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Community Perceptions and Spatial Patterns of the Effectiveness of Human-elephant conflict Mitigation strategies Around Mikumi National Park, Tanzania

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***Abstract*— *Human–elephant conflict is a critical challenge in elephant-dominated landscapes, significantly affecting community livelihoods. Various mitigation measures have been implemented to reduce conflicts and promote coexistence, yet evidence of their effectiveness in deterring elephant incursions remains limited. In villages adjacent to Mikumi National Park (MNP), similar strategies as used in other elephant-dominated areas have been applied, but their efficacy has largely been undocumented. This study evaluated the perceived effectiveness of these measures using household questionnaires with a five-point Likert scale (1 = extremely less effective; 5 = extremely effective). Descriptive analyses estimated mean scores, while Kendall's coefficient of concordance (W) and Fleiss' Kappa assessed the level of agreement among respondents. Spatial patterns were analyzed in QGIS by overlaying village boundary shapefiles with perception scores to generate heatmaps of mitigation effectiveness. Results show that the perceived effectiveness of mitigation measures ranged from low to moderate, with considerable variation across mitigation strategies. Kendall's W was weak but statistically significant agreement among respondents, reflecting respondents' rankings were not random. This supported the null hypothesis that communities generally share similar perceptions of mitigation effectiveness. Nevertheless, the weak agreement among respondents reflects diverse experiences and local contexts. Spatially, the effectiveness of mitigation strategies was unevenly distributed across villages, underscoring the need for locally tailored interventions and context-specific approaches. Based on these findings, this study advocates combined mitigation methods to achieve utmost efficacy and recommends further complement to existing strategies by use of biological control methods particularly use of lions' and army ants' scents to scare elephants.*

***Keywords*— Biological control methods, Elephant conflicts, Elephant Conflict mitigations, Mitigation effectiveness, Mitigation effectiveness patterns**

I. INTRODUCTION

Human–elephant conflict is a critical issue in Africa and Asia, posing threats to both human livelihoods and elephant conservation (Raycraft *et al*., 2024; Zang *et al*., 2024). Various mitigation measures have been implemented to reduce conflicts, promote coexistence, and support long-term ecosystem sustainability (Shaffer *et al*., 2019; Montgomery *et al*., 2021). Common strategies include chili-based deterrents, flashlights, shouting and banging objects, digging trenches, beehive fences, live fences, electric fences, and watchtowers (Gunaryadi & Hedges, 2017; Montgomery *et al.,* 2021). The effectiveness of these measures, however, varies across locations and is intended to increase local tolerance of elephants and willingness to coexist (Kissui *et al*., 2019; Terada *et al*., 2021).

Despite widespread implementation, the actual efficacy of conflict mitigation measures is rarely evaluated systematically, limiting the ability of communities to make informed decisions (Kapos *et al*., 2009; Artelle *et al*., 2018). This knowledge gap is particularly problematic in areas with high wildlife populations, where ineffective mitigation can exacerbate human–elephant conflicts (Gunaryadi & Hedges, 2017; Montgomery *et al*., 2021). Consequently, there is a pressing need for community-based evaluations to assess the cost-effectiveness and practical outcomes of mitigation strategies, thereby supporting sustainable human–elephant coexistence.

Human–elephant conflict mitigation strategies effectiveness has been studied extensively across elephant-dominated landscapes, providing insights into mitigation effectiveness under varying ecological and socio-economic contexts. In West Bengal, India, Chakraborty & Nabanita, (2021) evaluated community-based interventions in areas affected by crop-raiding Asian elephants and found only partial effectiveness of commonly applied measures. In southern India, Prasad *et al*., (2025) examined mitigation decisions across elephant conflict zones and highlighted the role of environmental and socio-economic factors in shaping community responses. In Indonesia, near Way Kambas National Park, Gunaryadi & Hedges, (2017) documented high success of chilli-based deterrents in reducing elephant incursions at the farm scale. In western Thailand, Van de Water & Matteson, (2018) assessed mitigation outcomes across villages and reported that firecrackers were more effective than non-electrical fences or watchtowers. Across Africa, Montgomery *et al*., (2021) conducted multi-country evaluations of interventions to protect crops from African elephants, emphasizing context-specific effectiveness. Despite this growing body of research, systematic assessments of mitigation effectiveness remain limited in Tanzania, particularly in villages surrounding Mikumi National Park (MNP), highlighting a critical knowledge gap that this study aims to address.

In villages surrounding MNP, mitigation measures have been widely employed to reduce crops and property damage and associated economic losses (Chang'a *et al*., 2017). However, there is limited information on how local communities perceive the effectiveness of these interventions, which constrains evidence-based decisions regarding their use. This study therefore aims to assess the effectiveness of existing mitigation measures in villages adjacent to MNP by examining community perceptions.

Specifically, the study assessed: (1) the perceived extent of effectiveness of the available mitigation measures, and (2) the spatial patterns of mitigation effectiveness across communities. It was hypothesized that communities would have similar perceptions on mitigation measures effectiveness in minimizing effects of human-elephant interactions within the surveyed villages. Furthermore, it was predicted that the effectiveness of mitigation measures would be consistent across the surveyed communities.

II. CONCEPTUAL FRAMEWORK FOR HUMAN-ELEPHANT INTERACTIONS

To guide this study, a conceptual framework integrating Human–Wildlife Conflict (HWC) theory and Social–Ecological Systems (SES) theory is adopted to examine how socio-ecological factors shape human–elephant interactions (HEI) and influence the effectiveness of conflict mitigation strategies (Fig. 1). The framework links ecological processes, human wellbeing, institutional governance, community resilience, and adaptive capacity to both direct and indirect effects of HEI, highlighting feedback loops through which repeated interactions shape community attitudes, governance responses, and long-term conservation outcomes (Barua et al., 2013; Shaffer et al., 2019; Zang et al., 2024). Indirect effects—such as psychosocial stress, disrupted routines, reduced safety, and food insecurity—accumulate over time, affecting household and community wellbeing and shaping perceptions of mitigation effectiveness (Mayberry et al., 2017; Jadhav & Barua, 2012).

Central to the framework are ecological and landscape drivers, including elephant and human population densities, shared access to water and forage, and human land-use patterns around protected areas. Habitat fragmentation, agricultural expansion, and settlement growth along park boundaries increase spatial overlap between farms and elephant movement routes, triggering crop raiding, property damage, night-time farm guarding, and household tensions (Barua et al., 2013; Shaffer et al., 2019; Zang et al., 2024). Empirical studies in Tanzanian landscapes, including Mikumi, indicate that these drivers strongly influence the timing and spatial distribution of elephant foraging in human-dominated areas (Sampson et al., 2021; Tripathy et al., 2022).

HEI generates direct effects—crop loss, property and livestock damage, and occasional human injury—that subsequently trigger indirect effects, including psychosocial stress, disrupted routines, reduced productivity, food insecurity, and economic vulnerability (Sitati et al., 2003; Sampson et al., 2021; Nyumba et al., 2020). Psychosocial impacts, such as fear, sleep disruption, and anxiety, reduce mental wellbeing and alter household dynamics, influencing how communities perceive mitigation strategies (Barua et al., 2013; Mayberry et al., 2017).

Institutional interventions, including compensation schemes, fencing, chili-based deterrents, and community engagement, moderate HEI outcomes. However, perceived inefficiencies, delays, or inequities can erode trust in governance, reduce tolerance for elephants, and weaken support for conservation policies (Naughton-Treves et al., 1998; Ogra & Badola, 2008; Zang et al., 2024). Household and community factors—wealth, livelihood diversity, social networks, farm location, and governance effectiveness—further shape vulnerability, either buffering or exacerbating indirect effects and influencing community perceptions and spatial patterns of mitigation effectiveness (Nyumba et al., 2020; Barua et al., 2013).

Overall, this conceptual framework links ecological drivers, socio-economic vulnerabilities, and governance responses to both direct and indirect impacts of HEI. It emphasizes feedback loops whereby community experiences and perceptions of mitigation strategies influence future exposure, risk, and conservation outcomes, providing a foundation for evidence-based interventions and spatially targeted management in Mikumi and similar human–elephant landscapes.

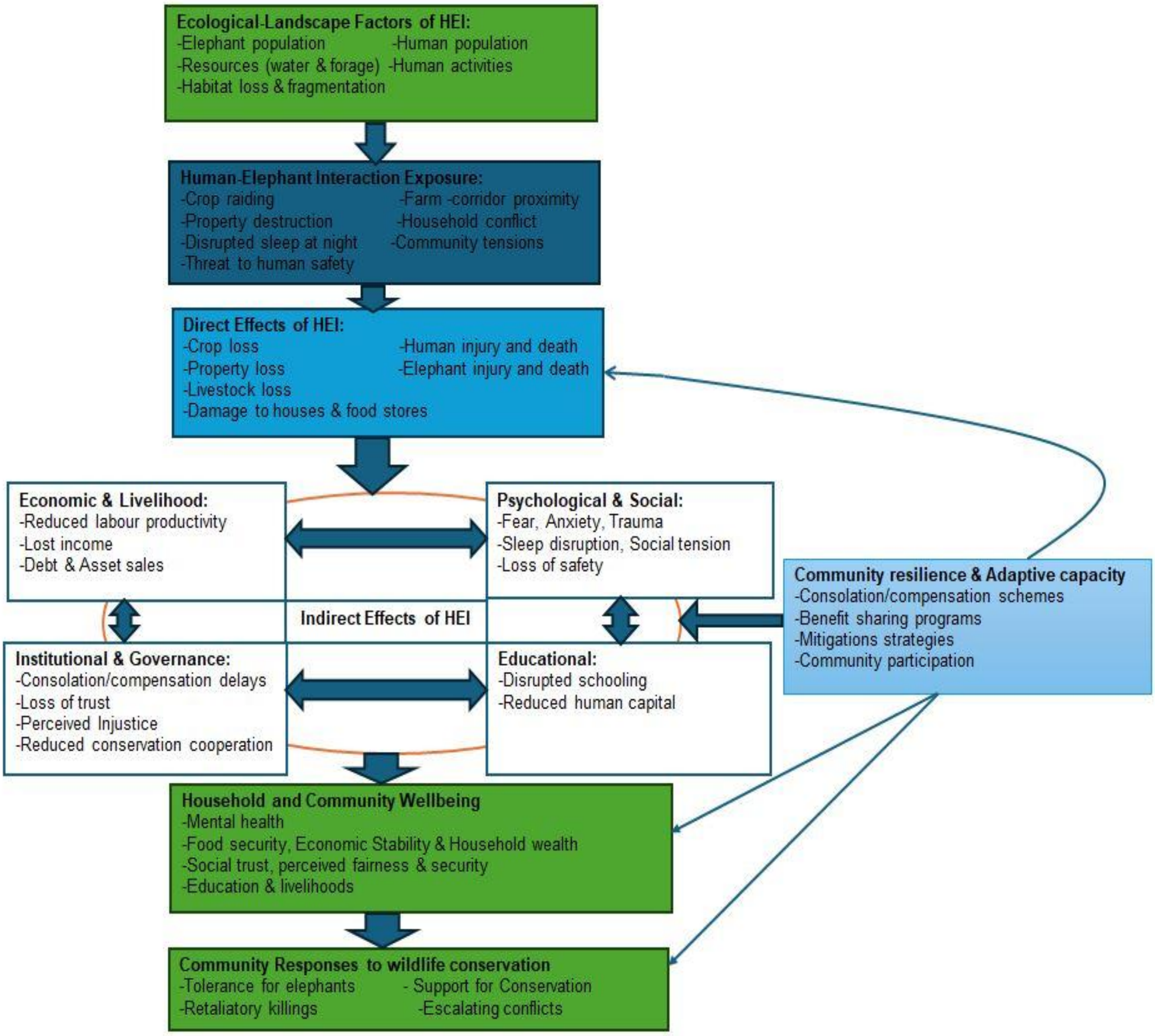

Fig.1 Conceptual framework model for human-elephant interactions illustrating how socio-ecological factors interact to produce direct and indirect effects (Adopted from Human–Wildlife Conflict theory & Social–Ecological System theory)

Guided by the conceptual framework of human–elephant interactions, this paper evaluates elephant mitigation effectiveness as an intervention point within the causal pathway linking direct elephant incursions to the indirect socio-economic and psychosocial effects on communities. Within the framework, mitigation measures are expected to disrupt or weaken the transmission of direct effects, such as crop damage and incursions into broader livelihood and wellbeing consequences. Assessing community-perceived effectiveness therefore provides a critical test of whether existing mitigation strategies meaningfully reduce exposure, vulnerability, and severity of human–elephant interaction outcomes.

III. METHODOLOGY

3.1 Study area

The study was conducted in ten villages bordering Mikumi National Park (MNP) in south-eastern Tanzania: Mikumi, Ihombwe, Kitunduweta, Mhenda, Mbamba, Kiduhi, Kilangali, Mkata, Doma, and Maharaka (Gunn *et al*., 2013; Fig. 2). These villages are part of the broader Nyerere–Mikumi–Selous landscape, which supports one of Tanzania's largest elephant populations, estimated at approximately 15,217 individuals (Lohay *et al*., 2020). Human–elephant interactions in these communities have historically led to intense conflicts, including crop raiding, human injuries and fatalities, and retaliatory killings of elephants (Gunn *et al*., 2013; Mayengo *et al*., 2017). To reduce these conflicts, a range of mitigation strategies have been implemented across the villages, including chili-based deterrents, beehive fences, trenches, and community guarding systems (Chang'a *et al*., 2016). The varied socio-ecological and livelihood contexts of the villages, combined with these interventions, provide the framework for assessing the effectiveness of mitigation measures in reducing the impacts of human–elephant interactions.

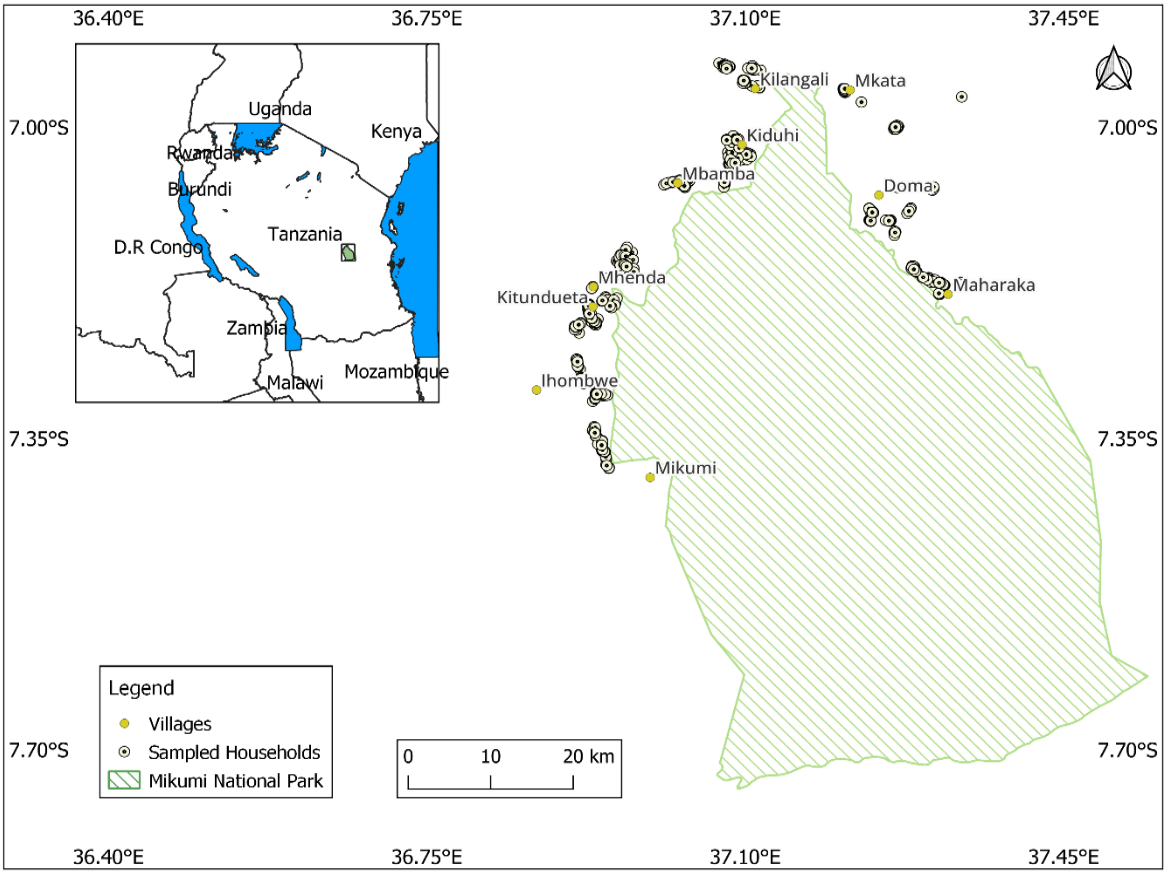

Fig.2 Locations of sampled households in villages adjacent to MNP (January-December 2023)

3.2 Study design and sampling strategy

The study employed a repeated cross-sectional observational design, using both closed- and open-ended questionnaires administered during the wet and dry seasons of 2023. The wet season, spanning January to June, coincides with peak crop cultivation and adequate rainfall for agricultural activities, while the dry season, from July to December, is characterized by reduced rainfall and drought conditions. Household surveys were conducted among 405 households across ten villages directly bordering Mikumi National Park (MNP). Villages were purposively selected based on a documented history of human–elephant conflict, accessibility, and direct adjacency to the park. The sample size was determined using Cochran's formula 1977 shown in equation (1) to ensure statistical representativeness (Uarkarn *et al.,* 2021).

$$n_0 = \frac{Z^2 \cdot P \cdot Q}{e^2} \ldots\ldots\ldots (1)$$

Where n_0 is the required sample size, $Z = 1.96$ corresponds to the 95% confidence level, $P = 0.5$ is the estimated population proportion to maximize sample size, $Q = 1 - P$, and $e = 0.05$ represents the 5% margin of error.

Household selection followed a systematic sampling approach. The first household was selected from the one nearest the village office, and subsequent households were chosen using a sampling interval calculated by dividing the total number of households in each village by 40. Only 1 respondent from each household was interviewed from either of the household heads, spouses, or any other adult aged 18 years older who had resided in the household for at least 12 months. Questionnaires were translated into Kiswahili and pretested on 20 households in Sewe and Mangae villages neighboring villages. These pretested villages did not participate in the survey.

Furthermore, prior to data collection, ethical clearance and research permits were obtained from relevant national institutions and local government authorities. Study objectives were clearly explained to respondents, and verbally informed consent was secured, with participation being entirely voluntary and without financial incentives. Strict confidentiality and anonymity were maintained throughout the research. Also, interviews with households affected by severe elephant-related losses, including injury or death of family members, were conducted sensitively to minimize emotional distress.

3.3 Data collection methods

Respondents were asked to evaluate the perceived effectiveness of existing mitigation measures used to prevent or deter elephant incursions into homesteads and/or agricultural fields, thereby reducing crop damage, property destruction, injuries and other elephant-related losses, following the approach of Shrestha *et al*. (2025). Prior to the main survey, a reconnaissance survey was conducted within the study area to identify mitigation strategies currently implemented by local communities. Based on this assessment, a standardized list of mitigation measures was developed and presented to respondents. Participants were then asked to rate the perceived effectiveness of each measure in deterring elephants using a five-point Likert scale ranging from 1 (extremely ineffective) to 5 (extremely effective). In addition, GPS coordinates were recorded for each interviewed household to enable spatial mapping of mitigation effectiveness patterns across the study area as in Mamboleo *et al.* (2021).

3.4 Data analysis

Descriptive statistical analyses were conducted using RStudio version 4.3.1 based on R (programming language) (R Core Team, 2020) to estimate mean perception scores for each mitigation method. Data was reshaped using the *pivot_longer* function to generate summary tables for comparative analysis. The internal consistency and reliability of Likert-scale items used to measure community perceptions of mitigation effectiveness were evaluated using Cronbach's Alpha, with values of 0.70 or higher considered acceptable. Respondents' consensus on the perceived effectiveness of mitigation measures was assessed using Kendall's coefficient of concordance followed by Fleiss' Kappa test on reliability of agreement among respondents. Spatial patterns in perceived mitigation effectiveness were analyzed using QGIS by overlaying village boundary shapefiles with respondents' perception scores to generate heatmaps highlighting spatial hotspots of mitigation effectiveness across surveyed villages.

IV. RESULTS

4.1 Effectiveness of mitigation measures

The mean scores for effectiveness of elephant conflicts mitigations for communities adjacent to MNP are shown in Table 1. Overall, the respondents' rating shows that most of conflict mitigation effectiveness was between moderate to low. Digging trenches around farms and homestead, Flashlights, and Making noise /shouting through bang of tins and other noise making objects with mean scores 2.61, 2.38, and 2.18 respectively. Consolation scheme, Disturbance of elephants by shooting, and Use of human urine to scare elephant were ranked between not effective at all and less effective with mean scores 1.32, 1.21 and 1.11 respectively. Kendall's coefficient of concordance test ($W = 0.222$, $df(9) = 809.19$, $p < 0.001$), indicating weak positive agreement among respondents on the perceived levels of effectiveness of the 10 elephant conflict mitigation measures**.**

Although the magnitude of concordance is relatively low, the significant result indicates that respondents' rankings of mitigation strategies are not random and reflect a consistency of agreement between the levels of effectiveness of the mitigations assigned by respondents. This accepts the null hypothesis which stated that; Communities would have similar perceptions on mitigation measures effectiveness towards minimizing effects of Human-elephant interactions within the surveyed villages. However, the weak agreement among respondents reflects the diverse perceptions and experiences among respondents, highlighting the need specific tailored conflict mitigations at specific localities because effectiveness of mitigation measures might vary depending on the context, location, or specific scenario.

Table 1 Communities' perceived effectiveness of elephant conflicts mitigations

Mitigation Method	Mean score effectiveness
Digging trenches around the farms	2.61
Flashlights and fire lights	2.38
Making noise /shouting through bang of tins and other noise making objects	2.18
Chilli fences and Oils	1.95
Building fences around the farms/houses	1.88
Chilli bombs	1.70
Beehives fences	1.62
Consolation/compensation schemes	1.32
Disturbance of elephants by shooting	1.21
Use of human urine to scare elephant	1.11
Kendall's Coefficient of Concordance among respondents (W = 0.222)	
Key:1= Extremely less effective, 2=Less effective,3=Moderate,4=Effective,5= Extremely effective	

4.2 Elephant conflict mitigation effectiveness patterns

The perceptions of local communities on elephant conflict mitigation patterns in villages adjacent to MNP is shown on Fig. 3. Mikumi, Mhenda, and Maharaka villages show dark shading as highly effective mitigations, indicating that respondents believed their conflict mitigations work relatively well to evict elephants and reduce conflicts between humans and elephants.

On the other hand, Kilangali and Mkata villages show lighter shading, indicating that measures are viewed between less effective to extremely less effective. In these locations, communities may still be experiencing significant challenges despite the interventions in place. Other villages like Kiduhi and Doma had perceptions of moderate effectiveness of conflict mitigations. The results highlight that some progress has been made in managing elephant conflicts, and that effectiveness mitigation strategies is not uniform across all villages. Fleiss Kappa test results for consistency of respondents on the effectiveness of mitigation measures (K= -0.011, p = 0.379), indicating very low level of agreement among respondents, slightly worse than what would be expected. The p-value shows that this lack of agreement is not statistically significant, meaning the differences in opinions could easily occur by chance. This rejects the Prediction which stated that effectiveness of mitigation measures would be consistent across the surveyed communities.

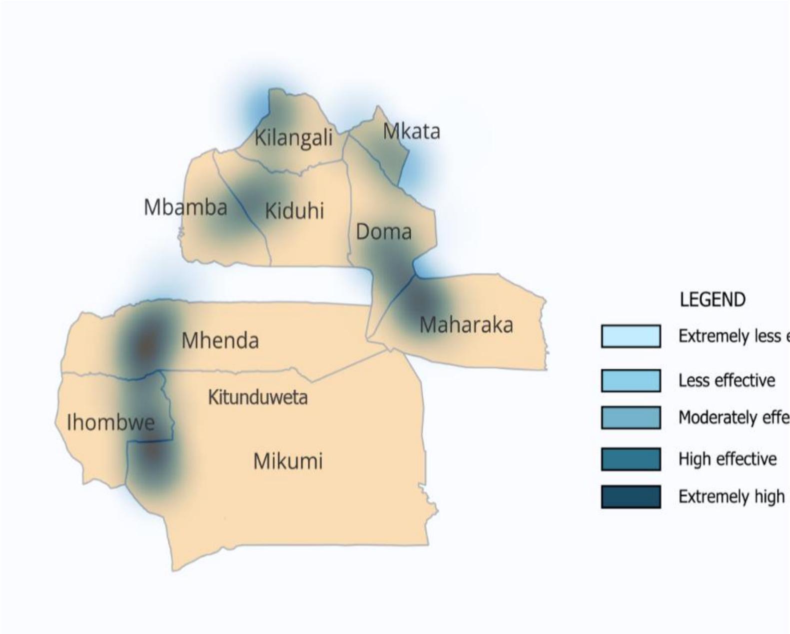

Fig.3 The heatmap of patterns of community perceptions of mitigation effectiveness against human–elephant interaction conflicts across villages

V. DISCUSSION

5.1 Effectiveness of mitigation measures

Perceived effectiveness of elephant conflict mitigation measures was generally low, with digging trenches ranked highest and compensation schemes, shooting, and human urine ranked lowest. This indicated that the problem is only partially managed and elephant conflicts remain a persistent challenge to villagers. Consistent with the conceptual framework of human–elephant interactions used in this study; ineffective or uneven mitigation measures sustain exposure to direct elephant encounters and perpetuate indirect community-level effects. Reasons for limited success of mitigation strategies potentially include elephants' adaptability behavior to learn and adjust in response to deterrents used. Some strategies are Site-specific working better in one area than in other areas. Further, local communities often operate with limited resources leading to low outputs.

Similar mitigation strategies have been reported globally (Enukwa, 2017; Montgomery *et al*., 2021), including the use of spotlights, fire and noise deterrents, fences (beehive, wire, and electric), chilli-based methods, playbacks, trenches, rapid response teams, and compensation schemes. However, the effectiveness of such interventions remains widely debated (Mumby & Plotnik, 2018; Shaffer *et al*., 2019). Many methods require sustained human presence, making them labor-intensive, costly, and difficult to maintain, particularly for resource-limited communities. In addition, several techniques are sensitive to weather conditions, demand technical expertise beyond local capacity, or incur high financial costs (Montgomery *et al*., 2021). Importantly, many deterrents provide only short-term relief by displacing elephants to nearby areas, while over time elephants habituate to these methods, reducing their long-term effectiveness (Nelson *et al*., 2003).

Chakraborty and Nabanita, (2021) documented that elephant conflict mitigation strategies in West Bengal, India including noisemaking, throwing objects, elephant drives, fire lights, crop guarding, and chilli fencing were only partially effective due to elephant habituation. Elephants often became habituated to these methods, sometimes exhibiting increased aggression toward humans, splitting into smaller groups, and causing more widespread crop invasions. Similarly, Chang'a *et al*., (2017) found that chilli-based deterrents were effective only at the small scale of individual farms near MNP, Tanzania. Comparably, in Way Kambas National Park, Indonesia, chilli-based methods were highly effective when applied systematically at farm scale (Gunaryadi & Hedges, 2017), while in western Thailand's Chong Sadao District, communities perceived firecrackers as effective deterrents, while watchtowers and non-electrical fences were considered less effective (Van de Water & Matteson, 2018). These comparisons underscore the importance of implementing integrated, context-sensitive mitigation strategies, as single interventions rarely achieve uniform success across landscapes.

The low to moderate effectiveness of elephant mitigation measures in the area increases community vulnerability to crop losses, human injuries, and fatalities, leading to food insecurity, economic hardship, and emotional distress. Repeated socio-economic and psychological impacts can foster negative perceptions of elephants and conservation efforts, potentially resulting in retaliatory killings and declines in elephant populations, thereby disrupting ecosystem balance. These socio-ecological challenges underscore the urgent need for evidence-based, scientifically informed mitigation strategies to safeguard both human livelihoods and elephant conservation.

5.2 Elephant conflict mitigation patterns

The perceived effectiveness of elephant conflict mitigation measures exhibited strong spatial heterogeneity, with overall patterns of effectiveness of conflict mitigations indicating that community members do not share a common perception about effectiveness of the current mitigation measures. While some people in different villages feel the protection methods are working, in other areas villagers view mitigations are not helping much. This inconsistency could arise from differences in how each village experiences elephant encounters, differences in landscape, elephant population and movement patterns, and type of interventions used to mitigate elephant conflicts. This highlights the need for more community engagement, awareness, and possibly redesigning or localizing mitigation measures so that they are effective and recognized as such by a larger portion of the community.

Studies across Africa and Asia have consistently shown that individual mitigation methods often fail when used in isolation, and no single approach is universally effective (Enukwa, 2017; Montgomery *et al*.,2021). Optimal outcomes are achieved when multiple strategies are implemented together, supported by regular monitoring and maintenance (Enukwa, 2017; Chakraborty & Nabanita, 2021; Prasad *et al*., 2025). Combined mitigation measures have proven effective in preventing elephant incursions into farms and homesteads (Chang'a *et al*., 2016; Van de Water & Matteson, 2018), but their success also depends on households' capacity to procure and maintain the necessary tools and methods (Jasmine *et al*., 2015; Chakrapani *et al*., 2016). Elephants' ability to learn and habituate can undermine poorly maintained setups, reducing long-term effectiveness (Chakraborty & Nabanita, 2021).

In line with these findings, some study villages, such as Ihombwe and Kilangali, practice large-scale sugarcane and paddy farming with intensive irrigation schemes. These practices compel households to invest more in combined mitigation strategies, which appear to reduce elephant incursions compared to other areas. The observed variation in mitigation effectiveness highlights the need for adaptive, context-specific strategies. Approaches that have proven successful in certain areas should be reinforced and potentially replicated, while areas with weaker measures require targeted improvements or alternative methods. Such tailored interventions, informed by local conditions and continuous monitoring, are essential for sustaining long-term elephant deterrence and reducing human–elephant conflict.

VI. CONCLUSION AND RECOMMENDATIONS

This study demonstrates that the perceived effectiveness of elephant conflict mitigation measures among communities surrounding MNP is generally low to moderate, with considerable variation across villages, highlighting spatial heterogeneity of effectiveness among villages. The study further reveals weak consensus among respondents underscoring the context-specific nature of mitigation effectiveness, influenced by factors such as farming practices, resource availability, local landscapes, and elephants' adaptive behaviors.

These findings highlight the importance of integrated, context-specific mitigation strategies over single or generic measures. Communities that implement combined approaches generally experience fewer crop raids, demonstrating the value of locally tailored interventions. Long-term success depends on continuous monitoring, proper maintenance of deterrent tools, and reinforcing methods that are effective, while simultaneously addressing weaknesses in areas where measures underperform.

Based on the results of this study, the following recommendations are proposed:

1. Adopt integrated mitigation strategies: Communities should implement multiple complementary measures simultaneously, combining physical, behavioral, and biological deterrents to maximize effectiveness.
2. Incorporate evidence-based biological controls: Novel deterrents, such as the strategic use of predator scents from lions and army ants, to be deployed along known elephant movement routes and around farms and homesteads to enhance elephant repellence.
3. Tailor strategies for local conditions: Mitigation approaches could be adapted to village-specific contexts, including farm types, resource availability, and landscape features, to ensure practical applicability and community acceptance.
4. Strengthening community capacity and resource allocation: Support for procurement, maintenance, and technical training is essential to sustain mitigation efforts and prevent habituation of elephants to deterrents.
5. Monitor and evaluate effectiveness regularly: Systematic assessment of mitigation outcomes should guide adaptive management, inform policy decisions, and ensure resources are directed toward strategies that demonstrate measurable success.
6. Promote community engagement and awareness: Involving local communities in designing, implementing, and evaluating mitigation measures to enhance adoption, foster positive attitudes toward elephants, and reduce retaliatory actions.

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CONFLICT OF INTERESTS

None

DATA AVAILABILITY STATEMENT

Available on request

ETHICAL STANDARDS

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AUTHORS' CONTRIBUTIONS

DBF: Design, data collection, analysis, result interpretation, and writing draft; **VGN:** Review and supervision; **RMB:** Review and supervision; **RMJK**: Results interpretation, review and Supervision.

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