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A FUZZY LOGIC-BASED EVALUATION OF FARMER-HERDER CONFLICTS IN KIRIKASAMMA AND GURI LOCAL GOVERNMENT AREAS IN JIGAWA STATE, NIGERIA

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ABSTRACT

This study applies a fuzzy decision-making model to address farmers-herders conflicts in Kirikasamma and Guri LGAs of Jigawa State, Nigeria. Two conflict resolution strategies designated grazing corridors and rotational grazing systems were evaluated using fuzzy linguistic scales and Hamming distance. Stakeholder preferences were aggregated and analyzed, revealing a slight preference for grazing corridors. The results demonstrate the suitability of fuzzy logic in resolving complex, multi-stakeholder conflicts.

1. INTRODUCTION

The farmer-herder conflict in Nigeria remains a persistent and escalating challenge, undermining agricultural productivity, social cohesion, and economic development. Historically, farmers and herders coexisted peacefully, but since Nigeria's return to democracy in 1999, competition over scarce land and water resources has intensified [1, 2]. The Fulani, who manage over 90% of Nigeria's livestock, are central to this conflict due to their pastoral mobility, which often leads to encroachment on farmlands [2, 3]. The resulting clashes have caused crop destruction, displacement, loss of livelihoods, and heightened insecurity [4, 5]. Several factors drive these conflicts, including environmental degradation, desertification, climate change, and ineffective land-use policies [6, 7].

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Rapid population growth and unplanned urbanization further strain resources [8, 9], exacerbating food insecurity and threatening national stability [10, 11]. Regional dynamics also play a role: in the Middle Belt and North-Central zones, agricultural expansion into grazing reserves has heightened tensions [1, 12], while the Boko Haram insurgency in the North-East has compounded instability [13].

In Jigawa State, particularly in Kirikasamma and Guri LGAs, farmer-herder conflicts are aggravated by socio-economic pressures, weak governance, and inadequate conflict resolution mechanisms [14, 15]. Although traditional leaders historically mediated disputes, their authority has been weakened by modern legal systems and political interference [2, 16]. Past studies propose solutions such as ranching, legal reforms, and community-based interventions [17, 18], but the complexity of stakeholder perspectives demands a more systematic approach.

Given the uncertainties in conflict resolution strategies, this study applies fuzzy logic [19] to model multi-stakeholder decision-making. Fuzzy logic is particularly effective in handling imprecise data and subjective judgments [20, 21], making it suitable for analyzing socio-economic conflicts. Building on foundational works in fuzzy decision-making [22, 23] and conflict analysis [11, 16], Motivated by the persistent and escalating farmer-herder conflicts in Kirikasamma and Guri LGAs of Jigawa State driven by resource scarcity, socio-political tensions, and the failure of conventional conflict resolution mechanisms this study develops a fuzzy-based evaluation model to provide a systematic and inclusive framework for assessing conflict resolution strategies. The model’s stability was assessed through defuzzification and Hamming distance analysis, ensuring consistency and robustness in evaluating stakeholder preferences across alternative solutions

2 PRELIMINARIES

Definition 2.1 Fuzzy Logic [21]

Fuzzy logic is a mathematical framework that enables reasoning and decision-making in situations characterized by uncertainty, vagueness, or imprecision. Fuzzy logic allows for degrees of truth represented by values between 0 and 1. This enables more flexible modelling of real-world problems using linguistic terms and approximate reasoning. Fuzzy logic provides a systematic approach for dealing with ambiguity in complex systems, making it particularly suitable for conflict resolution, control systems, and artificial intelligence applications.

Definition 2.2 Fuzzy Number [24]

A fuzzy number is defined as a convex and normalized fuzzy set on the real line, where each real number is associated with a membership degree ranging between 0 and 1. This membership degree reflects the extent to which the number is compatible with an imprecisely defined or uncertain quantity.

Definition 2.3 Triangular Fuzzy Numbers [23]

A triangular fuzzy number is a type of fuzzy number represented by three values: the lower limit, the most likely value, and the upper limit, used to express uncertainty in stakeholder preferences. These values provide a simple yet effective way to model subjective judgments.

Definition 2.4 Trapezoidal Fuzzy Number [22]

A trapezoidal fuzzy number is defined by four parameters: a, b, c, and d, where $a \leq b \leq c \leq d$. Its membership function increases gradually from 0 to 1 between a and b, stays at 1 between b and c, and then decreases from 1 to 0 between c and d. This model is commonly used due to its simplicity and flexibility in representing uncertain values

Definition 2.5 Linguistic term [25]

A linguistic term is a qualitative label used to describe the value of a variable in natural language, such as "low," "medium," or "high." These terms are fundamental to fuzzy logic systems because they allow vague or imprecise human reasoning to be represented mathematically. Each linguistic term is associated with a fuzzy set, enabling computation with words

Definition 2.6 Fuzzy Linguistic Scale [25]

A fuzzy linguistic scale is a set of qualitative terms (such as *Strongly Agree*, *Agree*, *Neutral*, *Disagree, and Strongly Disagree*) used to express subjective judgments or preferences in decision-making processes. These linguistic terms are then translated into fuzzy numbers to allow for mathematical modeling and analysis. Linguistic variables provide a way to represent imprecise information using words rather than numerical values, making them particularly suitable for human-centered evaluation and reasoning in fuzzy systems.

Definition 2.7 Defuzzification [21]

Defuzzification is the process of converting fuzzy numbers into crisp values to facilitate decision-making and interpretation of results. This step simplifies the analysis of stakeholder preferences by translating fuzzy outputs into actionable numeric values.

Definition 2.8 Ideal Solution [23]

An ideal solution is a theoretical outcome in the decision-making process that represents the best possible resolution, fully satisfying all stakeholders' preferences and minimizing conflict. In the context of fuzzy decision-making, it serves as a reference point for comparing alternative solutions using methods such as Hamming distance.

Definition 2.9 Hamming Distance [26]

Hamming distance is a mathematical measure used
to compare fuzzy numbers by calculating the difference between two sets of values, often used to determine the closeness of stakeholders' preferences to an ideal solution.

Definition 2.10 Farmers-Herders Conflict [2]

Farmers-Herders Conflict is a conflict arises from competition between farmers and herders over access to land, water, and other resources.

Definition 2.11 Stakeholders:

Stakeholders is an individual or group involved in the conflict and decision-making process, including government officials, traditional leaders, farmers, herders, and security agencies. Each stakeholder brings unique perspectives and priorities to the resolution process.

Definition 2.12 $\boldsymbol{Solution\ A}$

Refers to the proposal of establishing designated grazing corridors to minimize conflict between farmers and herders by separating their activities. This solution aims to reduce direct competition over land resources.

Definition 2.13 $\boldsymbol{Solution\ B}$

Refers to the proposal of implementing a rotational grazing system that alternates land use between farmers and herders to share resources sustainably. This solution seeks to balance resource usage and promote coexistence.

Definition 2.14 Rotational Grazing
A land management practice that involves alternating grazing areas to allow for sustainable resource use and minimize conflict between farmers and herders.

Definition 2.15 Grazing Corridor
A designated pathway or area allocated for herders to graze their livestock, designed to prevent encroachment on farmlands and reduce friction between farmers and herders.

Definition 2.16 Weighted Votes
Weighted votes are the individual votes casted by each stakeholder on the proposed solutions, adjusted by their assigned importance in the decision-making process. This approach ensures that the influence of each stakeholder is proportional to their role or expertise in the conflict resolution framework.

3 DATA COLLECTION

Data have been collected through structured interviews with key stakeholders. Ethical considerations have been adhered throughout the process, ensuring informed consent and confidentiality. The data collected was translated into fuzzy linguistic scales to capture the subjective preferences of the stakeholders regarding the two proposed solutions: $\boldsymbol{Solution\ A}$ (designated grazing corridors) and $\boldsymbol{Solution\ B}$ (rotational grazing systems).

3.1 The triangular fuzzy number [21]

A fuzzy number P is a triangular fuzzy number, if its membership functions μ_P: R→ $[0,1]$ has the following form

$$\mu_{\boldsymbol{P}(\boldsymbol{x})}= \begin{cases} 0 & if\ x \le p_1 \\ \frac{x-p_1}{p_2-p_1} & if\ p_1 < x \le p_2 \\ \frac{p_3-x}{p_3-p_2} & if\ p_2 < x \le p_3 \\ 0 & if\ x \ge p_3 \end{cases} \qquad \textbf{(1)}$$

Where p_1, p_2, p_3 are given numbers

3.2 Trapezoidal fuzzy numbers [22]

The trapezoidal fuzzy number P was determined by four parameters $p_1 \le p_2 \le p_3 \le p_4$ and is categorized by membership function μ_P: R→ $[0,1]$ in the shape of a trapezoid. For the membership function μ_A

$$\mu_{P(x)}= \begin{cases} 0 & if\ p_1 \le x < p_2 \\ \frac{x-p_1}{p_2-p_1} & if\ p_2 \le x \le p_3 \\ 1 & if\ p_3 < x \le p_4 \\ \frac{p_4-x}{p_4-p_3} & otherwise \\ 0 & \end{cases} \qquad \textbf{(2)}$$

Where (p_1, p_2, p_3, p_4) are given numbers.

3.3 Process of Decision Making

This section outlines the decision-making stages for resolving the farmers-herders conflict.

Stage 3.3.1 Selection of stakeholders for the decision making

The selected stakeholders include local government officials, traditional leaders, farmer-herder representatives, and security agencies. Each member contributes unique perspectives governmental, cultural, communal, and security-related ensuring a balanced and inclusive approach. As noted by [27, 28], involving diverse stakeholders enhances decision quality, especially in complex and uncertain situations.

Table 3.3.1 Members of decision-making

No	Profession	Position
1	Local government official	Member 1
2	Traditional leader	Member 2
3	Farmer representative	Member 3
4	Herder representative	Member 4
5	Security agencies	Member 5

Stage 3.3.2 Weight Assigned to each stakeholder

The stakeholder's weight in the decision-making was determined using predefined criteria such as expertise, seniority, or relevance to the conflict.

Table 3.3.2 Members of the decision making with assigned weight

Position	Profession	Degree of important	Triangular fuzzy number
Member 1	Local government official	Important	(0.6, 0.8, 1.0)
Member 2	Traditional leader	Very important	(0.8, 1.0, 1.0)
Member 3	Farmers representative	Moderately important	(0.4, 0.6, 0.8)
Member 4	Herders representative	Moderately important	(0.4, 0.6, 0.8)
Member 5	Security agencies	Important	(0.6, 0.8, 1.0)

Stage 3.3.3 Selection of Fuzzy Linguistic Scales

Fuzzy linguistic scales and their corresponding fuzzy numbers are defined to facilitate decision-making. A Likert scale was used due to its simplicity and effectiveness in capturing subjective responses [29]. Five fuzzy linguistic scales were applied, accommodating dual criteria for stakeholder weighting.

Table 3.3.3 Fuzzy linguistic scale for voting on the proposed solutions

Linguistic Term	Triangular fuzzy Number
Strongly Agree	(0.7, 1.0, 1.0)
Agree	(0.5, 0.7, 1.0)
Neutral	(0.3, 0.5, 0.7)
Disagree	(0.0, 0.3, 0.5)
Strongly Disagree	(0.0, 0.0, 0.3)

Stage 3.3.4 Voting by Stakeholders in the Decision-Making

Each stakeholder casts their vote using a predefined fuzzy linguistic scale to express their agreement or disagreement with a proposed solution. After all votes are casted, the group's overall average fuzzy number is computed.

Table 3.3.4 Fuzzy linguistic scale votes on the proposed solutions by decision makers

Decision-Maker	Vote on Solution A	Fuzzy Number ($Solution\ A$)	Vote on $Solution\ B$	Fuzzy Number ($Solution\ B$)
Member 1	Agree	$(0.5, 0.7, 1.0)$	Neutral	$(0.3, 0.5, 0.7)$
Member 2	Strongly Agree	$(0.7, 1.0, 1.0)$	Agree	$(0.5, 0.7, 1.0)$
Member 3	Disagree	$(0.0, 0.3, 0.5)$	Agree	$(0.5, 0.7, 1.0)$
Member 4	Neutral	$(0.3, 0.5, 0.7)$	Strongly Agree	$(0.7, 1.0, 1.0)$
Member 5	Agree	$(0.5, 0.7, 1.0)$	Disagree	$(0.0, 0.3, 0.5)$

3.4 Determination of the weighted Votes

In this study, the concepts of fuzzy votes (v) and weights (w) are central to the evaluation of conflict resolution strategies in the context of farmers-herders disputes. Each stakeholder expresses their opinion on proposed solutions using a predefined fuzzy linguistic scale (e.g., "Disagree", "Neutral", "Agree"), which is translated into a triangular fuzzy number of the form $v = (v_1, v_2, v_3)$, where v_1 is the lower bound, v_2 is the most likely value, and v_3 is the upper bound, reflecting their degree of agreement.

To incorporate the varying influence of each stakeholder, a corresponding weight w, derived from a fuzzy importance scale based on criteria such as expertise, authority, and involvement in the conflict, is assigned to each participant. These weights range from 0 to 1 and are used to adjust the stakeholder's vote, resulting in a weighted fuzzy vote computed by multiplying the weight with each component of the fuzzy number: $w \times (v_1, v_2, v_3,) = (wv_1, w\ v_2, wv_3)$, this component-wise multiplication ensures that stakeholders with greater relevance to the decision-making process exert proportionally more influence. Finally, the weighted fuzzy votes from all stakeholders are aggregated to derive a collective assessment of each proposed resolution strategy, forming the basis for more inclusive and balanced decision-making.

Determination of Weighted Votes for $Solution\ A$:

$$Member\ 1: (wv_1, wv_2, wv_3)$$

$$Member\ 2: (wv_1, wv_2, wv_3)$$

$$Member\ 3: (wv_1, wv_2, wv_3)$$

$$Member\ 4: (wv_1, wv_2, wv_3)$$

$$Member\ 5: (wv_1, wv_2, wv_3)$$

Determination of Weighted Votes for Solution$A$:

$$Member\ 1: = (0.3, 0.56, 1.0)$$

$$Member\ 2: = (0.56, 1.0, 1.0)$$

$$Member\ 3: = (0.0, 0.18, 0.4)$$

$$Member\ 4{:}\ = (0.12, 0.3, 0.56)$$

$$Member\ 5{:}\ = (0.3, 0.56, 1.0)$$

Determination of Weighted Votes for $Solution\ B$:

$$Member\ 1{:}\ (wv_1, wv_2, wv_3)$$

$$Member\ 2{:}\ (wv_1, wv_2, wv_3)$$

$$Member\ 3{:}\ (wv_1, wv_2, wv_3)$$

$$Member\ 4{:}\ (wv_1, wv_2, wv_3)$$

$$Member\ 5{:}\ (wv_1, wv_2, wv_3)$$

Determination of Weighted Votes for $Solution\ B$

$$Member\ 1{:}\ = (0.18, 0.4, 0.7)$$

$$Member\ 2{:}\ = (0.4, 0.7, 1.0)$$

$$Member\ 3{:}\ = (0.2, 0.42, 0.8)$$

$$Member\ 4{:}\ = (0.28, 0.6, 0.8)$$

$$Member\ 5{:}\ = (0.0, 0.24, 0.5).$$

Aggregate the Weighted Votes:

We compute the average fuzzy number by taking the sum of each member's weighted votes and dividing by the number of members:

1. Aggregated Fuzzy Number for $Solution\ A$:

Average Fuzzy Number for A is:

$$A = \left(\frac{\sum_i^3 wv_1}{5}, \frac{\sum_i^3 wv_2}{5}, \frac{\sum_i^3 wv_3}{5},\right)$$

$$A = (0.256, 0.520, 0.792)$$

2. Aggregated Fuzzy Number for $Solution\ B$:

Average fuzzy number for B is:

$$B = \left(\frac{\sum_i^3 wv_1}{5}, \frac{\sum_i^3 wv_2}{5}, \frac{\sum_i^3 wv_3}{5},\right)$$

B =(0.212,0.472,0.760)

3.5 Defuzzification [30]

Defuzzification methods are essential for converting fuzzy numbers into crisp values for practical decision-making. One commonly used method is the Center of Gravity (COG), also known as the centroid method, which calculates the balance point of a fuzzy number to obtain a representative crisp value. This method is preferred in this study due to its simplicity and effectiveness in aggregating fuzzy data The COG method gives us a crisp value that best represents the fuzzy number by averaging out the influence of the lower, middle, and upper bounds.

The formula for the Center of Gravity of a triangular fuzzy number is:

$$COG = \frac{a+2b+c}{4}$$

Where: a is the lower bound of the fuzzy number, b the middle value of the fuzzy number and c the upper bound of the fuzzy number.

The aggregated fuzzy numbers for both $Solution\ A$ and $Solution\ B$:

1. Defuzzification for Solution A:

   Aggregated fuzzy number for Solution A: (0.256,0.520,0.792)

   $COG\ for\ A = 0.522$

2. Defuzzification for $Solution\ B$:

   Aggregated fuzzy number for Solution B: (0.212,0.472,0.760)

   COG for $B\ = 0.479$

3.6 Hamming Distance [23]

To determine the final decision, the Hamming distance method is applied. These measures the difference between the group's average fuzzy number and the fuzzy numbers representing linguistic terms used for final decision interpretation. The proposed solution is accepted or rejected based on which linguistic term is closest to the group average i.e., the one with the shortest Hamming distance.

Step 3.6 1 Aggregated fuzzy numbers

From the voting results, the following aggregated fuzzy numbers were obtained for each solution:

$$Solution\ A: (0.256, 0.520, 0.792)$$

$$Solution\ B: (0.212, 0.472, 0.760)$$

We compared these fuzzy numbers to an ideal solution fuzzy number, which we defined as: Ideal Solution (Accept): $(0.6, 0.8, 1.0)$.

Step 3.6.2 Hamming distance formula

The Hamming distance between two fuzzy numbers $A = (a_1, a_2, a_3)$ and $B = (b_1, b_2, b_3)$ is calculated using the formula:

$$d(A, B) = |a_1 - b_1| + |a_2 - b_2| + |a_3 - b_3|$$

Step 3.6.3 Determination of for Each Solution

Determination for Solution A using the aggregated fuzzy number **A=** $(0.256, 0.520, 0.792)$ and the ideal solution fuzzy number $(0.6, 0.8, 1.0)$:

$$d(Solution\ A, accept) = 0.832$$

Therefore, the Hamming distance for $\boldsymbol{Solution\ A}$ is $\mathbf{0.832}$.

Solution for B: Using the aggregated fuzzy number for $\boldsymbol{Solution\ B} = (0.212, 0.472, 0.760)$ and the ideal solution fuzzy number $(0.6, 0.8, 1.0)$:

$$dd(Solution\ B, accept) = 0.956.$$

Therefore, the Hamming distance for $\boldsymbol{Solution\ B}$ is $\mathbf{0.956}$.

Difference = Hamming distance of $solution\ B$−Hamming distance of $solution\ A$

$$Difference = 0.124$$

Table 4**:**1 Final Weighted Votes for A

Decision-Maker	Degree of important	Vote on $Solution\ A$	Fuzzy Number ($Solution\ A$)	Weighted Vote for $Solution\ A$
Member 1	Important	Agree	$(0.5, 0.7, 1.0)$	(0.3,0.56,1.0)
Member 2	Very Important	Strongly Agree	$(0.7, 1.0, 1.0)$	(0.56,1.0,1.0)
Member 3	Moderately Important	Disagree	$(0.0, 0.3, 0.5)$	(0.2,0.42,0.8)
Member 4	Moderately Important	Neutral	$(0.3, 0.5, 0.7)$	(0.0,0.18,0.4)
Member 5	Important	Agree	$(0.5, 0.7, 1.0)$	$(0.3, 0.56, 1.0)$

Table 4**.**2**:** Final Weighted Votes for B

Decision-Maker	Degree of important	Vote on $Solution\ B$	Fuzzy Number ($Solution\ B$)	Weighted Vote $for\ Solution\ B$
Member 1	Important	Neutral	$(0.3, 0.5, 0.7)$	(0.18,0.4,0.7)
Member 2	Very Important	Agree	$(0.5, 0.7, 1.0)$	(0.4,0.7,1.0)
Member 3	Moderately Important	Agree	$(0.5, 0.7, 1.0)$	(0.0,0.18,0.4)
Member 4	Moderately Important	Strongly Agree	$(0.7, 1.0, 1.0)$	(0.28,0.6,0.8)
Member 5	Important	Disagree	$(0.0, 0.3, 0.5)$	$(0.0, 0.24, 0.5)$

Table 4.3: Final average fuzzy number for each solution based on the weighted votes

Solution	Average Fuzzy Number
$Solution\ A$	(0.256,0.520,0.792)
$Solution\ B$	(0.212,0.472,0.760)

Table 4.4: Final Defuzzification number

Solution	Defuzzification Number
$Solution\ A$	0.522
$Solution\ B$	0.479

Table4.5. Final Hamming distance

Solution	Aggregated Fuzzy Number	Hamming Distance
$Solution\ A$	(0.256, 0.520, 0.792)	0.832
$Solution\ B$	(0.212, 0.472, 0.760)	0.956
Difference		0.124

DISCUSSIONS

INTERPRETATION OF RESULTS

This study offers a data-driven framework for resolving the farmers-herders conflict in Kirikasamma and Guri LGAs of Jigawa state using fuzzy decision-making and Hamming distance analysis. Two solutions designated grazing corridors and rotational grazing systems were evaluated based on stakeholder input. Defuzzification results showed a slight preference for designated grazing corridors (0.522 vs. 0.479), and Hamming distance analysis confirmed that Solution A was closer to the ideal solution (0.832 vs. 0.956). Although the difference is modest (0.124), it suggests general stakeholder support for Solution A, while also indicating that a hybrid approach may be effective. These findings highlight the value of fuzzy logic in handling complex, multi-stakeholder decisions under uncertainty.

CONCLUSION

This study demonstrates the effectiveness of fuzzy decision-making in evaluating conflict resolution strategies for the persistent farmers-herders conflicts in Jigawa state. Among the two proposed solutions, the establishment of designated grazing corridors emerged as the preferred option. However, given the marginal difference in stakeholder preferences, a hybrid model combining both designated corridors and rotational grazing may offer a more comprehensive and adaptable solution to the conflict.

Future research should aim to enhance the proposed framework by integrating real-time data, incorporating additional conflict variables, and expanding stakeholder participation. Such advancements will further improve the reliability and inclusiveness of decision-making processes in complex, resource-based conflicts.

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