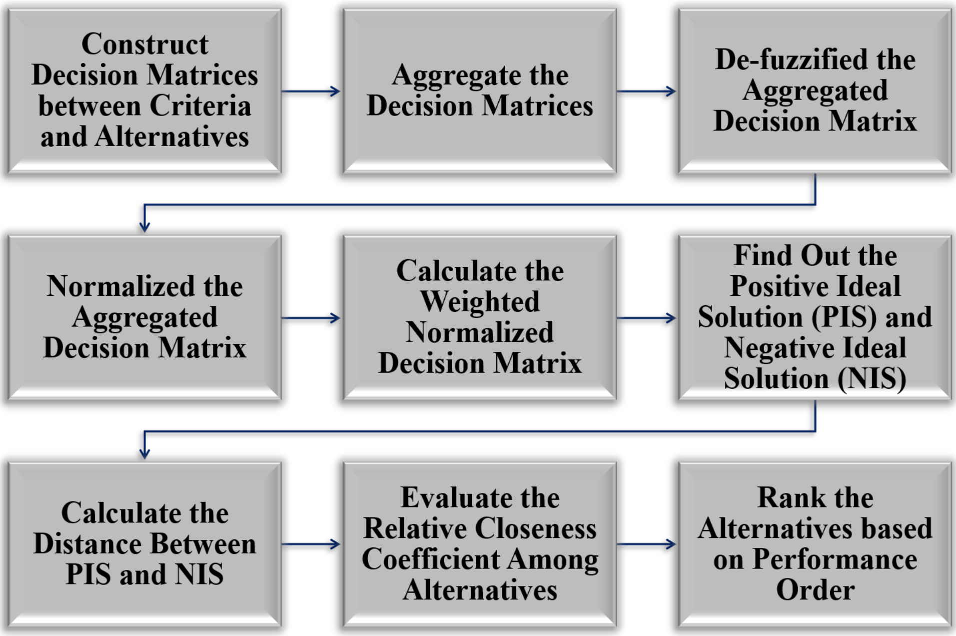

Fig. 4. Structural procedure of the TOPSIS methodology

Assume, C number of criteria $(q = 1, 2, \dots, C)$ and A numebr of alternative $(p = 1, 2, \dots, A)$ are taken to formulate the model. Additionally, D number of decision makers $(k = 1, 2, \ldots, D)$ are given opinions in the form of a dataset for this study. The exhaustive process for the TOPSIS technique in an intuitionistic fuzzy environment is presented as follows:

Step A. Construct the Decision Matrix $(\tilde{\mathcal{J}}_k)$ in terms of Intuitionistic Fuzzy Number (IFN):
The decision matrix $(\tilde{\mathcal{J}}_k)$ is constructed using linguistic terms based on the opinions of decision makers (DMs) using Table 7. Further, the linguistic terms are converted into intuitionistic fuzzy numbers (IFNs) by using Table 7. The decision matrix $(\tilde{\mathcal{J}}_k)$ given by k^{th} DMs as follows:

$$\tilde{\mathscr{J}}_k = \begin{bmatrix} (\tilde{\mathcal{F}}_{11})_k & (\tilde{\mathcal{F}}_{12})_k & \cdots & (\tilde{\mathcal{F}}_{1C})_k \\ (\tilde{\mathcal{F}}_{21})_k & (\tilde{\mathcal{F}}_{22})_k & \cdots & (\tilde{\mathcal{F}}_{2C})_k \\ \vdots & \vdots & \ddots & \vdots \\ (\tilde{\mathcal{F}}_{A1})_k & (\tilde{\mathcal{F}}_{A2})_k & \cdots & (\tilde{\mathcal{F}}_{AC})_k \end{bmatrix}_{A\times C} \tag{30}$$

here $\tilde{\mathscr{J}}_k = [(\tilde{\mathcal{F}}_{pq})_k]_{A\times C}$ represented the Equation (30), where $p = 1, 2, \ldots, A$, $q = 1, 2, \ldots, C$ and $k = 1, 2, \ldots, D$.

Step B. Aggregate the decision matrix $(\tilde{\mathscr{J}})$:
All the decision matrices $(\tilde{\mathscr{J}}_k)$ collected by D numbers of DMs are aggregated and produce single decision matrix $(\tilde{\mathscr{J}})$, as follows:

$$\tilde{\mathscr{J}} = \begin{bmatrix} \tilde{\mathcal{F}}_{11} & \tilde{\mathcal{F}}_{12} & \cdots & \tilde{\mathcal{F}}_{1C} \\ \tilde{\mathcal{F}}_{21} & \tilde{\mathcal{F}}_{22} & \cdots & \tilde{\mathcal{F}}_{2C} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\mathcal{F}}_{A1} & \tilde{\mathcal{F}}_{A2} & \cdots & \tilde{\mathcal{F}}_{AC} \end{bmatrix}_{A\times C} \tag{31}$$

where $\tilde{\mathcal{F}}_{pq}$ be the aggregated IFN of D number of DMs' opinions and aggregated by Equation (20) with $p = 1, 2, \ldots, A$, $q = 1, 2, \ldots, C$ and $k = 1, 2, \ldots, D$.

Step C. De-i-fuzzified aggregated decision matrix $(\mathscr{J})$:
The de-i-fuzzified aggregated decision matrix $(\mathscr{J})$ is evaluated from the aggregated decision matrix $(\tilde{\mathscr{J}})$ by using Equation (13). The de-fuzzified aggregated matrix $(\mathscr{J})$ formulate as

$$\mathscr{J} = [\mathcal{F}_{pq}]_{A\times C} \tag{32}$$

where $\mathcal{F}_{pq}$ be the de-i-fuzzified value of $\tilde{\mathcal{F}}_{pq}$ with $p = 1, 2, \ldots, A$ and $q = 1, 2, \ldots, C$.

Step D: Normalized Decision Matrix $(\mathcal{J}^n)$:
Now, we determined the normalized decision matrix $(\mathcal{J}^n)$ from the de-i-fuzzified aggregated decision matrix $(\mathcal{J})$. The pq^{th} entry of the normalized decision matrix $(\mathcal{J}^n)$ is evaluated as follows:

$$\mathcal{J}^n_{pq} = \left[\mathcal{F}^n_{pq}\right]_{A\times C} = \left[\frac{\mathcal{F}_{pq}}{\sum_{q=1}^{C} \mathcal{F}_{pq}}\right]_{A\times C} \tag{33}$$

where $p = 1, 2, \ldots, A$ and $q = 1, 2, \ldots, C$.

Step E. Determine Weighted Normalized Decision Matrix $(\mathcal{J}^w)$:
The weighted normalized decision matrix $(\mathscr{J}^w)$ evaluated from the normalized decision matrix

$(\mathcal{J}^n)$ and weight of the criteria $(\mathscr{W}_q)$ evaluated in the previous section by Equation (24), as follows:

$$\begin{aligned}\mathscr{J}^w &= \left[\mathcal{F}^w_{pq}\right]_{A\times C} = \mathscr{W}_q \times \left[\mathcal{F}^n_{pq}\right]_{A\times C} \\ &= \left[\mathscr{W}_q \times \mathcal{F}^n_{pq}\right]_{A\times C}\end{aligned} \tag{34}$$

where $p = 1, 2, \ldots, A$ and $q = 1, 2, \ldots, C$.

Step F. Find the Positive Ideal Solutions (PIS) and Negative Ideal Solutions (NIS):
The PIS and NIS are denoted by $\mathscr{P}^+$ and $\mathscr{N}^-$, respectively. So, we use the following formula,

$$\begin{aligned}\mathscr{P}^+ &= \left[\mathscr{P}^+_q\right]_{1\times C} = \left\{\mathcal{F}^+_1, \mathcal{F}^+_2, \ldots, \mathcal{F}^+_q, \ldots, \mathcal{F}^+_C\right\} \\ &= \left\{\max\left\{\mathcal{F}_{pq+} : q+ \in B.C.\left(P^+\right)\right\},\ \min\left\{\mathcal{F}_{pq-} : q- \in N.B.C.\left(N^-\right)\right\}\right\}\end{aligned} \tag{35}$$

and

$$\begin{aligned}\mathscr{N}^- &= \left[\mathscr{N}^-_q\right]_{1\times C} = \left\{\mathcal{F}^-_1, \mathcal{F}^-_2, \ldots, \mathcal{F}^-_q, \ldots, \mathcal{F}^-_C\right\} \\ &= \left\{\min\left\{\mathcal{F}_{pq-} : q- \in B.C.\left(P^+\right)\right\},\ \max\left\{\mathcal{F}_{pq+} : q+ \in N.B.C.\left(N^-\right)\right\}\right\}\end{aligned} \tag{36}$$

where $B.C.(P^+)$ and $N.B.C.(N^-)$ are the sets of beneficial and non-beneficial criteria, respectively.

Step G. Evaluate the relative distance for each alternative from the PIS and NIS:
The standard separation measures are defined in the following way,

$$LP^+_p = \sqrt{\sum_{q=1}^{C}\left(\mathcal{F}^w_{pq} - \mathscr{P}^+_q\right)^2} \tag{37}$$

and

$$LP^-_p = \sqrt{\sum_{q=1}^{C}\left(\mathcal{F}^w_{pq} - \mathscr{N}^-_q\right)^2} \tag{38}$$

where $p = 1, 2, \ldots, A$.

H. Determine the Relative Closeness Coefficient (RCC):
The Relative Closeness Coefficient (RCC) $(\tilde{\Upsilon}_\iota)$ to the ideal alternatives is denoted as,

$$RP_p = \frac{LP^-_p}{LP^+_p + LP^-_p} \tag{39}$$

where $p = 1, 2, \ldots, A$.

I. Required result:
This is the last and final step in this procedure. Here, the options that are ranked as ideal alternatives are those that are based on RCC (RP_p) determined by Equation (39). The closest coefficient is with the highest value of the first alternative and so on.

5. Related Criteria for Site Selection of a New Airport in India

Obstruction-free, steady and uniform land parts are to be confirmed through suitable geographical and topographical accountability. In contrast to that, climatic conditions and meteorological reinforcement must safeguard annual functioning with minimum weather related disturbance. Good communication and accessibility to important roads and railways, as well as the major cities, are necessary for smooth flight operations, while maintaining a contrusion-free aerial space to ensure safety in navigation. Ecological and environmental influences must be evaluated efficiently in order to protect biodiversity in the local area. Finally, socio-economic factors, including regional dynamic elevation, employment generation and tourism development, are vital to enhancing the airport's positive impact on the economy and community as well [12, 14–16]. Related criteria are as follows:

5.1 *Topographical and Geographical Criteria* (C_1)

The substantial outlook plays a basic role in considering the reliability of the airport's location [12]. Originally, the area needs to be smooth with minimal obstructions to facilitate the construction of the runway and other airport functions. Areas prone to floods or covered with hills or marshy landforms can be challenging for proper drainage and land levelling. If the land is hilly, the cost of levelling the elevated landforms may increase. On the other hand, flood-prone landforms may increase disaster management costs and disrupt frequent flight take-offs. Additionally, the location must be geologically stable, with reduced susceptibility to soil erosion and earthquakes, especially in areas near fault lines. In the event of any natural calamities, disaster management plays a crucial role in maintaining the frequency of flights.

5.2 *Meteorological and Climatic Criteria* (C_2)

The weather has a direct impact on the safety and operation of the airport's flights [52]. A location needs to have suitable climatic conditions all year round, with minimal chances of thunderstorms, fog, strong crosswinds and heavy rainfall that decrease visibility and disturb air traffic. Clean skies are of paramount importance for the safe arrival and landing of flights. The clouds can cause severe accidents on the airways. In the case of cyclones and thunderstorms, flight delays can occur, and these storms can also be a contributing factor to many fatal accidents. Fog is also a possibility that may cause aircraft crashes in the air. To ensure smooth functioning throughout the year, various long-term climatic data must be considered, including annual precipitation levels, fluctuating temperatures, and rising wind speeds.

5.3 *Connectivity and Accessibility* (C_3)

The success rate of the airport highly depends on its coordination with the local communication system. Accessibility of the location through railways, public communications, roadways and cargo movement is vital [53]. The volume of passengers and utilisation can be elevated by the proximity to major economic centres and important cities. The staff must reach their home safely after finishing their duty time. Then, the raw materials for the staff canteen and other machine servicing can only be done if the important urban centres are nearby. People residing far away from the airport must have access to the transport system. Popularity can be increased if the aircraft station is located in an area with a stable economic value. It may be needed to exist ideally or to be pre-planned through highways and railways. The time and cost depletion can be done if there is proximity to state or national highways. Additionally, metro stations and bus terminals enhance airport accessibility and have a significant impact on the region.

5.4 Airspace and Navigation Safety (C_4)

Aerospace management plays a crucial role in preventing overcrowding and ensuring the safe take-off and landing of flights [54]. The location must be in a place where flight operations can be easily managed and must not obstruct the path of any other flights from another airport or military base, causing navigation confusion or limiting the hours of operation. The area needs to be checked for high-rise buildings, telecommunications towers and high-voltage power lines. This kind of sky-high structure can pose various detrimental hazards to the lives of passengers. Additionally, it can affect scheduled flight times and cause delays in flight operations. In contrast, the region must be suitable for advanced navigation and surveillance systems, such as RADAR, ILS (Instrument Landing System), and ADS-B, without interruption from electromagnetic and terrain sources. These are necessary due to different technical interruptions, as well as delays in flight timings and military disruptions, which impact the economic circumstances of the aircraft stations.

5.5 Land Availability and Cost (C_5)

The accessibility of a vast, effective landform is essential for building an airport [15], as it requires a large area for runways, terminals, taxiways and future extensions. Originally, the location must be under public ownership or government inquisition to prevent any acquisition and legal disputes. To decrease the detention time, the ownership of the land must be confirmed. The land must be rightfully obtained to avoid any legal issues related to the construction of the infrastructure. The investment costs, land settlement costs, and resettlement costs must be lower than the profit gained from the aircraft station. A vast land area must be ensured for constructing all the necessary structural amenities required for smooth functioning. The region needs to be minimally populated to decrease replacement issues. The project's economic feasibility can be maintained through a reasonable land cost. To prevent a delayed timeline for project construction, the location must be free from any contested titles, endangered habitats or encroachments.

5.6 Environmental and Ecological Considerations (C_6)

Aircraft stations are an essential infrastructure that significantly impacts the native environment [52]. Corporate Social Responsibility needs to be incorporated in the environmental, social, design and implementation of the project. The project must be beneficial to the surrounding community and must add value to their lives. Strategies must be implemented to reduce noise levels, such as incorporating sound-absorbing materials or installing noise barriers. Emissions from aircraft, as well as vehicles, need to be controlled. Water-efficient fixtures must be implemented, along with composting. Recycling programs must be implemented to decrease landfill waste. Evaluating nearby rivers, forests, wetlands, and protected areas to mitigate ecological destruction for wildlife. Environmental Impact Assessments are necessary to evaluate the direct effects on he quality of air, water bodies and biodiversity. The region covered by any endangered species or any migratory birds should be avoided in compliance with the conservation regulations.

5.7 Regulatory and Strategic Considerations (C_7)

The location of the airport should align with both the state's and national aviation practices [13]. The area must act in accordance with the guidelines of the Ministry of Civil Aviation, the Directorate

General of Civil Aviation and the Airports Authority of India. The International Civil Aviation Organization suggests some practices and standards that need to be maintained. The Directorate General of Civil Aviation regulations must be looked at for technical and security standards. The security regulations at the airport's location must comply with the Bureau of Civil Aviation Security standards. The location must have proper zoning regulations and national and local building codes. The zoning permits of the area must be less challenging and less time-consuming. The important aspects of regulations include aligning with international aviation standards, ensuring security protocols, and incorporating environmental regulations. Approvals from various regulatory sectors, including regional planning boards, the Urban Development Authority, and the Board of State Pollution Control, must be secured in terms of both timeliness and reliability.

5.8 Socio-Economic Factors (C_8)

The selected area must be enhanced with various economic activities, including several tourism opportunities, as well as potential industrial opportunities [17]. The construction of an aircraft station must create job opportunities for local people, attract business and increase economic value. The area must be suitable so that job opportunities can be created directly in the operational and construction sectors. The location must offer sufficient opportunities for tourists, thereby enhancing its economic value and attracting investors. The hospitality, tourism, and logistics sectors must receive a significant employment boost. The region must be attractive enough to intrigue local and foreign investors. The area needs to offer options that enable businesses to access larger markets and opportunities. The impact on the native people needs to be taken into account; there must be no disproportionate distribution of land. Rehabilitation and compensation should also be provided. Location must facilitate internal growth, reduce regional disparities, and integrate underdeveloped regions into the national economy's structure.

6. Proposed sites for New Airport in India

Every alternative sites must be tracked both geographically and topographically. Climatic conditions and meteorological factors, such as the frequency of fog, heavy rainfall and wind, are to be taken into account. Proper communication systems, such as the availability of roads and railways along with urban centres, need to be considered. The ecological and environmental impacts must be compared through Environmental Impact Assessments to minimise their destructive effects on the ecosystem. Ease of obtaining all necessary approvals and regulatory viability, including aviation alignment and military policies, plays a crucial part. Finally, socio-economic factors should be considered, supporting the generation of industry and tourism employment. The alternatives are chosen from different states in India [55], as follows:

6.1 Baripada (L_1)

The headquarters of the Mayurbhanj district, situated in the northern part of Odisha, is located in Baripada, an area of interest to the National Park and Simlipal Tiger Reserve. The airfield holds great historical significance as it was the largest in Asia during the Second World War, spanning almost 160 acres of land. However, most of the land has since been utilised privately. The closeness to the spiritual and tourist terminus provides it with a huge advantage. This area is counted as one of India's most vital regions of the biosphere. In spite of its tourism and ecological significance, this place has an absence of any aircraft stations and the closest ones are even 230 km apart, including Bhubaneshwar and Kolkata. This place is important for the ecotourism around the Simpal district.

6.2 *Kanker* (L_2)

There is a region in the southern part of Chattishgarh, mostly covered with tribal presidings named as Kanker. This region is important for the tribal community and it also holds a significant place for the natural beauty. However, as this is a remote region, the aircraft station would get impacted immensely. The transportation time will decrease, making the place more accessible. The absence of an airport has been noticed in this area and the closest one is Raipur, which is even more than 140 km away and also had to be covered through a strenuous path of travel. An airport in the local area can reduce transportation time for the natives of Kanker and those in the surrounding areas. If the aircraft is being built in Kanker, it can hold diplomatic significance, leading to the rapid development of healthcare services, disaster management cells, and safety units.

6.3 *Balurghat* (L_3)

Balurghat is located in the Dakshin Dinajpur district in West Bengal, a centre of administration, near the border of Bangladesh and India. It lacks an airport and the closest airports are more than 200 km away. It is one of the important towns in North Bengal and an active aircraft station would elevate the airway of this area. The enhancements of small-scale factories by elevating market access and logistics can be encouraged in this area. Jobs can be created as well as revenue can be generated through tourism due to the proximity to the historical regions. The region has prospects of cultural tourism, regional development of communication, and trade across the border. This initiative offers the opportunity for increased availability and economic benefits in areas through improved communication with Kolkata and the northeastern part of India.

6.4 *Nandurbar* (L_4)

Nandurbar is an area mostly occupied by the tribal population. This region is located in the northern part of Maharashtra. This region is relatively lower in air connectivity, a relatively isolated place and the nearest airports are in Surat, Gujarat or in Aurangabad, Maharashtra. This can significantly reduce the time of transportation to the important urban centres and ease the movements of people. It will be more accessible to people because of its cultural diversions, eco-tourism and traversing off-beat destinations. In this place, the population exceeds 16 lakh, with less availability of railway stations or airports, thus the chances of accessibility to medical emergency services, commerce or education become less. The area contains even dry landforms that are most suited for establishing the infrastructure without disrupting the ecological balance.

6.5 *Motihari* (L_5)

Another suitable location for airport site selection is Motihari, known for the Champaran Satyagraha led by Mahatma Gandhi, which holds great historical significance. This place holds a large population and the people had to travel to Darbhanga or Patna to provide them with the much-needed access to air facilities. The improved air communication can attract several investors, as it will provide faster transportation of goods. The ease in the movement of goods can elevate the opportunities to enhance trade and commerce. As the area is near many religious sites, the aircraft station may increase the inflow and outflow of pilgrims as well. Although the closest airport lies in Patna, which is almost 140 km away from Motihari. The major drawback lies in the part as it deals with annual floods and improper establishment.

The proposed site details are described in Table 4. The locations, along with their corresponding states and distances from the nearest airport, are presented here. Further, the Latitude and Longitude of the proposed sites are described. Additionally, the reasons for the airport's need are presented in the table below. Furthermore, the geographical locations of the proposed sites are dipected in Figure 5.

Table 4
Suggested sites and their details for airport location selection in India

Airport site	Location	Latitude	Longitude	Distance to nearest Airport	Reason for Airport
Baripada (L_1)	Odisha	$21°56'0.6''N$	$86°43'19.2''E$	240 km	Eco-tourism (Simlipal), remote region
Kanker (L_2)	Chhattis- garh	$20°16'31.8''N$	$81°29'28.3''E$	140 km	Tribial region, strategic area
Balurghat (L_3)	West Ben- gal	$25°12'49.3''N$	$88°46'37.2''E$	200 km	Border trade, regional isolation
Nandubar (L_4)	Maharastra	$21°22'0.1''N$	$74°15'0.0''E$	150 km	Tribial upliftment, emer- gency service access
Motihari (L_5)	Bihar	$26°38'54.9''N$	$84°54'59.8''E$	140 km	Heritagr, population, education center

7. Model Formulation and Data Collection

This chapter discusses the model formulation of this study, followed by an explanation of the data collection for this model. This study was designed to select an airport in an urban area in India, considering multiple conflicting criteria, as well as expert opinions from alternative stakeholders and decision-makers.

7.1 Model formulation

This section discusses the formulation of this model in detail. There are eight criteria considered for this research, following a thorough literature review and consultation with decision experts in a scientific manner. All the criteria are either fully or partially dependent on the study's purpose and are described in Chapter 5. After considering the criteria for the airport site, we chose five sites in India where an airport is needed for multiple reasons, which are discussed in Chapter 6. Based on the selected criteria and alternatives, we evaluated the results in a complex and scientific way. Three decision-makers are presented with opinions for comparison and decision matrices in an unbiased and hassle-free manner. All decision makers (DMs) are professionals, unbiased and have enough knowledge in their respective fields. Three DMs are:

DM1: A senior professor in the field of social science department with 15 years of experience.

DM2: A government officer from the Ministry of Civil Aviation with more than 15 years of experience.

DM3: A social worker working for NGOs for more than 20 years.

Fig. 5. Suggested locations for Airport in India [55]

7.2 Data collection

This section provides an in-depth discussion of data sources, data collection procedures and the dataset. Three decision makers (DMs) give data in an unstructured way and the details on the DMs are provided in the previous section. First, we structured the comparison matrix of 8×8 order among the criteria to determine the criteria weights and checked the consistency ratio (CR) using the Analytic Hierarchy Process (AHP) method in linguistic terms by Table 5. After that, the decision matrix is formulated based on the criteria and alternatives of 5×8 order to evaluate the ranking of alternatives as sites using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methodology in linguistics terms by Table 7.

The comparison matrix is described in linguistic terms in Table 6 using the linguistic terms provided by three decision makers (DMs) from Table 5. The decision matrix is presented in Table 8 using the linguistic terms given by three DMs from Table 7. Further numerical illustrations using two MCDM methodologies of the proposed model are presented in a later section and evaluated using these datasets.

Table 5

Conversion table between linguistic terms and IFNs for comparison matrix

Linguistic Terms	Intuitionistic Fuzzy Numbers (IFNs)	Score Value	Accuracy Value
Truly Significant (TS)	$\{0.80, 0.10\}$	0.630	0.640
Strongly Significant (SS)	$\{0.75, 0.15\}$	0.540	0.550
Very Significant (VS)	$\{0.70, 0.20\}$	0.450	0.460
Comparably Significant (CS)	$\{0.65, 0.25\}$	0.360	0.370
Weakly Significant (WS)	$\{0.60, 0.30\}$	0.270	0.280
Slightly Significant (SS)	$\{0.55, 0.35\}$	0.180	0.190
Negligibly Significant (NS)	$\{0.50, 0.40\}$	0.090	0.100

8. Numerical Illustration

This chapter presented the numerical illustration of the proposed study by two MCDM methodologies in an intuitionistic fuzzy numbers (IFNs) environment. All the numerical computations are performed based on two MCDM methods discussed in Chapter 4 associated with the intuitionistic fuzzy numbers mentioned in Chapter 3, respectively. The numerical evaluation was performed as follows:

8.1 Weight of the criteria

The weight of the criteria is evaluated in this section using the AHP method within the IFNs environment. The AHP method is mathematically described in Section 4. Furthermore, the dataset is taken from the comparison matrix in Table 6 and converted into IFNs by using Table 5. All the comparison matrices given by DMs are aggregated using Equation (17) and then constructed into an aggregated comparison matrix. After aggregation, we determine the de-i-fuzzified aggregated comparison matrix using Equation (22) and present it in Table 9. Then, evaluated the normalized comparison matrix using Equation (23) and presented it in Table 10. After that, we determine the weight of the criteria using Equation (24) and present it in Table 11. This is the weight of the criterion considered for further numerical evaluation.

Table 6
Comparison matrix in linguistic terms given by three DMs

	Criteria vs Criteria	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$
DM1	Topographical and Geographical Criteria (C_1)	CS	SS	TS	CS	VS	WS	SS	CS
	Meteorological and Climatic Criteria (C_2)	LS	CS	VS	NS	WS	TS	VS	SS
	Connectivity and Accessibility (C_3)	VS	SS	CS	TS	VS	SS	TS	VS
	Airspace and Navigation Safety (C_4)	LS	NS	WS	CS	SS	VS	TS	VS
	Land Availability and Cost (C_5)	CS	SS	TS	VS	CS	SS	TS	TS
	Environmental and Ecological Considerations (C_6)	SS	TS	TS	VS	NS	CS	VS	SS
	Regulatory and Strategic Considerations (C_7)	LS	WS	VS	TS	TS	WS	CS	SS
	Socio-Economic Factors (C_8)	VS	SS	TS	WS	LS	VS	TS	CS
	Criteria vs Criteria	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$
DM2	Topographical and Geographical Criteria (C_1)	CS	SS	VS	TS	TS	VS	LS	SS
	Meteorological and Climatic Criteria (C_2)	CS	CS	SS	TS	VS	TS	VS	LS
	Connectivity and Accessibility (C_3)	NS	VS	CS	SS	TS	SS	WS	NS
	Airspace and Navigation Safety (C_4)	WS	LS	NS	CS	SS	VS	CS	TS
	Land Availability and Cost (C_5)	LS	SS	VS	TS	CS	TS	SS	VS
	Environmental and Ecological Considerations (C_6)	TS	VS	SS	SS	VS	CS	WS	SS
	Regulatory and Strategic Considerations (C_7)	VS	TS	SS	VS	TS	VS	CS	SS
	Socio-Economic Factors (C_8)	SS	VS	TS	TS	VS	SS	TS	CS
	Criteria vs Criteria	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$
DM3	Topographical and Geographical Criteria (C_1)	CS	TS	SS	VS	CS	WS	LS	SS
	Meteorological and Climatic Criteria (C_2)	TS	CS	SS	VS	VS	SS	TS	VS
	Connectivity and Accessibility (C_3)	CS	TS	CS	VS	SS	VS	TS	LS
	Airspace and Navigation Safety (C_4)	WS	TS	VS	CS	TS	SS	WS	NS
	Land Availability and Cost (C_5)	SS	VS	SS	TS	CS	WS	TS	SS
	Environmental and Ecological Considerations (C_6)	TS	SS	CS	VS	LS	CS	WS	NS
	Regulatory and Strategic Considerations (C_7)	VS	VS	CS	TS	VS	LS	CS	TS
	Socio-Economic Factors (C_8)	TS	CS	VS	TS	VS	SS	TS	CS

Table 7
Linguistic terms with corresponding IFNs for the decision matrix

Linguistic Terms	Intuitionistic Fuzzy Numbers (IFNs)	Score Value	Accuracy Value
Extremely Important (EI)	$\{0.90, 0.05\}$	0.8075	0.8100
Very Important (VI)	$\{0.85, 0.10\}$	0.7125	0.7150
Moderate Important (MI)	$\{0.80, 0.15\}$	0.6175	0.6200
Average Important (AI)	$\{0.75, 0.20\}$	0.5225	0.5250
Weakly Important (WI)	$\{0.70, 0.25\}$	0.4275	0.4300
Less Important (LI)	$\{0.65, 0.30\}$	0.3325	0.3350
Negligibly Important (NI)	$\{0.60, 0.35\}$	0.2375	0.2400

Table 8
Decision matrix in linguistic terms given by three DMs

	Criteria vs Alternatives	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$
DM1	Baripada (L_1)	EI	VI	MI	AI	WI	VI	AI	EI
	Kanker (L_2)	MI	WI	LI	AI	VI	EI	VI	AI
	Balurghat (L_3)	WI	MI	VI	WI	EI	VI	MI	VI
	Nandubar (L_4)	MI	VI	VI	EI	MI	AI	VI	MI
	Motihari (L_5)	EI	VI	MI	EI	MI	LI	AI	VI
	Criteria vs Alternatives	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$
DM2	Baripada (L_1)	MI	VI	AI	EI	VI	MI	VI	MI
	Kanker (L_2)	AI	MI	VI	EI	WI	LI	NI	AI
	Balurghat (L_3)	VI	WI	MI	LI	MI	VI	AI	VI
	Nandubar (L_4)	EI	VI	WI	AI	EI	MI	VI	AI
	Motihari (L_5)	LI	EI	AI	MI	VI	AI	EI	EI
	Criteria vs Alternatives	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$
DM3	Baripada (L_1)	VI	MI	AI	EI	WI	LI	VI	EI
	Kanker (L_2)	EI	VI	EI	MI	EI	MI	VI	AI
	Balurghat (L_3)	LI	MI	VI	EI	VI	VI	WI	LI
	Nandubar (L_4)	VI	VI	MI	AI	LI	EI	EI	MI
	Motihari (L_5)	AI	LI	EI	WI	VI	LI	VI	EI

Table 9
De-i-fuzzified aggregated comparison matrix

Criteria	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$
Topographical and Geographical Criteria (C_1)	0.36	0.57	0.54	0.48	0.48	0.33	0.30	0.48
Meteorological and Climatic Criteria (C_2)	0.39	0.36	0.51	0.39	0.39	0.60	0.51	0.39
Connectivity and Accessibility (C_3)	0.30	0.54	0.36	0.54	0.54	0.51	0.51	0.24
Airspace and Navigation Safety (C_4)	0.24	0.30	0.27	0.36	0.57	0.48	0.42	0.39
Land Availability and Cost (C_5)	0.36	0.51	0.54	0.57	0.36	0.48	0.60	0.54
Environmental and Ecological Considerations (C_6)	0.60	0.54	0.51	0.48	0.24	0.36	0.33	0.39
Regulatory and Strategic Considerations (C_7)	0.36	0.45	0.45	0.57	0.57	0.30	0.36	0.57
Socio-Economic Factors (C_8)	0.54	0.45	0.57	0.51	0.36	0.51	0.63	0.36

Table 10
Normalized comparison matrix

Criteria	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$
Topographical and Geographical Criteria (C_1)	0.114	0.153	0.144	0.123	0.137	0.092	0.082	0.1430
Meteorological and Climatic Criteria (C_2)	0.124	0.097	0.136	0.100	0.111	0.168	0.139	0.116
Connectivity and Accessibility (C_3)	0.095	0.145	0.096	0.139	0.154	0.143	0.139	0.071
Airspace and Navigation Safety (C_4)	0.076	0.081	0.072	0.092	0.162	0.135	0.115	0.116
Land Availability and Cost (C_5)	0.114	0.137	0.144	0.146	0.103	0.135	0.164	0.161
Environmental and Ecological Considerations (C_6)	0.191	0.145	0.136	0.123	0.068	0.101	0.090	0.116
Regulatory and Strategic Considerations (C_7)	0.114	0.121	0.120	0.146	0.162	0.084	0.098	0.170
Socio-Economic Factors (C_8)	0.171	0.121	0.152	0.131	0.103	0.143	0.172	0.107

Table 11
Weight of the criteria determined by the AHP technique

Criteria	Weight
Topographical and Geographical Criteria (C_1)	0.1240
Meteorological and Climatic Criteria (C_2)	0.1251
Connectivity and Accessibility (C_3)	0.1219
Airspace and Navigation Safety (C_4)	0.1047
Land Availability and Cost (C_5)	0.1398
Environmental and Ecological Considerations (C_6)	0.1191
Regulatory and Strategic Considerations (C_7)	0.1269
Socio-Economic Factors (C_8)	0.1385

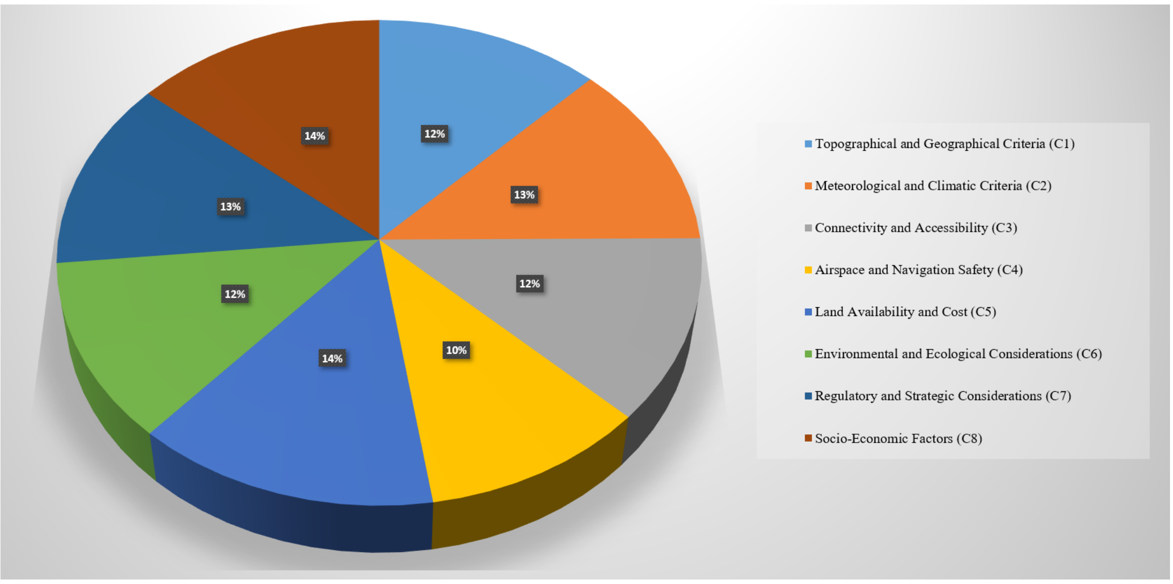

Fig. 6. Pi diagram of the criteria weight evaluated by the AHP method

Figure 6 graphically represents the Pi diagram of the criteria weights of the proposed Airport site section study. From Table 11 and Figure 6, we can conclude that the Land Availability and Cost (C_5) is the most weighted criterion, followed by Socio-Economic Factors (C_8) criteria. Further, Regulatory and Strategic Considerations (C_7), Meteorological and Climatic Criteria (C_2), Topographical and Geographical Criteria (C_1) and Connectivity and Accessibility (C_3) are the third, forth, fifth and sixth weighted criteria, respectively, for this model. Lastly, the criteria Environmental and Ecological Considerations (C_6) and Airspace and Navigation Safety (C_4) are the least weighted criteria, respectively, for this airport site selection problem.

Table 11 is further utilized for ranking the sites as alternatives in the next section. Now, using Equation (29) and Table 3 determine the consistency ratio of the proposed model. The consistency ratio of the comparison matrices is -0.4488, which is less than 0.1 (< 0.1). Therefore, the comparison matrix is consistent and takes the weight of the criteria for further evaluation.

8.2 *Ranking of the alternative*

Ranking of the alternatives is performed in this section using the TOPSIS method (discussed in Section 4) in the fields of intuitionistic fuzzy numbers (discussed in Chapter 3). In the numerical evaluation, the data sets are considered from the decision matrix from Table 8 and criteria weights presented in Table 11 using the conversion table for linguistic terms to the IFS conversion in Table 7, respectively. All the decision matrices given by DMs are merged into one aggregated decision matrix by Equation (20) and further determined the de-i-fuzzified aggregated decision matrix by using Equation (13) and presented in Table 12. Then, the normalised decision matrix was evaluated by utlizing Equation (33) and depicted in Table 13. Further, from the normalised decision matrix and criteria weight (in Table 11), determine the weighted normalized decision matrix using Equation (34) and presented in Table 14. After that, the positive ideal solution (PIS) and negative ideal solution (NIS) are calculated based on the beneficial and non-beneficial criteria using Equation (35) & Equation (36) and presented in Table 15. In this study, the criteria Land Availability and Cost (C_5) and Environmental and Ecological Considerations (C_6) are non-beneficial criteria and the remaining criteria are beneficial criteria for this study. Finally, the RP_p value of the alternatives (as sites) is determined using Equation (39) and ranks are calculated based RP_p values of the alternatives. Table 16 presents the rank of the sites.

Table 12
De-i-fuzzified aggregated decision matrix

Alternative	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$
Baripada (L_1)	0.713	0.681	0.554	0.713	0.523	0.554	0.649	0.744
Kanker (L_2)	0.649	0.586	0.618	0.649	0.649	0.586	0.554	0.523
Balurghat (L_3)	0.491	0.554	0.681	0.523	0.713	0.713	0.523	0.586
Nandubar (L_4)	0.713	0.713	0.586	0.618	0.586	0.649	0.744	0.586
Motihari (L_5)	0.554	0.618	0.649	0.618	0.681	0.396	0.681	0.776

Table 16 presents the ranking of the alternatives as proposed sites for airport locations associated with LP_p^+, LP_p^- and RP_p values, respectively. Furthermore, the geometric representation of the ranking alternatives through a Bar diagram analogous to RP_p values is presented in Figure 7.

From the above table and Figure 7, we see that the site Baripada (L_1) becomes an optimized site for airport location, followed by Motihari (L_5), which is the second most optimized site for airport. Furthermore, the sites Nandubar (L_4) and Kanker (L_2) are the third and fourth optimized sites for airport location. Additionally, Balurghat (L_3) becomes the least optimized location for an airport through this dataset and model.

Table 13
Normalized decision matrix

Alternative	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Baripada (L_1)	0.228	0.216	0.179	0.228	0.166	0.191	0.206	0.232
Kanker (L_2)	0.208	0.186	0.200	0.208	0.206	0.202	0.176	0.163
Balurghat (L_3)	0.157	0.176	0.221	0.168	0.226	0.246	0.166	0.182
Nandubar (L_4)	0.228	0.226	0.190	0.198	0.186	0.224	0.236	0.182
Motihari (L_5)	0.178	0.196	0.210	0.198	0.216	0.137	0.216	0.241

Table 14
Weighted normalized decision matrix

Alternative	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Baripada (L_1)	0.028	0.027	0.022	0.024	0.023	0.023	0.026	0.032
Kanker (L_2)	0.026	0.023	0.024	0.022	0.029	0.024	0.022	0.023
Balurghat (L_3)	0.020	0.022	0.027	0.018	0.032	0.029	0.021	0.025
Nandubar (L_4)	0.028	0.028	0.023	0.021	0.026	0.027	0.030	0.025
Motihari (L_5)	0.022	0.025	0.026	0.021	0.030	0.016	0.027	0.033

Table 15
Positive and negative ideal solutions for different criteria

Ideal Solution	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Positive (PIS)	0.028	0.028	0.027	0.024	0.023	0.016	0.030	0.033
Negative (NIS)	0.020	0.022	0.022	0.018	0.032	0.029	0.021	0.023

Table 16
Ranking of different sites based on the TOPSIS method

Alternative	LP_p^+	LP_p^-	RP_p	Ranking
Baripada (L_1)	0.018	0.050	0.7350	1
Kanker (L_2)	0.044	0.024	0.3482	4
Balurghat (L_3)	0.060	0.008	0.1141	5
Nandubar (L_4)	0.028	0.039	0.5816	3
Motihari (L_5)	0.024	0.044	0.6447	2

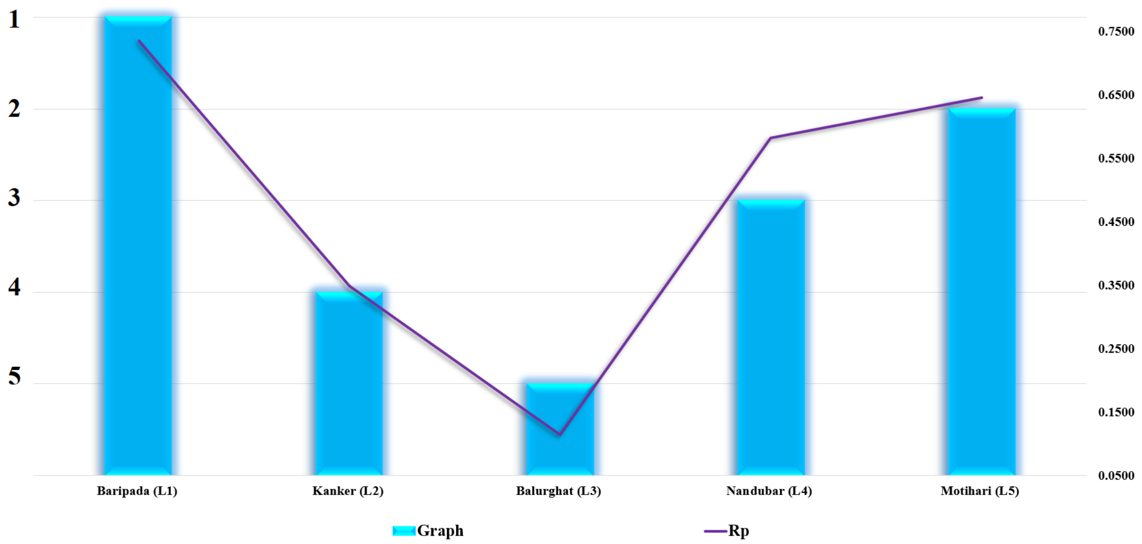

Fig. 7. Bar diagram of the alternative ranking determined by TOPSIS methodology

9. Conclusion and Future Study

In this research, we have evaluated the most preferred location for constructing a new airport in India using a hybrid Fuzzy MCDM approach. We have considered eight criteria based on environmental, technical, and logistical factors. We have also taken five potential locations across different cities in India. We have utilised Intuitionistic Fuzzy Numbers to obtain the results, employing the Analytic Hierarchy Process (AHP) to calculate the weights of the criteria and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for ranking alternatives.

From the weighted calculation methodology, we obtain that the Land Availability and Cost (C_5) and Socio-Economic Factors (C_8) are the most weighted criteria for this site selection model. For detailed weights of the criteria, see Table 11. Further, the sites Baripada (L_1) and Motihari (L_5) are the optimal locations for the airport based on the criteria and data sets. The full ranking of the alternatives is depicted in Table 16.

This research provides a scientifically informed decision-making solution for government authorities, policymakers from the aviation industry and urban planners. By utilising such a fuzzy MCDM framework, decision-making authorities can mitigate the risks of inconsistent and biased assessments. Moreover, evaluating a suitable airport site provides an advantage to society by securing cross-regional interconnectedness, promoting economic growth, increasing accessibility to essential services, and mitigating the impact of environmental and social consequences resulting from low-quality site selection.

9.1 *Further Research Scopes*

There are some further research scopes discussed as follows:

i) Here, we have considered 8 criteria associated with this problem. One can include more criteria and include sub-criteria to get better results.

ii) In this project, the AHP method is used to determine the weights of the criteria and sub-criteria and the TOPSIS method is applied for ranking the alternatives. One may apply MCDM methods, such as entropy, CRITIC, etc., to determine criteria and sub-criteria weights and methods like COPRAS, WASPAS and VIKOR for alternative ranking.

iii) In this project, we have considered 5 alternatives to determine the most suitable location for the Airport. One may consider additional locations to confirm whether there is a better alternative.

iv) Here, we considered opinions of 3 DMs. One may consider the opinions of a large number of decision-makers for better results.

v) Anyone can consider new fuzzy numbers for capturing the uncertainty of the data set and model, such as neutrosophic fuzzy sets, Pythagorean fuzzy sets, picture fuzzy sets, spherical fuzzy sets, probabilistic linguistic sets and grey numbers, among others.

vi) Further, a new de-i-fuzzification method can be considered for de-i-fuzzify the intuitionistic fuzzy numbers.

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Conflicts of Interest

The authors declare that they have no known conflicts of interest or personal relationships that could have appeared to influence the work reported in this paper. There are no conflicts of interest between authors.

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