Human Wildlife Conflicts in Central Bhutan: Farmers' Perceptions of Drivers, Mitigation Strategies, and Adoption of Digital Twin Technology

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Abstract

This study examines human-wildlife conflict (HWC) and its socio-economic and environmental consequences in farming communities of Dangkhar Trong Chiwog, Zhemgang, Bhutan. Using a qualitative study approach, data were collected through focus group discussions (n=30) and analysed using reflexive thematic analysis. All participating farmers (100%) reported the prevalence of crop depredation by wild animals, with losses being more severe in fields located closer to forest edges. Wild boar, sambardeer, and rodents were identified as the most damaging species, causing significant damage to cereals, livestock, vegetables, and cash crops. These losses impose severe socio-economic burdens on affected households, including reduced income, intensified labour demands, and heightened food insecurity, while contributing to broader ecological degradation through habitat fragmentation and increased human-wildlife conflict zones. Key conflict drivers include habitat encroachment, expanding wildlife species, and cultural and legal prohibition against retaliatory killing. Traditional conflict mitigation remains widespread but provides only temporary relief. All participating farmers expressed strong interest in digital solutions, including solar and electric fencing, and smart technologies such as Digital Twin and deterrent systems for real-time monitoring. The findings revealed a need for robust national policies and strategies to integrate digital technology pathways, community-led governance, and long-term mitigation interventions to achieve sustained human-wildlife coexistence in Bhutan.

Keywords: *Human wildlife conflict; Digital Twin technology; Mitigation strategies; Technology adoption; Rural livelihoods; Community-led governance*

1. BACKGROUND

Human-wildlife conflict (HWC) has increased globally in recent decades, driven by agricultural expansion, habitat fragmentation, climate change, and shifting wildlife behaviour (König et al., 2021; Minin et al., 2021). These conflicts present serious threats to food security, rural livelihoods, and long-term community support for conservation, while raising complex institutional challenges related to human-wildlife coexistence in shared landscapes. As farming activity increasingly encroaches on wildlife habitats, interactions between local communities and wildlife have grown more frequent, particularly in Asia, Africa, and Latin America, where smallholder agriculture is vital for survival and income (Bharti et al., 2025; Yeshey et al., 2022). Research further shows that climate change disrupts natural habitats and wildlife movement patterns, making wildlife more likely to forage in farmlands (Das et al., 2022). Growing evidence increasingly focuses on socio-ecological systems, coexistence frameworks, and monitoring approaches to reduce conflicts through technological innovation (Wangchuk, 2025).

HWC in Bhutan is largely shaped by the country's strong conservation values and its constitutional mandate to maintain over 70% forest cover (Birendra et al., 2023; Dorji, 2024). However, this conservation focus often intensifies conflict, especially in areas like Zhemgang where communities live adjacent to protected areas and active wildlife habitats. Farming communities in these areas experience a disproportionate burden of crop depredation, livestock loss, and heightened food insecurity (Wangchuk et al., 2023). Beyond these direct losses, HWC also imposes a significant psychosocial burden, with farmers reporting persistent fear, anxiety, loss of sleep, and restricted movement from living alongside wildlife, even in the absence of direct crop or livestock loss (Yeshey et al., 2022). This burden falls unevenly across households, with femaleheaded households and households with limited assets facing greater vulnerability to both the material and psychological effects of conflict. Existing HWC prevention approaches in Bhutan have largely centered on reducing material losses through fencing, guarding, and compensation, with less attention to the psychological wellbeing of affected farmers or differentiated impacts across household types (Yeshey et al., 2023).

Farmers have historically relied on traditional methods such as guarding, basic deterrent devices, and basic fencing as mitigation strategies. These approaches, however, offer only temporary relief, as wildlife rapidly adapts to such interventions, rendering them largely ineffective and unsustainable (Burudi et al., 2025; Walsh et al., 2023). In response to these shortcomings, farmers and institutions are increasingly adopting digital-based solutions such as electric fencing and improved deterrent systems, which have demonstrated effectiveness in reducing crop damage when properly installed and timely maintained (Banamwana et al., 2021; Grange et al., 2022). The long-term adoption of technology is impacted due to financial constraints and inadequate technical support, particularly in economically disadvantaged communities.

The growing adoption of digital and sensor-based technologies is transforming HWC management through real-time wildlife monitoring, enabling farming communities to take preventive action before crop damage occurs (Biswas, 2025; Thangavel & Shokkalingam, 2022). Technologies such as AI-based early warning systems, drones, sensor networks, Internet of Things (IoT) based applications, and Digital Twin simulations offer innovative approaches to predicting and reducing conflict (Dorji et al., 2025; Kumar et al., 2024; Nandutu et al., 2022; Nguyen et al., 2022; Prasad et al., 2023;). These tools have been instrumental in shifting conflict management from reactive responses to predictive and data-driven approaches. The Digital Twin (DT) technology represents a particularly promising emerging technology that combines real-time data with socio-environmental factors to manage HWC scenarios, support predictive analytics, and inform strategic deterrent deployment (Dawn et al., 2023; Pylianidis et al., 2021). Although the application of DT is still in the early stages in wildlife management, it holds considerable potential to enhance mitigation strategies. However, evidence from Bhutan and comparable contexts suggests that effectiveness depends not only on technical capacity but equally on durability, maintenance, community acceptance, local capacity, and institutional support (Naik et al., 2025; Osipova et al., 2018; Talero et al., 2022).

This study investigates experiences and perceptions of wildlife conflict among farming communities and local officials in Dangkhar Trong Chiwog, Zhemgang, Bhutan. Drawing on focus group discussions, it examines existing mitigation strategies and their effectiveness, and community awareness and acceptance of technology-based solutions, including emerging digital innovations such as Digital Twin technology for conflict management. Based on the findings, the study also aims to provide context-specific policy and practical recommendations to enhance HWC management in rural Bhutan.

2. METHODOLOGY

2.1 Study Context

Dangkhar Trong Chiwog, Zhemgang district, in central Bhutan is known for its rugged terrain, dense forests, and important biological corridors, making it one of the country's main hotspots for human-wildlife conflict (Figure 1). The farming communities in this area are predominantly subsistence-based, with households growing a variety of cereal crops like rice, maize, wheat, mustard, millet, buckwheat, and barley. Rice is the primary staple crop, produced mainly as red rice and white rice. Most farmers cultivate rice mainly for household consumption, with only a few households selling surplus in the market to purchase imported white rice and other household essentials. This pattern reflects the subsistence nature of the local farming systems.

This study focused on five high-conflict villages - Dangkhar, Dungbi, Tingbi, Grisbi Pam, and Wangdigang - where agricultural fields are located adjacent to vegetation, making them vulnerable to wildlife intrusions. Wild animal species such as wild boar, sambardeer, monkeys, and rodents frequently damage cereal crops, vegetables, and cash crops, increasing livelihood security. Despite the use of mitigation measures like solar fencing, barbed wire fencing, electric fencing, and basic sound-light repellents, HWC continues to affect various stages of crop production, reflecting the persistent challenges faced by the farming communities. Collectively, these features position Zhemgang as a representative high-conflict, low-resource context to explore farmers' experiences with conflicts, assess current mitigation strategies, and evaluate community readiness for technological solutions in rural Bhutan.

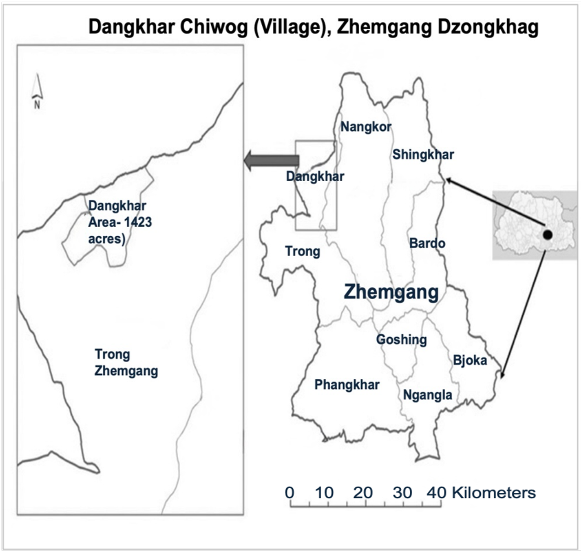

Fig. 1: *Study site in Zhemgang*

2.2 Data Collection

This study adopted a random sampling method to select participants for the focus group discussions. Dangkhar Trong Chiwog has a total of 70 households with wetlands. Of these, 40 households engaged in paddy cultivation over the last two years were shortlisted. From this group, 30 participants were randomly selected and divided into two groups of 15 for the focus group discussions. This approach ensured that every eligible household had an equal opportunity of being chosen, reducing the risk of selection bias. It also helped ensure the discussions reflected a fair representation of farming households' experiences in the Chiwog. Representatives from the agriculture, forestry, and local government sectors also attended the discussions to provide institutional perspectives on conflict management. The discussions used open-ended, structured questions covering major areas of community conflict experiences, mitigation strategies, and perceptions on new technologies. Discussions were audio recorded, transcribed, and analysed using NVivo 15. Standard ethical procedures were followed throughout, including informed consent, voluntary participation, anonymity, and respect for local cultural norms.

2.3 Demographic Profile of Participants

According to the 2017 Population and Housing Census of Bhutan, Trong Gewog is the most populous gewog in Zhemgang District, with 2,968 persons (1,546 male, 1,422 female) across 584 households (National Statistics Bureau [NSB], 2018). Within Trong Gewog, the Dangkhar Trong Chiwog, the study site, has a population of 753 persons (420 male, 333 female) spanning a wide age range from young children through the elderly (NSB, 2018). Educational attainment across Trong Gewog is low, with 40.5% of the population having never attended school and only 32.0% currently attending (NSB, 2018).

The study findings show notable similarities alongside important differences with the Census data. Among the 30 participating farmers, 24 were women and 6 were men, reflecting the prominent role women assume in household and agricultural management within the study area. Participants' ages ranged from 32 to 73 years, with most falling between 41 and 50 years(Figure 2). The household size varied between 2 and 9 members. Educational attainment was generally low; only three participants (9%) had completed formal schooling at grades 6, 10, or 12, while the remaining 27 participants (90%) had no formal education (Figure 3). All participants depend primarily on rice cultivation for their livelihood, supplemented by growing cash crops and rearing livestock. The size of landholdings varied widely, with wetland ranging from 0.50 to 5 acres.

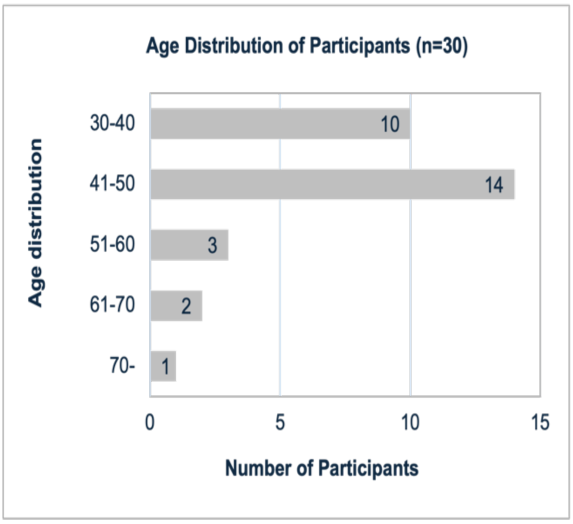

Fig. 2: *Age distribution of participants*

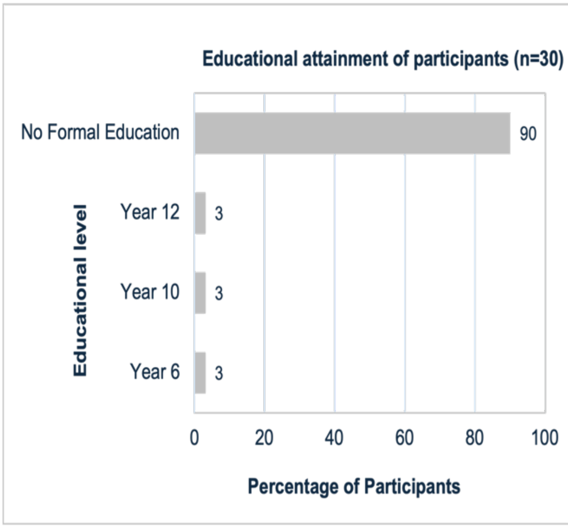

Fig. 3: *Education attainment of participants*

2.4 Data Analysis

A qualitative study design was employed to examine farmers' experiences with HWC and their perceptions of technology-based mitigation in Dangkhar Trong Chiwog, Zhemgang district. The field data were analysed following Braun and Clarke's (2021) reflexive thematic analysis approach, guided by an iterative coding process that combined participant perspectives with themes derived from conflict and technology adoption studies. Key themes identified included causes of wildlife intrusion, types of crop damage, mitigation practices, technology awareness, barriers to technology use, and digital readiness. To establish credibility, clear coding criteria and consistency checks were maintained throughout the analytical process, with theme frequencies serving as indicators of thematic prevalence within the dataset.

3. RESULTS

3.1 Livelihood and Rice Production Challenges

Focus group discussions revealed that wildlife damage, rodent infestation, climate-related issues, and water challenges were the major livelihood and rice production challenges faced by farming communities in Dangkhar Trong Chiwog, Zhemgang (Figure 4). Wildlife damage to crops, cash crops, livestock, and property was the most prevailing concern, with rodent infestation and climate-related issues identified as the most persistent challenges in rice production. These findings are consistent with established patterns of agricultural vulnerability in Himalayan farming systems, where the combined pressures of wildlife intrusion, pest infestation, and environmental stressors consistently undermine crop productivity and household food security (Birendra et al., 2023; Jamtsho & Katel, 2019).

Rodent infestation was identified as one of the most persistent and intractable challenges, with rats causing considerable damage across the entire rice production cycle, from planting until storage. Unlike other challenges that can be addressed through physical barriers or infrastructure investment, rat infestation has no immediate solution, as farming households mostly avoid the use of pesticides for rat control, allowing rat populations to proliferate each growing season. This makes rat infestation a persistent and recurring threat to rice productivity, which is documented in related studies in the Himalayan regions (Nasiadka et al., 2025).

The climate and water challenges were closely interrelated, with drought, erratic rainfall, heavy downpour, and landslides disrupting planting cycles and impacting yields, while the majority of farming households, lacking reliable irrigation infrastructure, are heavily dependent on rainfall for cultivation. This dependence on rain-fed agriculture makes rice production vulnerable to seasonal and climatic variability, reinforcing broader findings that climate instability and inadequate infrastructure present a significant threat to smallholder rice production in Himalayan farming communities (Dendup et al., 2023; Panwar et al., 2023; Waiba, 2024).

These interrelated major challenges underline the vulnerability of smallholder farming systems in Dangkhar Trong Chiwog, with significant consequences for household food security and livelihood sustainability.

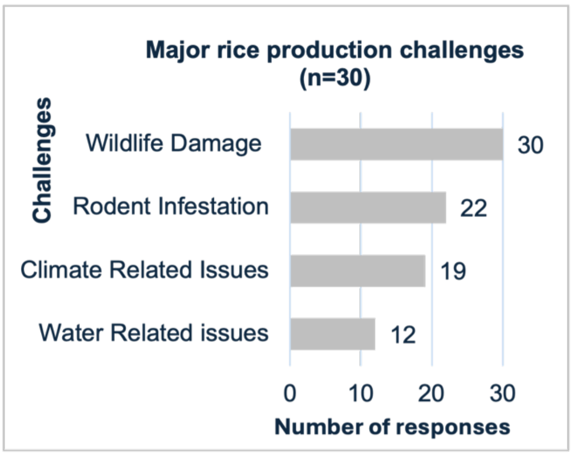

Fig. 4: *Major rice production and livelihood challenges*

3.2 Wildlife Species Causing Crop Damage

Focus group discussions revealed wild boars, rodents, sambardeer, monkeys, birds, and porcupines as the primary wildlife species responsible for crop damage in Dangkhar Trong Chiwog (Figure 5), with wild boars emerging as the most destructive, causing widespread damage to rice, maize, and cash crops. Rodents and sambar deer were equally significant, with rats causing losses through the growing and post-harvest storage stages, while sambar deer exerted significant pressure on young crops, hindering crop maturation and lowering productivity, with significant consequences for seasonal harvests. The participants also reported persistent damage caused by monkeys, birds, and porcupines, contributing to overall agricultural losses. The prevalence of multiple species in crop damage reveals the multifaceted and widespread nature of the wildlife challenge facing farming households in the Chiwog, aligning with similar patterns documented across Himalayan farming communities (Khattak et al., 2022; Rai & Rai, 2024).

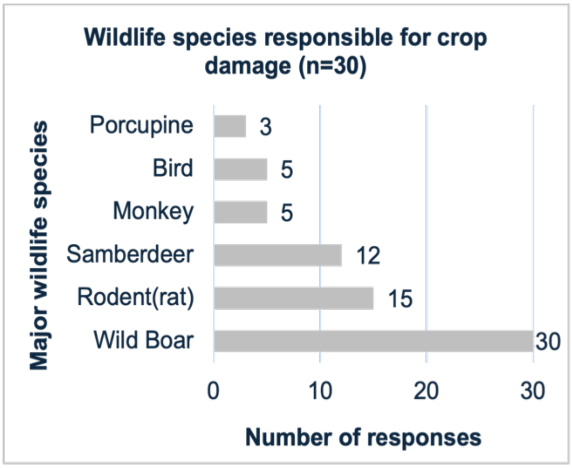

Fig. 5: *Wildlife species for crop damage*

The farming communities reported a notable increase in wildlife intrusions into their farmlands, driven by five interconnected factors, as shown in Figure 6. Escalating human encroachment along adjacent forests and reduced food availability in natural habitats were the most prominent drivers, with habitat degradation and climate disruptions forcing wildlife onto farmlands in search of alternative food. Religious and cultural prohibitions against killing wildlife have further intensified the frequency and scale of wildlife intrusion. Similar patterns have been evidenced in related research in Bhutan (Letro & Fischer, 2020). Further, dense vegetation cover along the farm boundaries and rising predator numbers additionally created more corridors, allowing easy movement of wildlife toward adjacent farmlands. These interconnected challenges highlight the multifaceted and increasing nature of human-wildlife conflict and its serious implications for food security and agricultural livelihoods in Dangkhar Trong Chiwog, Zhemgang

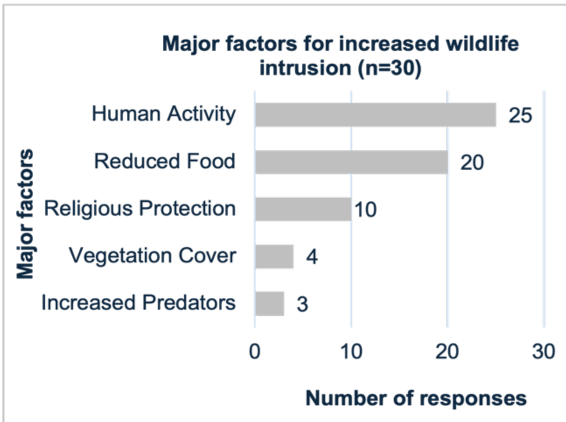

Fig. 6: *Factors for increase wildlife intrusion*

3.3 Conflict Mitigation Strategies

Communities in Dangkhar Trong Chiwog employ a combination of traditional and modern mitigation strategies, as illustrated in Figure 7. Field guarding and wood and bamboo fencing appeared as the most prevalent practices, reflecting the continued dependence on accessible, low-cost traditional methods, which require considerable time and labour. Barbed wire fencing, scarecrows, and bush clearing supplemented these practices, while lethal devices were employed by a smaller number of farmers within ethical and legal restrictions. Exposure to technology-based interventions remained notably limited, with only a small number of farmers having experience with solar and electric fencing, and only one respondent reporting use of a basic sound-light deterrent device. Most farming households lacked experience with technology-based mitigation, compounded by the absence of any institutional support to pilot or promote digital-based interventions in the Chiwog.

As outlined in Table 1, every mitigation strategy carries inherent limitations that constrain its effectiveness. Traditional methods, though widely practiced, are constrained by labour intensity, wildlife habituation, and poor durability, offering largely short-term to temporary relief. Modern interventions such as solar, electric, and chain-link fencing offer greater potential but remain challenged by power dependency, infrastructure failures, and high installation costs. These persistent constraints reveal the limitations of current mitigation efforts, reflecting the need for stronger institutional support, affordable technology access, and sustained community engagement to safeguard agricultural livelihood. Similar patterns of limited institutional support, restricted technology access, and weak community engagement have been reported in comparable rural farming contexts leading to low technology adoption (Burudi et al., 2025; Kichloo et al., 2023; Matata et al., 2022; Nima & Gurung, 2023; Wangchuk et al., 2024).

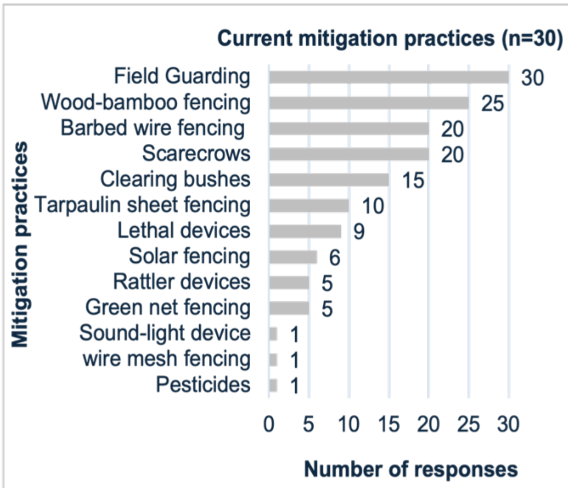

Fig. 7: Current mitigation practices

Table 1: *Mitigation practices and their perceived challenges*

Mitigation Practices	Common mitig ation strategy(s)	Perceived challenges
Non-technology	Night guarding	Labour intensi ve, sleep loss
	Bamboo/Woo d /barbed wire fencing	Easily breached by wildlife
	Clearing bushes	Temporary effectiveness
	Lethal device (e.g. traps)	Ethical and legal constraints
Technolog y-based	Solar fencing	Battery, inverter, maintenance issues
	Sound-light deterrent	Power dependence, maintenance
	Chain-link fencing	High upfront cost, installation needs

3.4 Technology Awareness, Digital Readiness and Digital Twin Perceptions

Farming communities in Dangkhar Trong Chiwog show varying levels of technology awareness regarding conflict mitigation technologies, as shown in Figure 8. Participants widely recognised chain-link and solar fencing as the most familiar tech-based interventions, which are implemented through short-term or grant-based initiatives. Awareness of electric and solar fencing and lethal devices was moderate, while exposure to more advanced systems such as sound-light deterrents and drones is minimal. This limited awareness of innovative conflict technologies is consistent with regional trends, where technology awareness depends mostly on project-based interventions (Chandio et al., 2024; Musajan et al., 2024; Nasirahmadi & Hensel, 2022).

Despite limited exposure to advanced mitigation technologies, farming communities shared high digital readiness, citing their successful adoption of solar and electric fencing as evidence of their readiness to embrace new technologies. Upon introduction to the concept and potential usefulness of Digital Twin technology, participants expressed strong interest in its adoption as a viable tool for reducing human-wildlife conflict, provided solutions are user-friendly and receive institutional support. Community members further noted that digital platforms could enhance coordination and enable faster response strategies, thereby reducing crop losses. These findings suggest that digital-based technology holds considerable promise for conflict mitigation in Dangkhar Trong Chiwog, contingent on accessibility, usability, and sustained institutional support (Feder et al., 2021; Pylianidis et al., 2021; Tzachor et al., 2022).

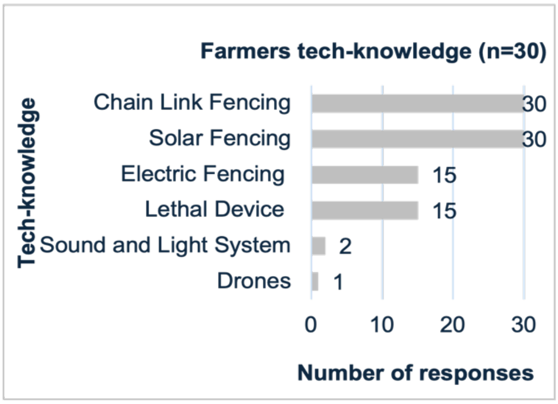

Fig. 8: *Farmers knowledge of conflict mitigation technologies*

3.5 Technology Support Needs

Farming communities in Dangkhar Trong Chiwog identified nine key technology support needs, ranked by priority in Table 2. Capacity building emerged as the top priority, with participants calling for training and skills development on farm technology to address gaps in installing, operating, and maintaining deterrent systems. Subsidised technology was another high priority, with participants requesting cost-sharing mechanisms to ease the financial burden of technology deployment. Solar fencing maintenance also ranked highly, reflecting a need for long-term technical and repair support once systems are installed. Participants further called for durable solar fencing, seeking a reliable supply of solar panels and electric poles able to withstand local conditions.

***Table 2:** Technology support needs of farmers*

Support needs (priority ranking)	Focus
Capacity building	Training and skills development on farm tech for farmers
Subsidised technology	Cost-sharing mechanisms for technology deployment
Solar fencing maintenance	Long-term technical and repair support
Durable solar fencing	Supply of durable solar and electric poles
Solar fencing inverter capacity	Increase solar power inverter capacity by household usage
Mobile network connectivity	Strengthen coverage, signal strength and stability
Electricity cost concession	Subsidised electricity costs for powering farm tech
Power connection	Establishing reliable grid lines for technological device
Road access	Road access for technology installation and maintenance

Increased solar fencing inverter capacity was another priority, with households requesting greater capacity to match their power usage needs. Stronger mobile network connectivity was also raised, with participants seeking better coverage and more stable signal strength to support technology use. Electricity cost concessions featured prominently as well, with subsidised electricity rates seen as necessary to sustain the running costs of farm technology. Reliable power connections were identified as important for supporting technological devices, while road access, though ranked lowest among the nine needs, remained necessary for enabling technology installation and ongoing maintenance in the Chiwog.

These findings indicate institutional constraints, rather than community reluctance, as the primary impediments to technology adoption in the Chiwog. Addressing these constraints will need financial support, infrastructure investment, and community-led governance (Dibbern et al., 2024; Gebresenbet et al., 2023; König et al., 2021).

4. DISCUSSION

Evidence from Dangkhar Trong Chiwog, Zhemgang, reveals a multifaceted and escalating pattern of human-wildlife conflict shaped by ecological disruption, cultural practices, and expanding agricultural activities. Increasing conflicts caused by wildlife behavioural shifts, habitat encroachment, and decreasing natural food availability reflect trends well documented across Himalayan landscapes, where smallholder farming communities bear a substantial burden of crop and livelihood losses (Penjor et al., 2022). The prevalence of wild boars, sambar deer, and rodents as the most damaging species is in line with established patterns of species-specific crop loss in similar farming systems. The cultural and religious restrictions against lethal wildlife control have contributed to a steady rise in conflict species populations, intensifying the tension between conservation goals and the livelihood security of farming communities (Letro & Fischer, 2020; Wangchuk et al., 2023).

Mitigation practices in the Chiwog continue to depend heavily on traditional practices such as field guarding, fencing, and clearing bushes, which remain susceptible to wildlife habituation and heavy labour demands, and which remain insufficient as conflict pressures escalate. Such limitations are also evidenced in similar Himalayan contexts (König et al., 2020). In contrast, modern interventions such as solar and electric fencing offer more durable alternatives but are hindered by high upfront costs, unreliable power supply, and poor maintenance continuity, collectively limiting their accessibility to most smallholder households. The lack of coordinated institutional efforts to introduce, pilot, or financially support technology-based mitigation in the Chiwog has created a gap between the availability of mitigation solutions and actual community-level implementation. These findings highlight that weak institutional engagement and resource gaps remain among the most persistent impediments to effective rural conflict management (Kifworo & Dube, 2024).

Community willingness and capacity to embrace new technology show encouragement and opportunity for advancing conflict mitigation. The implementation of solar and electric fencing and basic sound-light deterrents has built technological confidence and adaptability among farming communities, strengthening their readiness to engage with more advanced solutions. The participating farmers and officials have also shown considerable interest in the use of Digital Twin as an emerging technology for conflict mitigation. This shows a growing technological interest and openness to digital innovation among rural farming communities and is consistent with evidence on user-driven adoption in comparable rural contexts (Green et al., 2024; Wilkinson et al., 2023). Overcoming these challenges and leveraging the technology's potential requires institutional support such as cost-sharing mechanisms, skills development, rural infrastructure investment, and community-led governance frameworks. The wider body of research affirms that such institutional support is fundamental in transforming community readiness into actual technology deployment (Gebresenbet et al., 2023; König et al., 2021).

This study captured farmers' and officials' perceptions of Digital Twin technology and their willingness to adopt it, not its actual field implementation. Accordingly, claims about its effectiveness, scalability, and policy relevance should therefore be regarded as provisional rather than established. The study design was also qualitative and limited to a single Chiwog, so the findings reflect conditions specific to Dangkhar Trong Chiwog and may not extend to other Districts with different wildlife pressures, infrastructure, or governance arrangements. Future research should integrate pilot implementation of digital based technology with longitudinal monitoring, allowing these perceptions to be verified against measured outcomes.

5. POLICY IMPLICATION

The existence of robust policies, rules, and regulations is critical to managing human-wildlife conflict effectively; however, the farming communities pointed to significant policy loopholes and weak institutional mechanisms to address the persistent wildlife conflicts. The participants pointed out several gaps between the policy mandates and the actual field level implementation. The Forest and Nature Conservation Rules and Regulation, 2023 establishes a foundational conservation governance framework. However, its implementation does not explicitly address human-wildlife conflict at the district level, creating gaps in community land use practices, forest encroachment, and household vulnerability unaddressed in its current application (Dorji, 2024; Wangchuk et al., 2023). Similarly, the Food and Nutrition Security Policy does not sufficiently cover wildlife-driven crop and livestock losses as a structural food security risk. On the other hand, while crop insurance, compensation, and emergency relief provisions exist, their coverage remains limited, delivery inconsistent, and implementation project-driven in nature, leaving affected households exposed to compounding conflicts (Mukherjee, 2021).

The adequacy of physical mitigation infrastructure is impacted by limited budgets. The heavy dependence on external or project-based funding for solar and electric fencing creates inconsistent coverage and poor maintenance outcomes, with most households unable to independently finance durable solutions. Existing government cost-sharing and subsidy provisions, while present, are poorly enforced, unevenly applied, and insufficiently resourced to address the full extent of conflict-driven agricultural losses. Addressing this requires a policy mechanism that could direct regular disbursement, transparent accountability, and community-level monitoring to establish a reliable and institutionalised mitigation support system (Akhila et al., 2025).

Institutional mandates for deploying digital conflict management tools in high-conflict districts remain limited, despite established community readiness to embrace emerging technology solutions. The GovTech Digital Strategy must prioritise rural connectivity, IoT infrastructure, and encourage emerging technology deployment in high conflict areas. Promoting the uptake of emerging technologies by the farming communities, such as Digital Twin technology, within this strategic framework provides practical benefits, consistent with a growing body of evidence on digital innovation in rural agricultural contexts (Li et al., 2025).

Addressing these challenges requires immediate amendment of the Bhutan National Human Wildlife Conflict Management Strategy to develop a comprehensive cross-sectoral response integrating conservation, food security, digital innovation, and community governance into an integrated framework. Such an approach is essential to protecting farming livelihoods while sustaining Bhutan's conservation commitments, as evidenced in related research on conflict management governance in Bhutan (Gross et al., 2025).

6. CONCLUSION

This study shows the persistent and escalating nature of human-wildlife conflict in Dangkhar Trong Chiwog, Zhemgang, where smallholder farming households face compounding agricultural losses driven by ecological change, habitat encroachment, shifting wildlife behaviour, and cultural norms. The prevalence of wild boars, sambar deer, and rodents as the most damaging species, heightened by persistent damage from monkeys and birds, reflects well-documented evidence of species-specific crop loss across comparable Himalayan farming systems (Mishra et al., 2025). Besides wildlife pressure, climate variability, rain-fed agriculture dependence, and inadequate irrigation infrastructure intensify household vulnerability, underscoring that conflict cannot be viewed in isolation from broader agricultural and environmental vulnerabilities (Waiba, 2024).

The traditional mitigation practices, though widely used, are challenged by labour burdens, wildlife habituation, and poor durability. In contrast, while modern physical interventions such as solar, electric, and chain-link fencing provide better effectiveness, they remain largely inaccessible to most households due to financial constraints, infrastructure deficiencies, and the lack of continued institutional support. Cultural and religious prohibitions against lethal control contribute to a steady rise in wildlife populations, further escalating the tension between Bhutan's conservation commitments and the livelihood security of rural farming communities, a pattern well evidenced in Bhutanese conservation contexts.

The primary impediment to progress in technology adoption and implementation lies in structural constraints rather than community reluctance to adopt effective mitigation, reflecting a broader pattern of institutional disengagement in conflict management. The study also uncovers a notable observation of community readiness and willingness to adopt change, as revealed through past technology adoption experience and an indication of strong interest in the deployment of digital-based interventions such as Digital Twin conflict management. The integration of such potential remains contingent on accessibility, affordability, and institutional support, reinforcing findings that enabling conditions are fundamental to transforming community readiness into effective technology adoption outcomes (Kamande et al., 2023).

Addressing human-wildlife conflict eventually demands a coherent cross-sectoral response that moves beyond fragmented project-based interventions. This necessitates amending existing policy frameworks - including the Forest and Nature Conservation Rules and Regulation, the Food and Nutrition Security Policy, the Digital Strategy, and the Bhutan National Human Wildlife Conflict Management Strategy - into a comprehensive and enforceable strategy, integrating ecological assessment, community-led governance, digital innovation, and sustained financial support. In the absence of such structural reform, farming communities will continue to shoulder the intensifying costs of human-wildlife conflict, threatening food security, rural livelihoods, and Bhutan's long-term vision of sustainable human-wildlife coexistence (Gross et al., 2025).

The conclusions of this study draw on two distinct types of evidence. The findings on conflict drivers, mitigation practices, and their limitations come directly from the empirical data collected in focus group discussions. The policy directions on digital technology adoption, including Digital Twin technology are based on participants' expressed interest and not on evidence of actual field-tested performance. These policy directions should be viewed as recommendations for further research rather than validated policy measures.

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