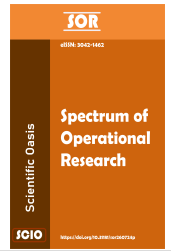




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Multi-Criteria Decision-Making for Sustainable Agritourism: An Integrated Fuzzy-Rough Approach

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ABSTRACT

Agriculture remains the backbone of Pakistan's economy, supporting a substantial segment of the rural population. Recently, agritourism has emerged as a viable avenue for economic diversification, offering new income streams in rural communities. This study explores stakeholder perceptions of sustainable development in agritourism and seeks to identify the key criteria and alternatives necessary for strategic decision-making in this sector. The fuzzy rough set approach is used for multi-criteria decision-making on the data collected from a questionnaire-based survey. Seven alternatives are analyzed for ten criteria. The analysis revealed that retail opportunities, agri-farm tours, farm stays, and on-site activities are the high-ranked alternatives for balancing sustainable agritourism's economic, environmental, and social impacts.

1. Introduction

Agritourism has emerged as a significant aspect of rural development and farm sustainability, offering both farmers and visitors economic, cultural, and educational benefits. A comprehensive literature review highlights several key themes in agritourism research, including its role in diversifying farm income, the influence on visitor behavior and satisfaction, and its contributions to community development. Agritourism serves as a strategy for farm income diversification, providing an alternative revenue stream that helps mitigate the financial instability faced by traditional farming practices. It involves a variety of activities, such as farm tours, educational workshops, and hands-on experiences with agricultural practices. The interaction between tourism and agriculture has been emphasized as crucial for the socio-economic stability of rural areas, enabling farmers to maintain their agricultural practices while engaging visitors [1].

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Studies also highlight the factors driving visitors to agritourism sites, focusing on motivations like seeking authentic rural experiences, engaging in nature-based activities, and participating in agricultural education. Visitor satisfaction is closely tied to their perception of the environment, the quality of the experiences, and the overall enjoyment of the farm-based activities [2]. This satisfaction is not only important for return visits but also influences word-of-mouth recommendations, which can be vital for the growth of agritourism businesses.

From a broader perspective, agritourism contributes to rural community development by promoting local culture, supporting small-scale farmers, and fostering a connection between urban visitors and rural landscapes. As a sustainable practice, it emphasizes environmental stewardship and awareness among visitors, often encouraging a deeper appreciation for agricultural and natural resources. Moreover, recent bibliometric analyses have mapped out the key research themes and collaborations in the field of agritourism, identifying trends and emerging areas for future research. These analyses suggest that there is an increasing focus on sustainable practices and their role in ensuring long-term success for agritourism ventures. Overall, agritourism has evolved into a multifaceted concept that balances economic goals with environmental and cultural sustainability, making it an area of growing interest for both researchers and practitioners in rural development. For a more in-depth review of specific studies and methodologies, accessing detailed bibliometric studies and systematic reviews would provide further insights into this dynamic field.

The process of selecting a course of action or solution from available alternatives is called decision-making. It involves identifying problems, obtaining information, generating options, evaluating and analyzing them, applying decision-making techniques, choosing the best option, implementing the decision, and evaluating the results. Effective decision-making can help to optimize the existing resource management and allocation, and coherence between policy, plan, and actions. Multi-criteria decision-making (MCDM) is recognized as a complex decision-making method that includes both quantitative and qualitative factors. MCDM is a structured process used to evaluate and compare alternatives based on multiple criteria. It allows decision-makers to consider trade-offs and interdependencies among factors before making a final decision. The steps involve problem identification, criteria development, weight assignment, alternative evaluation, aggregation and ranking, sensitivity analysis, and decision-making. MCDM techniques provide a systematic and transparent approach to handling complex decisions, considering diverse perspectives and criteria.

Real-life decision-making problems are subject to uncertain information associated with gathered data or due to decision-maker's choices. Zadeh [3] was the first to address such concerns. His findings termed fuzzy set theory a tool more powerful than the classical probability and evidence theory. The theory is based on the concept of grade or degree of membership of elements of a universe within the universe. In 1982, Pawlak [4] laid the notion of rough set theory (RST) a theoretical framework capable enough to deal with the uncertainties and complexities associated with the data analysis. The proposed theory approximates sets based on the available information, particularly when that information is incomplete, vague, or uncertain. The underlying idea of the rough sets is based on the classification of objects that may be indiscernible from one another based on a set of attributes. Rough set theory has significant applications in multi-criteria decision-making (MCDM) to handle complex problems involving conflicting criteria, alternatives, and attributes such as resource allocation or environmental management.

Agritourism in Pakistan is a relatively emerging concept, which aims to combine agriculture with tourism to generate additional income for farmers while offering tourists an insight into rural life. The idea involves using farms as sites for educational, recreational, and cultural experiences, allowing visitors to participate in agricultural activities and enjoy the rural environment. This could include activities like farm stays, local food tasting, educational tours, and hands-on farming experiences. A comprehensive analysis of the impact of policy implication, social acceptance, public-private partner-

ship, local and international investment opportunities, and climate change on agritourism is essential for the sustainable development of marginal communities.

2. Literature review

Global agritourism practices vary widely across regions, reflecting different cultural, environmental, and economic contexts, but they share common goals of promoting sustainable development and offering unique rural experiences. The belief in innovation in agritourism has increased over the years focusing on the need for the sustainability of agritourism. Innovation in agriculture practices is inevitable for the sustainable development of rural areas. Modern agricultural farms producing organic foods and providing services at the location are seen as an attraction for tourists [5]. Enhancement of farm infrastructure, human resource development, implementation of modern technology, and cultivating fruits and vegetables that are not common in the region are some of the innovative methods that can be used to upgrade farming. These practices not only direct farm diversification and integration of the tourists' products as a compound product in a farm or agricultural land but also promote best practices to be adopted by others for sustainable development of rural areas [6]. Santeramo and Barbieri [7] studied methodologies and practices used in agritourism and recommended isolating the features, amenities, and landscape that draw visitors to an agritourism destination. Mironkina *et al.*, [8] investigated that low competition, low threshold for entering the market, minimal risks, the ability to expand the business, and increasing demand play a vital role in the growth of agritourism. Their analysis indicates that the transition of traditional agricultural practices to a new agritourism predominately occurred during the pandemic and is essential for the active development of agritourism in the region. Mahmoodi *et al.*, [9] compared practices, and challenges associated with agritourism in Poland and Iran. The study showed that agritourism in Poland is more sustainably developed due to its long history and is perhaps more than in Iran. Agritourism has significantly grown in almost all parts of the world and is very successful in rural development. However, the success is lacking policy implementation and public and private agritourism support measures. Grillini *et al.*, [10] studied agritourism in Italy, the USA, and South Africa and suggested that both public and private participation contribute to success; however, clear criteria and further research are needed to fully understand the implications. Domi and Belletti [11] applied structural equation modeling (SEM) methodology to examine the impact of product quality linked to its geographical location and networking on agritourism performance.

The agritourism sector is largely influenced by factors including seasonal variations, climate change, abrupt weather change, crop failures, price changes, and consumer behavior. The tourism and income associated with it depend on agricultural products at the location. Gordan *et al.*, [12] involved locally estimated scatterplot smoothing method to analyze the effect of seasonal variation on the number of tourists and their boarding choices. Their funding can help to change the policies and entrepreneur behavior where the farm income is subject to the above-stated factors. Mahaptra *et al.*, [13] used the Analytic Hierarchy Process to identify the key influential factors of rural tourism in India. Cultural factor is found the most influential followed by heritage and local quality factors.

Fuzzy sets, introduced by Zadeh in 1965, extend classical set theory by allowing elements to have varying degrees of membership between 0 and 1, rather than just belonging or not belonging to a set [3]. This flexibility makes fuzzy sets useful for modeling uncertainty and vagueness in real-world problems, where boundaries between classes are not always clear-cut. Wu *et al.*, [14] used a hybrid fuzzy multi-criteria decision model to select the most suitable agritourism location in Vietnam for long-term investment. The two-stage model addresses social, economic, and environmental factors. The integration of the fuzzy analytic hierarchy process and the fuzzy technique for order preference (TOPSIS) using similarities to ideal solution provide the best alternative in complex decision-making

processes. Criteria, alternatives, and weight of the criteria are the three pillars of any decision-making technique. Puška *et al.*, [15] applied fuzzy Pivot Pairwise RElative Criteria Importance Assessment (PI-PRECIA) method to assign weights of criteria and sub-criteria and fuzzy Measurement of alternatives and ranking according to COMpromise solution (MARCOS) method to observe agrotourism facilities in Bosnia and Herzegovina. Rezaeifar *et al.*, [16] used the fuzzy Delphi method, the fuzzy decision-making trial and evaluation laboratory method, and the fuzzy decision-making trial and evaluation laboratory-based analytic network process method to design a sustainable development model for the agricultural sector during the pandemic. In their study, environmental, social, health, and entrepreneurial factors, emerged as the important criteria for sustainable agricultural development in uncertain scenarios.

Vazin *et al.*, [17] employed a survey-analytical approach, utilizing the fuzzy analytic hierarchy process with Super Decision software and the fuzzy overlay method in ArcGIS to identify suitable villages for agritourism. In their approach, the TOPSIS model is used to rank the villages based on factors like natural resources, tourism infrastructure, and community capacity. Ghaforiyan Vazin *et al.*, [18] used the Antifragility Analysis Algorithm (AAA) to identify and prioritize tourism strategies in the western region of Mazandaran, Iran. Experts' opinions were gathered using Neutrosophic Sets (NSs) to manage uncertainty and ambiguity. Eleven strategies and five key environmental indicators were identified, with thirteen alternative scenarios (one current and twelve future) developed. The strategies' performance in various scenarios was assessed using NSs, and antifragility scores were calculated. The findings indicated that all strategies were antifragile, with market research, infrastructure development, community engagement, diversification, and monitoring recommended for initial implementation, followed by destination branding, halal tourism, and crisis management.

In the early 2000s, researchers worked on expanding the theoretical foundations of fuzzy rough sets by defining new operators, relations, and measures for better incorporation of fuzzy information. Jensen and Shen [19] made remarkable contributions to the field by developing fuzzy decision-making models and attribute reduction techniques based on fuzzy set theoretic concepts. Pakistan's economy is largely based on the agriculture sector. In recent years, agritourism emerged as a new source of income in rural areas. Therefore, it is essential to understand stakeholder perception of sustainable development in this sector. The article is an attempt to establish criteria and alternatives that need to be considered while making decisions for the development and promotion of sustainable agritourism. Section 3, introduces the fundamental concepts necessary to understand the subject matter. Section 4, provided multi-criteria decision-making methodology based on fuzzy and rough set theories. In section 5, a case study is presented by conducting a questionnaire-based survey followed by the conclusion, and future recommendations.

3. Preliminaries

In this section, we will define the fundamental concepts which are essential to understand the methodology.

3.1 Knowledge base system

We argue that knowledge is deeply ingrained in human classification skills, whereas knowledge of other species is predicated on object classification. Mathematically, knowledge is defined as: Let U be a non-empty set called a universe. Any non-empty subset of U is called a concept or category in U and any collection of concepts in U is called an abstract knowledge about U . Thus the primary focus is on finding a collection that conveys accurate and precise information about the universe under consideration, ensuring that the concepts do not overlap. This task can be easily achieved by defining

a suitable equivalence relation. A relation R on the universe U is a non-empty subset of $U \times U = \{(x, y) : x, y \in U\}$. The statement $(x, y) \in R$ reads “ x is R -related to y ” and is written in infix notation as xRy . The relation R is called an equivalence relation if:

1. xRx for all $x \in U$ (reflexive);
2. if xRy , then yRx for all $x, y \in U$ (symmetric);
3. if xRy and yRz , then xRz for all $x, y, z \in U$ (transitive).

For $x \in U$, the set $\{y \in U : xRy\}$ is called the equivalence class of x under the relation R and is denoted by $[x]_R$. The collection U/R of all such classes defines a partition of U because

1. $U = \cup_{x \in U} [x]_R$;
2. $[x]_R = [y]_R$ if and only if $[x]_R \cap [y]_R \neq \emptyset$.

A knowledge base system is an ordered pair $KBS = (U, C_{ER})$, where U is a finite universe and C_{ER} is a collection of equivalence relations over U [20].

3.2 Indiscernibility Relation

Let $KBS = (U, C_{ER})$ be a knowledge base system and $\emptyset \neq P_{ER} \subseteq C_{ER}$. Then the intersection of all equivalence relations belonging to P_{ER} is called the indiscernibility relation over P_{ER} , denoted by $IND(P_{ER})$. That is,

$$IND(P_{ER}) = \cap_{P \in P_{ER}} P.$$

In this case

$$[x]_{IND(P_{ER})} = \cap_{P \in P_{ER}} [x]_P.$$

The collection of concepts $U/IND(P_{ER})$ represents the knowledge linked with the family of equivalence relations in P_{ER} , called P_{ER} -basic knowledge about U in $KBS = (U, C_{ER})$. The indiscernibility relation over $KBS = (U, C_{ER})$ is the minimal set of equivalence relations, containing all elementary relations of KBS , and closed under set theoretical intersection of equivalence relations. That is,

$$IND(KBS) = \{IND(P_{ER}) : \emptyset \neq P_{ER} \subseteq C_{ER}\}.$$

3.3 Rough Set

A subset of objects cannot be precisely expressed using the knowledge at hand. As a result, we have the notion of approximating a set by other sets, which is covered in more detail in this section. For a given knowledge base system $KBS = (U, C_{ER})$ and each subsets X of U and an equivalence relation $A \in IND(KBS)$, we define two subsets as follows:

1. $\underline{A}X = \cup\{Y \in U/A : Y \subseteq X\}$
2. $\overline{A}X = \cup\{Y \in U/A : Y \cap X \neq \emptyset\}$

where $\underline{A}X$ is called the lower approximation and $\overline{A}X$ is called the upper approximation of X . The set X of U is called A -definable if $\underline{A}X = \overline{A}X$, otherwise A -rough [20].

3.4 Fundamental properties

Consider a knowledge base system $KBS = (U, C_{ER})$ and non-empty subset X of U . Then for any $A \in IND(KBS)$ the following conditions are true.

1. $\underline{A}X \subseteq X \subseteq \overline{A}X$
2. $\underline{A}\emptyset = \overline{A}\emptyset = \emptyset$
3. $\overline{A}(X \cup Y) = \overline{A}X \cup \overline{A}Y$
4. $\underline{A}(X \cap Y) = \underline{A}X \cap \underline{A}Y$
5. $X \subseteq Y$ implies $\underline{A}X \subseteq \underline{A}Y$
6. $X \subseteq Y$ implies $\overline{A}X \subseteq \overline{A}Y$
7. $\underline{A}(X \cup Y) \supseteq \underline{A}X \cup \underline{A}Y$
8. $\overline{A}(X \cap Y) \subseteq \overline{A}X \cap \overline{A}Y$
9. $\underline{A}(-X) = -\overline{A}X$
10. $\overline{A}(-X) = -\underline{A}(X)$
11. $\underline{A}\underline{A}X = \overline{A}\overline{A}X = \underline{A}X$
12. $\overline{A}\overline{A}X = \underline{A}\underline{A}X$

3.5 Dependency of knowledge

Let $KBS = (U, C_{ER})$ be a knowledge base system and $\emptyset \neq P_{ER}, Q_{ER} \subseteq C_{ER}$. Then

1. Knowledge Q_{ER} depends on knowledge P_{ER} if and only if

$$IND(P_{ER}) \subseteq IND(Q_{ER}).$$

2. Knowledge P_{ER} and Q_{ER} are equivalent if and only if

$$IND(P_{ER}) = IND(Q_{ER}).$$

3. Knowledge P_{ER} and Q_{ER} are totally independent if and only if neither $IND(P_{ER}) \subseteq IND(Q_{ER})$ nor $IND(Q_{ER}) \subseteq IND(P_{ER})$

The knowledge Q_{ER} depends in a degree α from knowledge P_{ER} if and only if

$$\alpha = \frac{|POS_{P_{ER}}(Q_{ER})|}{|U|}, \quad (1)$$

where

$$POS_{P_{ER}}(Q_{ER}) = \bigcup_{X \in U/IND(Q_{ER})} \underline{IND(P_{ER})}X$$

called the positive region of Q_{ER} in P_{ER} . If $\alpha = 1$, then Q_{ER} totally depends from P_{ER} ; if $0 < \alpha < 1$, then Q_{ER} roughly (partially) depends from p_{ER} , and if $\alpha = 0$, then Q_{ER} is totally independent from P_{ER} .

3.6 Knowledge representation system

A variety of low and high level models of generic rough sets can be used to describe knowledge relationship between qualities and collections that have deeper decision-related properties. The most general technique in which an object can have multiple values of attributes. The information about the objects of an information system produced by multiple sets of characteristics may depend on each other in a variety of ways, resulting in a proper subset of a set of attributes that classifies the objects with the same accuracy as the original set. A knowledge representation system (KRS) is an ordered pair $KRS = (U, \mathcal{S}_{ATR})$ where U is a non-empty finite set called the universe and \mathcal{S}_{ATR} is a non-empty set of primitive attributes. Every primitive attributes $s \in \mathcal{S}_{ATR}$ is a total function from $U \rightarrow V_s$ where V_s is called the domain of s . The primitive attributes are further classified as condition and decision attributes. The condition attributes are the variables or inputs that are used to describe the characteristics of the data. These attributes are considered to be the independent variables in the dataset. They are used to form conditions or rules that help in decision-making. The decision attributes are the variables or outputs that represent the result or decision that needs to be predicted or classified. They are considered to be the dependent variables in the dataset. Consider a knowledge representation system $KRS = (U, \mathcal{S}_{ATR})$. For each $\emptyset \neq \mathcal{T}_{ATR} \subseteq \mathcal{S}_{ATR}$ define an equivalence relation (called the indiscernibility relation) over U as:

$$IND(\mathcal{T}_{ATR}) = \{(x, y) \in U \times U : s(x) = s(y) \text{ for all } s \in \mathcal{T}_{ATR}\}. \quad (2)$$

Then the collection of all such relations, that is,

$$C_{ER}^{ATR} = \{IND(\mathcal{T}_{ATR}) : \emptyset \neq \mathcal{T}_{ATR} \subseteq \mathcal{S}_{ATR}\}$$

constitute a knowledge base system $KBS = (U, C_{ER}^{ATR})$ over U .

Conversely, consider a knowledge base system $KBS = (U, C_{ER})$. Let $R \in C_{ER}$ such that $U/R = \{X_i : i = 1, \dots, n\}$. Define an attribute s_R with total function $U \rightarrow V_{s_R} = \{1, \dots, n\}$ as $s_R(x) = i$ if and only if $x \in X_i$. Thus,

$$\mathcal{S}_{ATR}^{ER} = \{s_R : R \in C_{ER}\}$$

constitutes a set of attributes for the knowledge representation system $KRS = (U, \mathcal{S}_{ATR}^{ER})$ over U [20].

3.7 Fuzzy Rough Set

Let U be a universe, a fuzzy subset A of U , characterized by a map $\mu_A : U \rightarrow [0, 1]$, is a collection of ordered pairs $(x, \mu_A(x))$, where $x \in U$. A fuzzy relation R on U is a fuzzy subset of $U \times U$. The fuzzy relation R is called fuzzy reflexive if $\mu_R(x, x) = 1$ for all $x \in U$, fuzzy symmetric if $\mu_R(x, y) = \mu_R(y, x)$ for all $x, y \in U$ and fuzzy transitive if $\mu_R(x, z) \geq \inf\{\mu_R(x, y), \mu_R(y, z)\}$ for all $x, y, z \in U$. A fuzzy reflexive, symmetric, and transitive relation on U is called a fuzzy equivalence relation on U .

In a crisp environment, a relation R on U is called a preference relation if it is transitive, and for any $x, y \in U$ either xRy or yRx (completeness). The fuzzy preference relations [21] are defined similarly as below.

Let $\tilde{A} = \{a_1, a_2, \dots, a_n\}$ be a finite collection of choices or alternatives. A fuzzy preference relation over \tilde{A} is the fuzzy binary relation on \tilde{A} with membership function: $\mu_R : \tilde{A} \times \tilde{A} \rightarrow [0, 1]$ the preference degree of choice a_i over a_j is denoted by $\mu_R(a_i, a_j) = \tilde{e}_{ij}$ which satisfies

$$\tilde{e}_{ij} + \tilde{e}_{ji} = 1 \text{ (additive reciprocity) and } \tilde{e}_{ii} = 0.5 \forall i, j = 1, 2, \dots, n.$$

The membership grades $\tilde{e}_{ij} = \mu_R(a_i, a_j)$ can be narrated as:

- $\tilde{e}_{ij} < 0.5$ indicates a_j is preferred over a_i ;
- $\tilde{e}_{ij} = 0.5$ indicates a_i and a_j are indifferent;
- $\tilde{e}_{ij} > 0.5$ indicates a_i is preferred over a_j .

Now we use fuzzy set and fuzzy preference relation to define a fuzzy rough set.

For a finite universe U , fuzzy subset A of U , and fuzzy preference relation R over U the lower approximation of A relative to R is a fuzzy subset $\underline{R}(A)$ of U with membership function defined in Eq (3) as:

$$\underline{R}(A)(x) = \inf_{y \in U} \max\{1 - R(x, y), \mu_A(x)\}. \quad (3)$$

Similarly, the upper approximation of A relative to R is a fuzzy subset $\overline{R}(A)$ of U with membership function defined in Eq (4) as:

$$\overline{R}(A)(x) = \sup_{y \in U} \min\{R(x, y), \mu_A(x)\}. \quad (4)$$

If $\underline{R}(A)(x) \neq \overline{R}(A)(x)$ for all $x \in U$, then A is called a fuzzy rough set.

4. Multi-criteria decision-making methodology

The methodology is based on the following steps.

1. Choose the set of alternatives X_{ALT} and a set of criteria Y_{CR} .
2. Divide the set of criteria into two disjoint sets $CA_{Y_{CR}}$ and $DA_{Y_{CR}}$, called the set of condition attributes and the set of decision attributes respectively. Construct a knowledge representation system using Y_{CR} on the set of stakeholders/decision-makers. Using Eq (2) find $IND(CA_{Y_{CR}})$ and $IND(DA_{Y_{CR}})$. Use Eq (1) to check the degree of dependence of decision attributes on the condition attributes.
3. For each criterion, define a fuzzy subset $A_{X_{ALT}}^{CR}$, fuzzy preference relation $R_{X_{ALT}}^{CR}$ of the set of alternatives X_{ALT} and compute fuzzy lower and fuzzy upper approximations (see Eq (3) and Eq (4)).
4. For each criterion, calculate the Positive region (the set of alternatives with high lower approximations (closer to 1)), Boundary region (the set of alternatives with high upper approximations but low lower approximations), and Negative region (the set of alternatives with low values for both lower and upper approximations).
5. For each alternative, compute the degree of dependence on the set of criteria as in Eq (5)

$$Deg(x_{ALT}^i) = \frac{|APR(x_{ALT}^i)|}{|Y_{CR}|} \quad (5)$$

where $APR(x_{ALT}^i)$ is the set of criteria y_{CR}^j such that x_{ALT}^i belongs to the positive region of y_{CR}^j .

6. Rank the alternatives based on the degree of dependence.

5. Case Study

The fuzzy rough set approach is used to analyze the stakeholder perspective on practices and development of sustainable agritourism. A questionnaire was designed and circulated among the stakeholders including Farmers (land owners and workers on farms), local community members (local residents and businessmen), visitors (persons who visited agritourism sites), government (ministries like agriculture, water, climate change, etc), academia (faculty members from agriculture, economics, business management, and environmental science departments), non-profit organizations (promoting agriculture, heritage, and rural development), media (social media influencers), investors (contractors, land developers, and financiers), disaster management professionals (government and non-profit organizations).

1. The set of alternatives and criteria are given in Table 1 and 2.

Table 1
 Set of alternatives X_{ALT}

Notation	Alternative	Description
x_{ALT}^1	Argi farm tours	Personal and guided tours
x_{ALT}^2	Awareness sessions	Seminars, workshops, and training on farming techniques and sustainable practices
x_{ALT}^3	Educational programs	Field trips of educational institutes, internship or volunteer involvement
x_{ALT}^4	On-site activities	Visitors engagement in seasonal events cooking, crafting, plantation, and harvesting
x_{ALT}^5	Wildlife and nature	Birds, animal watching and hiking trails
x_{ALT}^6	Farm stay and accommodation	Hotel, resorts and camping facility within or nearest to farm
x_{ALT}^7	Retail opportunities	Farmer's market selling farm products

Table 2
 Set of criteria Y_{CR}

Notation	Criteria	Description
y_{CR}^1	Market demand	Assess local and regional tourism audience, demand and trends
y_{CR}^2	Accessibility	Ensure that the agritourism site is easily accessible by road or public transport
y_{CR}^3	Infrastructure	Develop visitor-friendly facilities including restrooms and picnic areas
y_{CR}^4	Unique selling proposition	Identify heritage, organic practices, and seasonal events that make the agritourism experience unique
y_{CR}^5	Sustainability	Implement eco-friendly practices like organic products, waste management and water conservation
y_{CR}^6	Partnerships and collaborations	Collaborate with local businesses and educational institutes for mutual promotion
y_{CR}^7	Marketing	Develop a strong online presence, use local media for promotions
y_{CR}^8	Safety and compliance	Ensure compliance with health and safety regulations
y_{CR}^9	Visitor engagement	Create interactive experiences that involve visitors in farm activities
y_{CR}^{10}	Economic viability	Analyze cost-effectiveness of on-site activities and infrastructure that reflect value and attract visitors

2. Market demand, accessibility, infrastructure, unique selling proposition, and sustainability are categorized as condition attributes as they impact the viability and attractiveness of agritourism. Whereas, partnership and collaboration, marketing, safety and compliance, visitor engagement, and economic viability are the attributes related to choices and strategies that a farmer can make to enhance the success of the agritourism venture, influenced by the condition attributes. Thus $CA_{Y_{CR}} = \{y_{CR}^1, y_{CR}^2, y_{CR}^3, y_{CR}^4, y_{CR}^5\}$ and $DA_{Y_{CR}} = \{y_{CR}^6, y_{CR}^7, y_{CR}^8, y_{CR}^9, y_{CR}^{10}\}$. The stakeholders are divided into eight groups and a decision table (see Table 3) is obtained by considering the mode (the most repeated response) of the responses of each group.

Table 3
 Decision table

Stakeholder	Criteria									
	y_{CR}^1	y_{CR}^2	y_{CR}^3	y_{CR}^4	y_{CR}^5	y_{CR}^6	y_{CR}^7	y_{CR}^8	y_{CR}^9	y_{CR}^{10}
S_1 =Farmers	5	3	3	4	3	4	4	3	4	5
S_2 =Visitors	3	4	4	5	4	3	3	5	5	4
S_3 =Government	4	4	4	5	4	5	4	3	4	5
S_4 = Academia	5	3	4	5	3	5	4	3	4	5
S_5 =Non-profit organizations	4	4	2	4	4	5	5	3	4	3
S_6 =Media	4	4	3	5	3	5	5	5	5	4
S_7 =Investors	4	4	3	5	3	5	5	3	4	4
S_8 =Disaster management professional	3	4	4	3	3	4	3	5	3	4

Then

$$Stakeholder/IND(CA_{Y_{CR}}) = \{\{S_1\}, \{S_2\}, \{S_3\}, \{S_4\}, \{S_5\}, \{S_6, S_7\}, \{S_8\}\} \quad (6)$$

$$Stakeholder/IND(DA_{Y_{CR}}) = \{\{S_1\}, \{S_2\}, \{S_3, S_4\}, \{S_5\}, \{S_6\}, \{S_7\}, \{S_8\}\} \quad (7)$$

imply

$$\begin{aligned} POS_{CA_{Y_{CR}}}(DA_{Y_{CR}}) &= \underline{IND(CA_{Y_{CR}})}\{S_1\} \cup \underline{IND(CA_{Y_{CR}})}\{S_2\} \cup \underline{IND(CA_{Y_{CR}})}\{S_3, S_4\} \\ &\quad \cup \underline{IND(CA_{Y_{CR}})}\{S_5\} \cup \underline{IND(CA_{Y_{CR}})}\{S_6\} \cup \underline{IND(CA_{Y_{CR}})}\{S_7\} \\ &\quad \cup \underline{IND(CA_{Y_{CR}})}\{S_8\} \\ &= \{S_1\} \cup \{S_2\} \cup \{S_3, S_4\} \cup \emptyset \cup \emptyset \cup \{S_7\} \cup \{S_8\} \\ &= \{S_1, S_2, S_3, S_4, S_7, S_8\}. \end{aligned}$$

and using Eq (1),

$$\alpha = \frac{|POS_{CA_{Y_{CR}}}(DA_{Y_{CR}})|}{|Stakeholder|} = \frac{6}{8} = 0.75. \quad (8)$$

Thus, according to stakeholders, the decision on measures for sustainable agritourism depends 75% on the described conditions.

- The fuzzy subset $A_{X_{ALT}}^{CR}$ against each criterion is defined based on the principal criteria indicator given in Table 4.

Table 4

Membership function of a fuzzy subset of the set of alternatives against each criterion

Alternative	Criteria									
	y_{CR}^1	y_{CR}^2	y_{CR}^3	y_{CR}^4	y_{CR}^5	y_{CR}^6	y_{CR}^7	y_{CR}^8	y_{CR}^9	y_{CR}^{10}
x_{ALT}^1	1	0.8	0.8	1	1	1	1	1	0.8	1
x_{ALT}^2	1	1	0.6	1	1	0.8	1	1	1	1
x_{ALT}^3	0.6	1	0.8	0.6	1	0.8	0.8	1	1	0.8
x_{ALT}^4	1	1	0.8	1	1	0.8	1	0.6	1	0.8
x_{ALT}^5	0.8	0.6	0.8	0.8	1	0.6	0.8	0.8	0.8	0.6
x_{ALT}^6	1	0.8	1	1	1	1	0.6	1	0.6	0.8
x_{ALT}^7	1	1	1	1	1	1	1	0.8	0.8	1

For each criteria, membership function of fuzzy preference relation $R_{X_{ALT}}^{y_{CR}^i}$ is given in Table 5.

Table 5

Membership function of fuzzy preference relation							
Alternative	x_{ALT}^1	x_{ALT}^2	x_{ALT}^3	x_{ALT}^4	x_{ALT}^5	x_{ALT}^6	x_{ALT}^7
Membership function of fuzzy preference relation $R_{X_{ALT}}^{y_{CR}^1}$							
x_{ALT}^1	0.50	0.60	0.26	0.65	0.27	0.75	0.45
x_{ALT}^2	0.40	0.50	0.08	0.23	0.91	0.15	0.75
x_{ALT}^3	0.74	0.92	0.50	0.54	1.00	0.08	0.44
x_{ALT}^4	0.35	0.77	0.46	0.50	0.11	0.96	0.00
x_{ALT}^5	0.73	0.09	0.00	0.89	0.50	0.77	0.82
x_{ALT}^6	0.25	0.85	0.92	0.04	0.23	0.50	0.87
x_{ALT}^7	0.55	0.17	0.25	1.00	0.18	0.13	0.50
Membership function of fuzzy preference relation $R_{X_{ALT}}^{y_{CR}^2}$							
x_{ALT}^1	0.50	0.81	0.91	0.13	0.91	0.63	0.10
x_{ALT}^2	0.19	0.50	0.28	0.55	0.96	0.96	0.16
x_{ALT}^3	0.09	0.72	0.50	0.97	0.96	0.49	0.80
x_{ALT}^4	0.87	0.45	0.03	0.50	0.14	0.42	0.92
x_{ALT}^5	0.09	0.04	0.04	0.86	0.50	0.79	0.96
x_{ALT}^6	0.37	0.04	0.51	0.58	0.21	0.50	0.66
x_{ALT}^7	0.90	0.84	0.20	0.08	0.04	0.34	0.50
Membership function of fuzzy preference relation $R_{X_{ALT}}^{y_{CR}^3}$							
x_{ALT}^1	0.50	0.92	0.29	0.76	0.75	0.38	0.57
x_{ALT}^2	0.08	0.50	0.08	0.73	0.53	0.78	0.93
x_{ALT}^3	0.71	0.92	0.50	0.13	0.57	0.47	0.01
x_{ALT}^4	0.24	0.27	0.87	0.50	0.34	0.16	0.79
x_{ALT}^5	0.25	0.47	0.43	0.66	0.50	0.31	0.53
x_{ALT}^6	0.62	0.22	0.53	0.84	0.69	0.50	0.17
x_{ALT}^7	0.43	0.07	0.99	0.21	0.47	0.83	0.50
Membership function of fuzzy preference relation $R_{X_{ALT}}^{y_{CR}^4}$							
x_{ALT}^1	0.50	0.43	0.24	0.27	0.22	0.68	0.64
x_{ALT}^2	0.57	0.50	0.75	0.18	0.23	0.77	0.44

x_{ALT}^3	0.76	0.25	0.50	0.24	0.73	0.17	0.87
x_{ALT}^4	0.73	0.82	0.76	0.50	0.49	0.64	0.32
x_{ALT}^5	0.78	0.77	0.27	0.51	0.50	0.23	0.34
x_{ALT}^6	0.32	0.83	0.23	0.36	0.77	0.50	0.25
x_{ALT}^7	0.36	0.56	0.13	0.68	0.66	0.75	0.50
Membership function of fuzzy preference relation $R_{X_{ALT}}^{y5CR}$							
x_{ALT}^1	0.50	0.51	0.91	0.63	0.10	0.39	0.05
x_{ALT}^2	0.49	0.50	0.50	0.43	1.00	0.81	0.49
x_{ALT}^3	0.09	0.50	0.50	0.89	0.14	0.39	0.93
x_{ALT}^4	0.37	0.57	0.11	0.50	0.92	0.71	0.62
x_{ALT}^5	0.90	0.00	0.86	0.08	0.50	0.34	0.94
x_{ALT}^6	0.61	0.19	0.61	0.29	0.66	0.50	0.12
x_{ALT}^7	0.95	0.51	0.07	0.38	0.06	0.88	0.50
Membership function of fuzzy preference relation $R_{X_{ALT}}^{y6CR}$							
x_{ALT}^1	0.50	0.81	0.91	0.13	0.91	0.63	0.10
x_{ALT}^2	0.19	0.50	0.28	0.55	0.96	0.96	0.16
x_{ALT}^3	0.09	0.72	0.50	0.97	0.96	0.49	0.80
x_{ALT}^4	0.87	0.45	0.03	0.50	0.14	0.42	0.92
x_{ALT}^5	0.09	0.04	0.04	0.86	0.50	0.79	0.96
x_{ALT}^6	0.37	0.04	0.51	0.58	0.21	0.50	0.66
x_{ALT}^7	0.90	0.84	0.20	0.08	0.04	0.34	0.50
Membership function of fuzzy preference relation $R_{X_{ALT}}^{y7CR}$							
x_{ALT}^1	0.50	0.95	0.03	0.36	0.66	0.28	0.23
x_{ALT}^2	0.05	0.50	0.71	0.62	0.59	0.66	0.05
x_{ALT}^3	0.97	0.29	0.50	0.35	0.45	0.24	0.72
x_{ALT}^4	0.64	0.38	0.65	0.50	0.86	0.28	0.73
x_{ALT}^5	0.34	0.41	0.55	0.14	0.50	0.14	0.84
x_{ALT}^6	0.72	0.34	0.76	0.72	0.86	0.50	0.14
x_{ALT}^7	0.77	0.95	0.28	0.27	0.16	0.86	0.50
Membership function of fuzzy preference relation $R_{X_{ALT}}^{y8CR}$							
x_{ALT}^1	0.50	0.65	0.23	0.28	0.12	0.27	0.26
x_{ALT}^2	0.35	0.50	0.33	0.15	0.35	0.12	0.88
x_{ALT}^3	0.77	0.67	0.50	0.09	0.93	0.40	0.05
x_{ALT}^4	0.72	0.85	0.91	0.50	0.34	0.74	0.79
x_{ALT}^5	0.88	0.65	0.07	0.66	0.50	0.54	0.69
x_{ALT}^6	0.73	0.88	0.60	0.26	0.46	0.50	0.89
x_{ALT}^7	0.74	0.12	0.95	0.21	0.31	0.11	0.50
Membership function of fuzzy preference relation $R_{X_{ALT}}^{y9CR}$							
x_{ALT}^1	0.50	0.93	0.81	0.48	0.76	0.23	0.97
x_{ALT}^2	0.07	0.50	0.99	0.86	0.39	0.45	0.25
x_{ALT}^3	0.19	0.01	0.50	0.78	0.88	0.91	0.56
x_{ALT}^4	0.52	0.14	0.22	0.50	0.60	0.15	0.90
x_{ALT}^5	0.24	0.61	0.12	0.40	0.50	0.45	0.21
x_{ALT}^6	0.77	0.55	0.09	0.85	0.55	0.50	0.90
x_{ALT}^7	0.03	0.75	0.44	0.10	0.79	0.10	0.50

Membership function of fuzzy preference relation $R_{X_{ALT}}^{y_{CR}^{10}}$							
x_{ALT}^1	0.50	0.88	0.72	0.02	0.67	0.44	0.44
x_{ALT}^2	0.12	0.50	0.12	0.81	0.32	0.25	0.34
x_{ALT}^3	0.28	0.88	0.50	0.38	0.55	0.56	0.40
x_{ALT}^4	0.98	0.19	0.62	0.50	0.40	0.52	0.66
x_{ALT}^5	0.33	0.68	0.45	0.60	0.50	0.95	0.72
x_{ALT}^6	0.56	0.75	0.44	0.48	0.05	0.50	0.40
x_{ALT}^7	0.56	0.66	0.60	0.34	0.28	0.60	0.50

Using Eq (3) and Eq(4) fuzzy lower and upper approximations are computed for the set of alternatives against each criterion. The membership values are in Table 6-7.

Table 6
 Membership function of a fuzzy lower approximation against each criterion

Alternative	Criteria									
	y_{CR}^1	y_{CR}^2	y_{CR}^3	y_{CR}^4	y_{CR}^5	y_{CR}^6	y_{CR}^7	y_{CR}^8	y_{CR}^9	y_{CR}^{10}
x_{ALT}^1	0.74	0.60	0.60	0.76	1.00	0.76	0.72	0.72	0.77	0.60
x_{ALT}^2	0.80	0.60	0.60	0.60	1.00	0.60	0.60	0.80	0.60	0.68
x_{ALT}^3	0.60	0.60	0.60	0.60	1.00	0.60	0.76	0.80	0.60	0.60
x_{ALT}^4	0.60	0.80	0.73	0.60	1.00	0.80	0.72	0.60	0.80	0.60
x_{ALT}^5	0.80	0.60	0.60	0.73	1.00	0.60	0.80	0.60	0.60	0.60
x_{ALT}^6	0.60	0.79	0.78	0.77	1.00	0.79	0.60	0.74	0.60	0.80
x_{ALT}^7	0.75	0.80	0.80	0.80	1.00	0.80	0.60	0.79	0.80	0.72

Table 7
 Membership function of a fuzzy upper approximation against each criterion

Alternative	Criteria									
	y_{CR}^1	y_{CR}^2	y_{CR}^3	y_{CR}^4	y_{CR}^5	y_{CR}^6	y_{CR}^7	y_{CR}^8	y_{CR}^9	y_{CR}^{10}
x_{ALT}^1	0.75	0.91	0.76	0.68	0.91	0.80	0.95	0.65	0.93	0.88
x_{ALT}^2	0.80	0.80	0.93	0.77	1.00	0.96	0.71	0.80	0.99	0.80
x_{ALT}^3	0.92	0.97	0.71	0.87	0.93	0.80	0.97	0.80	0.80	0.88
x_{ALT}^4	0.96	0.92	0.80	0.82	0.92	0.92	0.80	0.91	0.80	0.98
x_{ALT}^5	0.89	0.96	0.66	0.78	0.94	0.96	0.84	0.88	0.61	0.80
x_{ALT}^6	0.87	0.66	0.80	0.83	0.66	0.66	0.80	0.88	0.85	0.75
x_{ALT}^7	1.00	0.84	0.83	0.75	0.95	0.90	0.95	0.95	0.79	0.66

- For each criterion, the Positive region (the set of alternatives with high lower approximations (greater than 0.7)), Boundary region (the set of alternatives with high upper approximations (greater than 0.7) but low lower approximations (less than 0.7)), and Negative region (the set of alternatives with low values for both lower and upper approximations) are given in Table 8.

Table 8
 Positive, boundary, and negative region against each criterion

Criteria	Positive region	Boundary region	Negative region
y_{CR}^1	$x_{ALT}^1, x_{ALT}^2, x_{ALT}^5, x_{ALT}^7$	$x_{ALT}^3, x_{ALT}^4, x_{ALT}^6$	empty
y_{CR}^2	$x_{ALT}^4, x_{ALT}^6, x_{ALT}^7$	$x_{ALT}^1, x_{ALT}^2, x_{ALT}^3, x_{ALT}^5$	empty
y_{CR}^3	$x_{ALT}^4, x_{ALT}^6, x_{ALT}^7$	$x_{ALT}^1, x_{ALT}^2, x_{ALT}^3, x_{ALT}^5$	empty
y_{CR}^4	$x_{ALT}^1, x_{ALT}^5, x_{ALT}^6, x_{ALT}^7$	$x_{ALT}^2, x_{ALT}^3, x_{ALT}^4$	empty
y_{CR}^5	All alternatives	empty	empty
y_{CR}^6	$x_{ALT}^1, x_{ALT}^4, x_{ALT}^6, x_{ALT}^7$	$x_{ALT}^2, x_{ALT}^3, x_{ALT}^5$	empty
y_{CR}^7	$x_{ALT}^1, x_{ALT}^3, x_{ALT}^4, x_{ALT}^5$	$x_{ALT}^2, x_{ALT}^6, x_{ALT}^7$	empty
y_{CR}^8	$x_{ALT}^1, x_{ALT}^2, x_{ALT}^3, x_{ALT}^6, x_{ALT}^7$	x_{ALT}^4, x_{ALT}^5	empty
y_{CR}^9	$x_{ALT}^1, x_{ALT}^4, x_{ALT}^7$	$x_{ALT}^2, x_{ALT}^3, x_{ALT}^5, x_{ALT}^6$	empty
y_{CR}^{10}	x_{ALT}^6, x_{ALT}^7	$x_{ALT}^1, x_{ALT}^2, x_{ALT}^3, x_{ALT}^4, x_{ALT}^5$	empty

5. For each alternative, compute the degree of dependence using Eq (5).

$$Deg(x_{ALT}^1) = \frac{|APR(x_{ALT}^1)|}{|Y_{CR}|} = \frac{7}{10} = 0.7 \tag{9}$$

$$Deg(x_{ALT}^2) = \frac{|APR(x_{ALT}^2)|}{|Y_{CR}|} = \frac{3}{10} = 0.3 \tag{10}$$

$$Deg(x_{ALT}^3) = \frac{|APR(x_{ALT}^3)|}{|Y_{CR}|} = \frac{3}{10} = 0.3 \tag{11}$$

$$Deg(x_{ALT}^4) = \frac{|APR(x_{ALT}^4)|}{|Y_{CR}|} = \frac{6}{10} = 0.6 \tag{12}$$

$$Deg(x_{ALT}^5) = \frac{|APR(x_{ALT}^5)|}{|Y_{CR}|} = \frac{4}{10} = 0.4 \tag{13}$$

$$Deg(x_{ALT}^6) = \frac{|APR(x_{ALT}^6)|}{|Y_{CR}|} = \frac{7}{10} = 0.7 \tag{14}$$

$$Deg(x_{ALT}^7) = \frac{|APR(x_{ALT}^7)|}{|Y_{CR}|} = \frac{8}{10} = 0.8 \tag{15}$$

6. Conclusion

In this article fuzzy rough sets with preference relation are used to analyze the stakeholder perception of agritourism. A total of seven alternatives including argi farm tours, awareness sessions, educational programs, on-site activities, wildlife and nature, farm stay and accommodation, and Retail opportunities are considered. Whereas, market demand, accessibility, infrastructure, unique selling proposition, sustainability, partnerships and collaborations, marketing, safety and compliance, and visitor and economic viability are the criteria set for the analysis. The criteria are further classified as condition and decision attributes and as per stakeholder perception, decision attributes 75% depend on the condition attributes. This implies that market demand, accessibility, infrastructure, unique selling proposition, and sustainability largely influence partnerships and collaborations, marketing, safety and compliance, and visitor and economic viability. Fuzzy preference relation is a well-known mathematical term used to indicate preferences for alternatives over each other in a fuzzy environment. To compute fuzzy preference relation, three experts from each stakeholder group are requested to fill the designed grid. The average of their responses is then used to compute Table 5. Fuzzy subsets

of the set of alternatives against each criterion are developed by using the principal criteria indicator. Fuzzy preference relations and fuzzy subsets are then used to find fuzzy lower and upper approximations, positive, boundary, and negative regions. The degree of dependency of the alternatives reveals that retail opportunities (with degree 0.8) are the most desired alternative for sustainable agritourism followed by farm stay (with degree 0.7), agri farm tour (with degree 0.7) and on-site activities (with degree 0.6). Since the analysis is based on the perspectives of a relatively small community, future work should be expanded by incorporating more alternatives and criteria, as well as gathering input from a wider, nationwide audience. This would provide a more comprehensive understanding and valuable insights for policymakers and stakeholders.

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Conflicts of Interest

The authors declare no conflicts of interest.

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