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Risk analysis of human-wildlife conflict in Leuser Ecosystem Area, Indonesia

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Abstract. *Irwandi, Rauf A, Rahmawaty, Delvian, Harahap RH, Purwoko A. 2026. Risk analysis of human-wildlife conflict in Leuser Ecosystem Area, Indonesia. Biodiversitas 27 (1): d270120. https://doi.org/10.13057/biodiv/d270120.* Over the past six years, the Aceh Natural Resources Conservation Agency recorded 542 incidents of human-elephant conflict. In 2023 alone, 13 farmers and residents were attacked by wild tigers and elephants, resulting in injuries and fatalities. Additionally, at least 19 tigers died in Aceh between 2019 and 2022. This study aims to assess the risk of wildlife conflict to community livelihoods in seven villages within the Leuser Ecosystem Area. A mixed-methods approach was employed, combining quantitative and descriptive qualitative methods. Data collection involved the distribution of questionnaires covering 10% of households from the total population. The combined population of the seven surveyed villages is 2,673 households, from which 268 households (10%) were sampled using proportionate random sampling based on population size in each village. In addition to questionnaires, the study also conducted Focus Group Discussions (FGDs). In addition to questionnaires, the study also conducted Focus Group Discussions (FGDs). These were designed to validate survey findings and capture deeper community perspectives on risk perception, conflict experiences, and local coping strategies. Data analysis followed the Miles and Huberman model, consisting of three stages: data reduction, data display, and conclusion drawing. The study found that the perceived risk of wildlife conflict to livelihoods was generally low. However, some villages reported a medium level of risk. Most villages exhibited moderate vulnerability, with significant variation across dimensions of human, social, economic, physical, and environmental vulnerability. From a risk assessment perspective, the combination of low vulnerability and low threat levels contributes to a low overall risk of wildlife conflict for local government.

Keywords: Community livelihoods, conflict impact, human-wildlife conflict, mixed methods, risk

INTRODUCTION

Human-wildlife conflict (HWC) is an increasingly critical challenge for conservation and sustainable development worldwide (Gross et al. 2025). It threatens human welfare and biodiversity conservation (Green et al. 2024) and affects both humans and wildlife (Göttert and Starik 2022). The International Union for Conservation of Nature (2020) defines HWC as a struggle arising when wildlife presence or behavior poses real or perceived, direct, and recurrent threats to human needs or interests, leading to disputes among people and adverse consequences for humans and/or wildlife. Such conflicts are most severe for communities living near wildlife habitats and often involve elephants (*Elephas maximus*), tigers (*Panthera tigris*), orangutans (*Pongo abelii*), and bears (Ursidae) (König et al. 2021; Meyer and Börner 2022; Nkansah-Dwamena 2023).

Human-elephant conflict is documented across Sri Lanka (Gunawansa et al. 2023; Kamalrathne and Herath 2025), India (Chakraborty and Paul 2021; Guru and Das 2021; Tripathy et al. 2021; Majumder et al. 2022; Nad et al. 2022; Baskaran et al. 2024; Shameer et al. 2024; Roy et al. 2025), China (Ba et al. 2023; Li et al. 2023; Liang et al. 2025), Thailand (Jarungrattanapong and Olewiler 2024), Myanmar (Thant et al. 2021), Vietnam (Nguyen et al. 2021), and Bangladesh (Billah et al. 2021). As part of the Oriental biogeographic region, Indonesia faces similar pressures, with conflicts reported in Kalimantan (Serenari et al. 2025), Barisan Selatan National Park (Febryano et al. 2024), Lampung (Kuswanda et al. 2022), Bengkulu (Laksmitha et al. 2023), and Riau (Kuswanda et al. 2022; Yoza et al. 2023). In Aceh, several studies also report substantial conflict incidence (Diana et al. 2021; Wilson et al. 2021; Efendi et al. 2023; Jakfar et al. 2023). The Aceh Natural Resources Conservation Agency (2024) recorded 542 elephant-related incidents over the past 6 years, and in 2023 alone reported 13 attacks by Sumatran tigers and wild elephants on humans, resulting in injuries and fatalities.

Human-tiger conflict is also frequent, documented in West Sumatra (Rahman et al. 2023), Riau (Kuswanda et al. 2022; Neo et al. 2023; Pudyatmoko et al. 2023), North Sumatra (Patana et al. 2023), Bengkulu (Ekarini et al. 2022), and the Leuser Ecosystem area (Hadi et al. 2025; Saputra et al. 2025). BKSDA Aceh reports 19 Sumatran tiger deaths during 2019-2022, primarily due to poaching. Human-sun bear conflict (*Helarctos malayanus*) is less documented but reported (Widodo et al. 2022; Sibarani et al. 2024). Negative human-orangutan interactions are increasingly noted in Aceh (Suhardono et al. 2024), North Sumatra (Sulistiyono et al. 2021; Purwoko et al. 2022; Zaitunah et al. 2023; Harahap et al. 2024; Samsuri et al. 2024), Kalimantan (Santika et al. 2022; Schreer 2023), and the Bukit Tiga Puluh landscape (Harianja et al. 2021).

Overall, HWC is primarily driven by habitat loss and fragmentation that intensify encounters between people and wildlife (Gross et al. 2021; Pamungkas and Jones 2021; Wilson et al. 2021; Kuswanda et al. 2022; Syaban et al. 2024). This study was conducted from December 2023 to February 2024 using factual data from the Aceh Natural Resources Conservation Agency (2024) and surveys in seven conflict-prone villages in the Leuser landscape: Pucuk Lembang, Alur Dua Mas, Durian Kawan, Seuleukat, Alue Keujrueng, Kapai Seusak (South Aceh Regency), and Pasir Belo (Sultan Daulat Sub-district, Subulussalam City). Building on Leuser-focused research on conflict characteristics, drivers, impacts, and governance (Patana et al. 2018; Qomariah et al. 2019; Lubis et al. 2020; Patana et al. 2021; Rifaie et al. 2021; Patana et al. 2023; Sulistiyono et al. 2023; Ridayani et al. 2024), this study provides a village-level, multispecies assessment focusing on elephants, tigers, orangutans, and sun bears through: i) Wildlife Conflict Threat Risk Mapping (WCTRM); ii) Perceived Probability of Wildlife Conflict (PPWC); iii) assessment of vulnerability levels to human-wildlife conflict.

MATERIALS AND METHODS

Study area

The study area was selected based on indicators of regions affected by human-wildlife conflict, covering seven villages: Seulekat, Durian Kawan, Kapai Seusak, Alue Keujrueng, Alur Dua Mas, Pucok Lembang, and Pasir Belo in South Aceh Regency, Indonesia. These villages represent locations with a high level of interaction between communities and wildlife, particularly elephants, tigers, orangutans, and sun-bears key species within the Leuser Ecosystem. The locations of the seven target survey villages are illustrated in the map below (Figure 1).

These areas not only exhibit recurring conflict frequency but also reflect significant variations in patterns of economic, social, and ecological losses, thereby providing a comprehensive overview of the dynamics of impacts and coping mechanisms at the village level. The selection of these villages was also based on ecological relevance, their proximity to wildlife habitat corridors, and their representativeness of the socio-economic conditions of local communities that are highly dependent on agriculture and forest resources.

Partisipants

The population in this survey comprised all households residing permanently in the target villages. The total population across the seven surveyed villages was 2,673 households. For the purpose of descriptive analysis, a sampling rate of 10% was applied, resulting in a total sample size of 268 households. A proportional random sampling technique was used, with sample distribution adjusted according to the population size of each village. The participants were native villagers, and the study was conducted over four weeks. An explanation can be seen in Table 1.

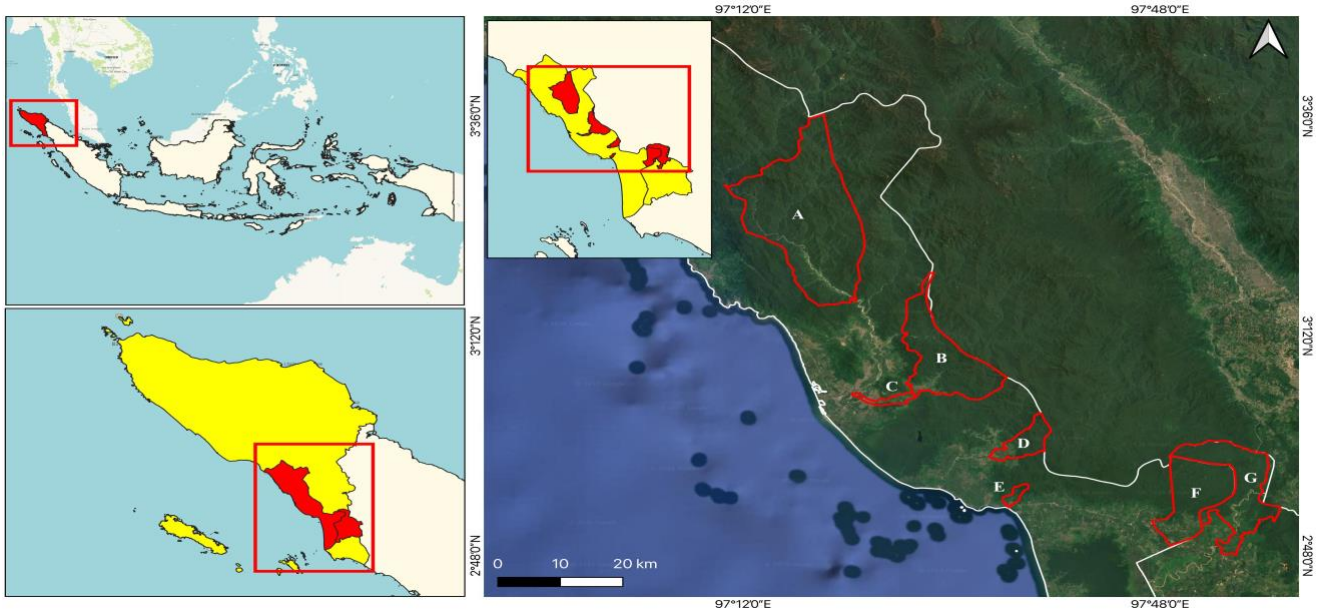

Figure 1. Locations of the target survey villages. A. Alue Keujrung, B. Pucok Lembang, C. Durian Kawan, D. Alur Dua Mas, E. Seulekat, F. Kapai Seusak, G. Pasir Belo, in South Aceh Regency, Aceh Province, Indonesia

Table 1. Percentage distribution of respondents

Village	Population	Sample (10%)	%
Seulekat	265	27	9.91
Durian Kawan	480	48	17.96
Kapa Seusak	543	54	20.31
Alue Keujrung	486	49	18.18
Alur Dua Mas	300	30	11.22
Pucok Lembang	299	30	11.19
Pasir Belo	300	30	11.22
Total	2673	267	100

Data collection

The survey was conducted in 3 main phases: preparation, implementation, and reporting. In the preparation phase, enumerators received intensive training on technical procedures, including data exploration and exploitation techniques, as well as strategies for addressing potential community-related dynamics during fieldwork. In the implementation phase, the team leader first established rapport with village authorities and key stakeholders to minimize resistance and facilitate smoother data collection by enumerators. The primary data collection instrument was a structured questionnaire, developed based on predefined research indicators. The questionnaire underwent a pilot test on a limited sample population to validate its reliability and construct validity. Data were collected in person by trained enumerators to ensure respondent comprehension and to minimize the risk of data entry errors.

To complement the quantitative data and provide a deeper contextual understanding, a triangulation phase was conducted through Focus Group Discussions (FGDs). These FGDs were designed to further explore key findings from the household survey and field observations, particularly issues that could not be fully captured through structured questionnaires. Each FGD involved 10-15 participants representing key community groups, including local leaders, farmers, women, and youth. Discussions were conducted in a participatory manner, guided by a pre-designed topic outline, facilitated by a trained moderator, and documented through detailed note-taking and audio recording.

The household survey itself was based on the Sustainable Livelihoods Framework (SLF) which served as a tool to assess perceived threats, probabilities, impacts, and livelihood vulnerabilities. Respondents were selected through proportionate random sampling from permanent households in each village, with only adults knowledgeable about household livelihoods included in the interviews. Prior to full deployment, the questionnaire was piloted to ensure reliability and validity. Data collection was carried out face-to-face by trained enumerators to maximize comprehension and accuracy.

In addition, secondary data on socio-demographic conditions were obtained from official village profile documents. Supplementary information from relevant government agencies was also utilized to enrich and contextualize the analysis of the findings.

Data analysis

The data analysis in this study adopts the approach proposed by Miles and Huberman (1994), which consists of three interrelated and iterative stages: data reduction, data display, and conclusion drawing or verification. These components are carried out simultaneously throughout the research process, rather than only after data collection is complete. i) The first stage, data reduction, involves selecting, simplifying, and focusing raw data collected from interviews, focus group discussions (FGDs), and document reviews. During this process, the researcher identifies key categories relevant to the research focus, discards irrelevant information, and highlights recurring themes that emerge from the data. ii) The second stage is data display, in which the reduced data are organized into descriptive narratives, tables, charts, or matrices. This visual and structured presentation enables the researcher to better understand the interconnections among categories or themes, and facilitates the identification of emerging patterns or anomalies. iii) The final stage is conclusion drawing and verification. Initial conclusions are drawn provisionally and may evolve as more data become available. Verification is carried out through triangulation, repeated data examination, and validation with key informants. This process ensures the credibility and reliability of the research findings.

The data reduction and interpretation process in this study is guided by the theoretical framework of the Sustainable Livelihood Framework (SLF) developed by the Department for International Development (DFID). The SLF provides an analytical structure to understand and assess the livelihood conditions of communities, and to design interventions that promote sustainable development. It helps identify the strengths, weaknesses, opportunities, and constraints within livelihood systems, as well as how different interventions can improve community capacity and resilience in the face of economic, environmental, or social pressures.

Livelihood assets are interrelated and collectively influence the sustainability of household livelihoods. Therefore, it is essential to understand the linkages between livelihood assets and the vulnerability context, which are shaped by structural and social processes. These include access to governance, markets, institutions, regulations, cultural norms, and practices. Understanding these access dimensions is critical for analyzing livelihood strategies and outcomes, such as increased income, enhanced well-being, reduced vulnerability, improved food security, and sustainable natural resource use. The sustainable livelihoods framework can be seen in Figure 2.

Several key elements within the theoretical framework of the Sustainable Livelihood Framework (SLF) include: vulnerability context, transforming structures and processes, livelihood strategies, livelihood outcomes and livelihood assets. The vulnerability context typically refers to external factors that drive change, such as seasonal variations, trends, or shocks that affect a given region and its target communities.

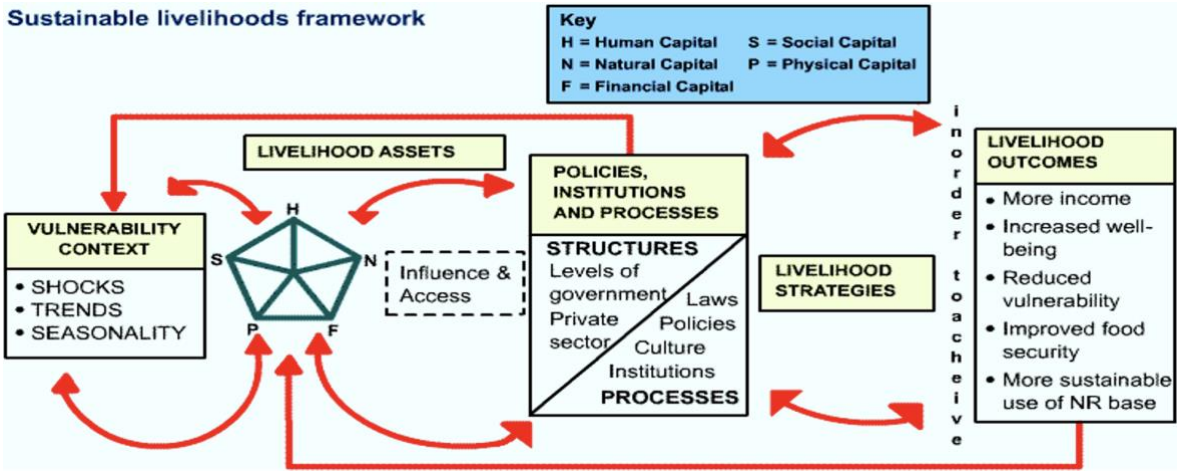

Figure 2. Sustainable livelihoods frameworks

Transforming structures and processes relate to institutional or structural changes, whether initiated through planned interventions or emerging organically over time. Strategies encompass the approaches or methods adopted within a program to achieve the intended livelihood outcomes, which may include increased income, improved well-being, or reduced vulnerability. Livelihood assets are categorized into five groups, commonly referred to as the Asset Pentagon, namely: i) Human capital: This includes factors such as health, education, knowledge and skills, the capacity to work, and the ability to adapt to changing conditions. ii) Natural capital: This consists of resources such as land and its productivity, water and aquatic resources, trees and forest products, wild fibers and food, biodiversity, and other environment-related resources. iii) Financial capital: This includes household income levels, savings, ownership of productive assets, ownership of individual and/or group enterprises, and access to transportation means. iv) Social capital: This encompasses networks and connections, established patronage, neighborly harmony, relationships based on mutual trust and support, formal and informal groups, social norms and sanctions, representation, participatory decision-making mechanisms, and leadership. v) Physical capital: This includes infrastructure such as transportation networks, vehicles, buildings and housing, sanitation and clean water facilities, energy supply, and communication networks. It also covers tools and technologies used in production, such as farming tools, seeds, fertilizers, pesticides, and traditional technologies.

Quantitative data from the household survey were analyzed using descriptive statistics and risk scoring, while qualitative data from FGDs were analyzed thematically. The two datasets were not merged; instead, FGD findings served as triangulation to validate and enrich the quantitative results. In cases where group dynamics produced different emphases compared to individual survey responses, these divergences were reported as complementary insights rather than aggregated into survey measures.

RESULT AND DISCUSSION

Wildlife Conflict Threat Risk Mapping (WCTRM)

Wildlife Conflict Threat Risk Mapping (WCTRM) is a spatially driven approach designed to identify, map, and predict the vulnerability of human-wildlife conflicts (HWC) by integrating habitat distribution, land-use dynamics, and human activity patterns. Within the Leuser Ecosystem, Aceh, risk mapping serves as a strategic tool to delineate areas most exposed to negative human-wildlife interactions. A growing body of research highlights the utility of WCTRM across diverse ecological contexts. Applications range from conflicts involving Sumatran tigers, elephants, and orangutans in Gunung Leuser (Lubis et al. 2020; Figel et al. 2021; Achmad et al. 2022; Kuswanda et al. 2022; Purwoko et al. 2022; Lubis et al. 2023; Patana et al. 2023; Slater et al. 2024), to HWC in Bengkulu (Ekarini et al. 2022), muntjacs (*Tragulus kanchil*), leopard cats (*Panthera pardus*), and wild boars (*Sus scrofa*) in the Merapi landscape (Sulaksono et al. 2023), elephant (*Elephas maximus*) - human interactions in Johor, Peninsular Malaysia (Kaliyappan 2023), macaque conflicts in Riau lowlands (Metananda et al. 2024), brown bear (*Ursus arctos*) conflicts in Iran (Nayeri et al. 2022), wildlife interactions in the Eastern Himalayas (Sharma et al. 2020), and elephant distribution in Sri Lanka (Gunawansa et al. 2024). Collectively, these studies reaffirm that risk mapping is not only a diagnostic instrument but also a cornerstone of evidence-based mitigation strategies in conflict-prone landscapes. Building on these insights, this study advances the discourse by generating conflict threat maps for seven villages within the Leuser landscape (Figure 3), offering spatially explicit insights into community-level vulnerabilities and potential intervention priorities.

Based on the survey findings, the overall perceived threat of human-wildlife conflict (HWC) remains very low, with particularly notable cases in Pucuk Lembang and Alur Dua Mas, where 100% of respondents reported minimal or non-existent levels of conflict risk. Among the seven surveyed villages, a clear variation emerges in perceived

threat levels. Both Pucuk Lembang and Alur Dua Mas exhibit an exceptionally low perceived threat (100%), suggesting relatively stable coexistence between humans and wildlife in these areas. Similarly, Durian Kawan demonstrates a predominantly low threat perception (98%), reinforcing patterns of generally harmonious human-wildlife interactions. Nonetheless, it is important to highlight that 2% of respondents in Durian Kawan reported higher levels of perceived threat, although this proportion remains statistically minor within the overall community perception.

The survey results reveal substantial variation in the perceived levels of human-wildlife conflict (HWC) threats across the seven study villages. In Seuleukat, the majority of respondents (85.2%) reported a low threat perception, although 14.5% identified a moderate threat, indicating a need for localized conflict management measures. Pasir Belo similarly demonstrated a predominantly low threat perception (83.3%); however, the presence of both moderate and high threat responses suggests that potential risks remain and warrant proactive monitoring. By contrast, Alue Keujrueng presents a more concerning profile, with only 52% of respondents perceiving a low threat. A considerable proportion (40%) reported moderate threat levels, and 8% reported high levels of perceived threat, underscoring the urgency for intensified mitigation strategies. Kapai Seusak represents the most critical case, recording the highest proportion of moderate threat perception (61.7%), while 35% of respondents assessed the threat as low and 3.3% as high. This distribution reflects the pressing need for comprehensive and context-sensitive planning to balance human activities with wildlife conservation imperatives. Taken together, these findings highlight the heterogeneous nature of HWC dynamics across villages. While certain communities experience relatively stable coexistence with wildlife, others exhibit heightened vulnerability that requires tailored interventions to safeguard both ecological integrity and human livelihoods.

Perceived Probability of Wildlife Conflict (PPWC)

Perceived Probability of Wildlife Conflict (PPWC) reflects the subjective perceptions of local communities regarding the likelihood of experiencing conflicts with wildlife. In Indonesia and other regions, PPWC-related studies have been conducted across various contexts. For instance, Ardiantiono et al. (2021) examined community attitudes and their willingness to coexist with Sumatran elephants around Way Kambas National Park (TNWK), Lampung. Similarly, Ardiantiono et al. (2023) integrated socio-ecological information to identify high-risk areas for human-saltwater crocodile (Crocodylidae) conflict in the Indonesian archipelago.

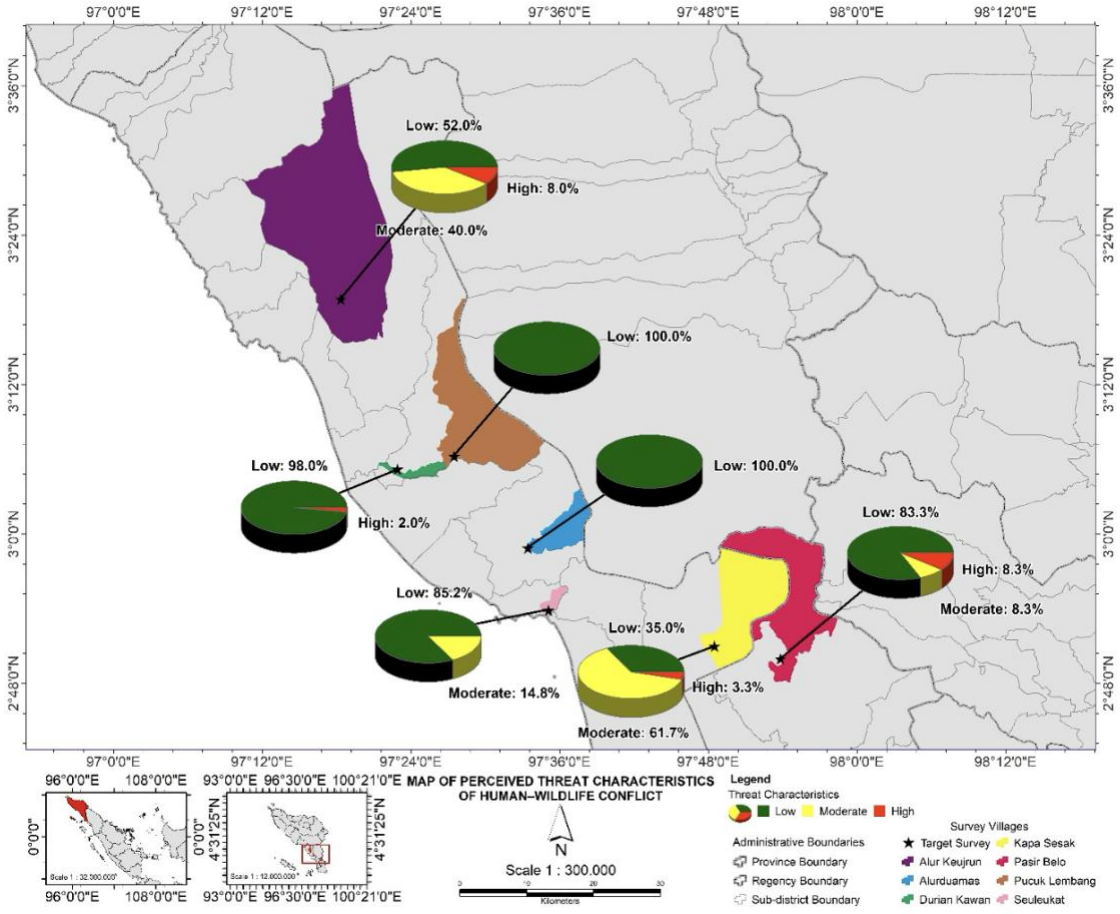

Figure 3. Perceived threat characteristics of human-wildlife conflict

Beyond Indonesia, Pimid et al. (2022) highlighted the role of social dimensions in wildlife conservation from multiple stakeholder perspectives in Kinabatangan, Sabah, Malaysia, while Karimullah et al. (2022) conducted a large-scale survey to understand potential conflicts between humans and non-human primates (Primates) in Malaysia. Other studies addressed human perceptions of conflict with gorillas (Gorilla) and their implications for life satisfaction in the Virunga landscape of Africa (Sabuhoro et al. 2023), as well as situational factors driving leopard killings (*P. pardus*) in South Africa (Viollaz et al. 2021). Collectively, these studies underscore the critical importance of perception-based dimensions in understanding the risks of human-wildlife conflict. Building upon this body of work, the present study investigates PPWC across seven conflict-prone villages in the Leuser Ecosystem, with findings presented in Figure 4.

The survey results reveal that the majority of respondents perceived the probability of wildlife conflict to be low. More than 80% of participants assessed the likelihood of conflict as minimal, with Alur Dua Mas distinguished by unanimous responses (100%) indicating a low level of threat. Only a very small proportion approximately 2.33% perceived a high probability of conflict, and these were limited to three villages: Pasir Belo, Alue Keujrueng, and Durian Kawan. A further 17.11% of respondents reported a moderate level of perceived threat. These findings suggest that, overall, communities in the surveyed villages perceive wildlife conflict as relatively unlikely. However, the presence of moderate to high perceptions in specific locations underscores localized vulnerabilities and highlights the need for targeted monitoring and context-specific mitigation strategies to prevent escalation and safeguard community livelihoods.

Based on respondents' assessments of the impacts of wildlife conflict across the seven surveyed villages (Figure 4), the majority (80.81%) perceived the impacts as low. In this context, "low impact" denotes minimal observable consequences for both local communities and the surrounding environment. This was most evident in Durian Kawan Village, where all respondents reported no impacts.

Table 2. Perceived probability of conflict

Category	Frequency	%
Low	215	80.60
Moderate	46	17.10
High	7	2.30
Total	268	100

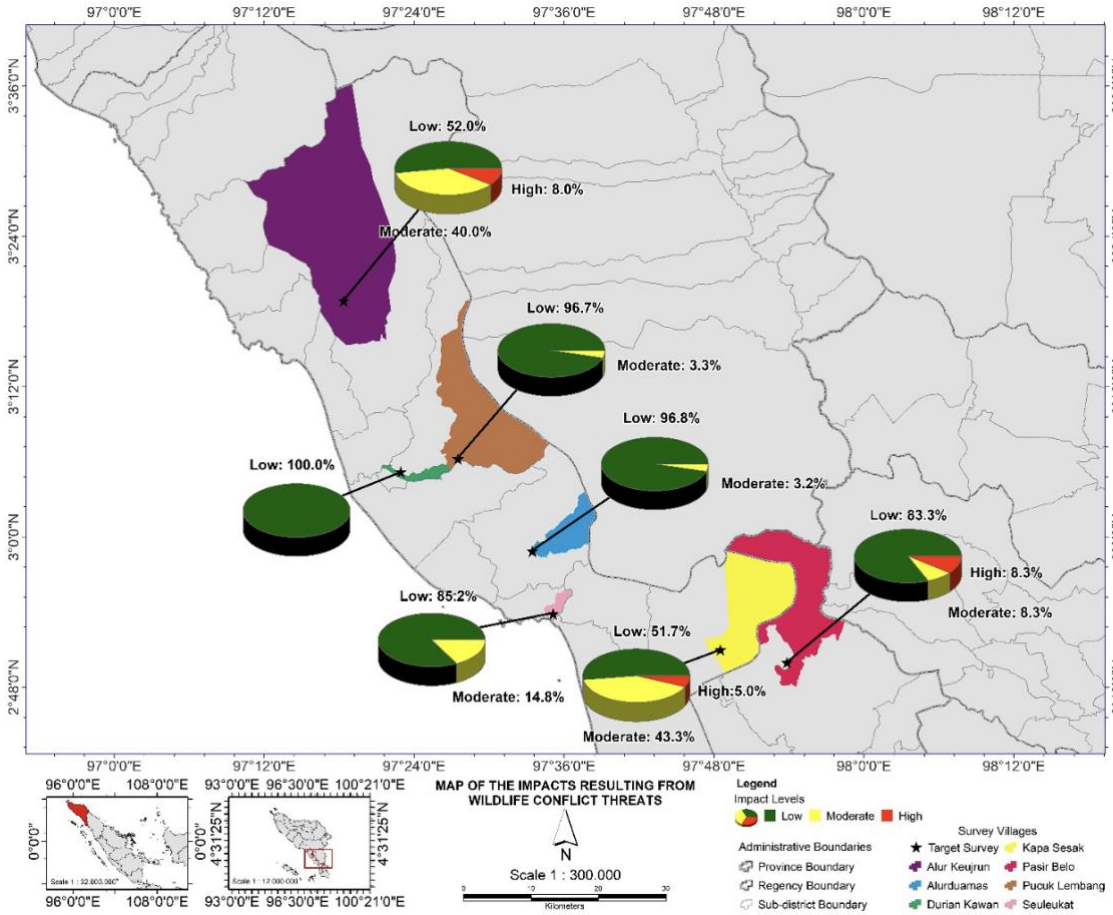

Figure 4. Assessment of the impacts resulting from wildlife conflict threats

A smaller proportion of respondents identified moderate impacts, particularly in Kapa Seusak and Alue Keujrueng, reflecting limited but tangible consequences of human-wildlife interactions. High-impact conflicts were reported in three villages Pasir Belo (8.3%), Alue Keujrueng (8%), and Kapa Seusak (5%) indicating localized areas of heightened vulnerability. When viewed alongside the wildlife conflict threat risk mapping, several villages, including Seuleukat, Durian Kawan, Alur Dua Mas, Pucuk Lembang, and Pasir Belo, were characterized by both low threat probabilities and low impact levels. These findings indicate that, overall, human-wildlife interactions across the surveyed areas are largely non-confrontational and present minimal risks to community well-being. However, certain villages exhibit localized vulnerabilities, underscoring the necessity for context-specific and adaptive mitigation strategies.

In contrast, Alue Keujrueng Village presents a unique case where the probability of wildlife conflict is categorized as low, yet the resulting impacts are relatively moderate. This indicates that while the overall risk of conflict is limited, when such events do occur, they can still pose considerable disruptions to local communities. Thus, this village requires targeted management efforts to reduce the negative consequences of wildlife conflict. Meanwhile, Kapa Seusak Village is characterized by both moderate conflict probability and moderate impact levels. This points to a higher overall risk compared to other surveyed villages, both in terms of the likelihood of wildlife conflict and its potential consequences. Therefore, this area warrants increased attention and more comprehensive mitigation strategies to minimize risks and safeguard community well-being (Figure 5).

Based on the assessment of overall vulnerability levels, the majority of respondents perceived the vulnerability caused by wildlife conflict to be at a moderate level, with an average percentage of 46.47%. Further analysis reveals that three villages Pasir Belo (66.7%), Kapa Seusak (60%), and Alur Dua Mas (54.8%) demonstrate relatively moderate levels of vulnerability. Conversely, the villages reporting the lowest levels of vulnerability include Durian Kawan (62.7%), Alue Keujrueng (52%), and Alur Dua Mas (45.2%), where a significant proportion of respondents categorized vulnerability as low.

Table 3. Perceived impact of conflict

Category	Frequency	%
Low	216	80.80
Moderate	29	10.80
High	23	8.40
Total	268	100

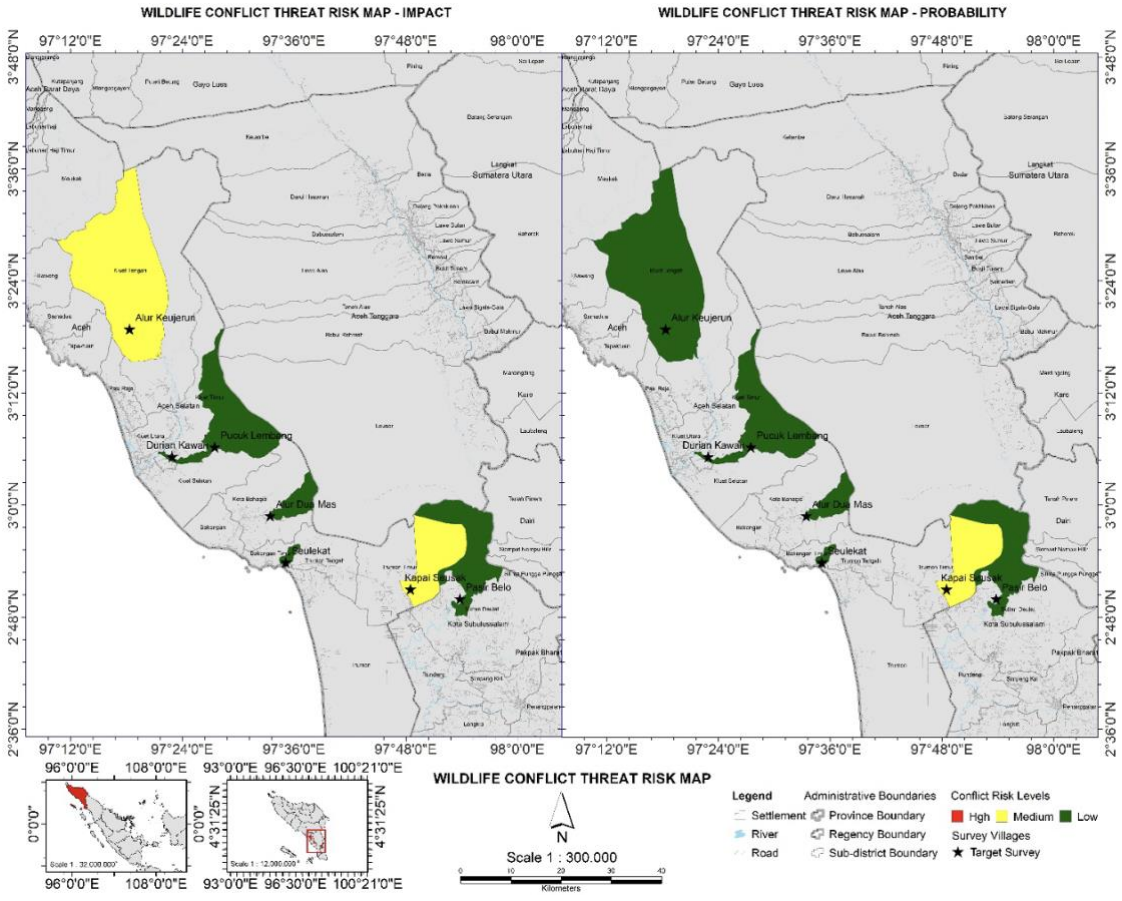

Figure 5. Wildlife conflict threat risk mapping

Interestingly, several respondents did indicate high levels of vulnerability, with the most prominent reports coming from Seuleukat, Pucuk Lembang, Durian Kawan, Kapa Seusak, Pasir Belo, and Alue Keujrueng. Notably, none of the respondents in Alur Dua Mas classified the level of vulnerability as high. This may suggest that the village has successfully implemented effective conflict mitigation strategies or benefits from more stable environmental conditions, thereby reducing its vulnerability to wildlife conflict.

Assessment of vulnerability levels to human-wildlife conflict

The variability in vulnerability perceptions across different villages underscores the need for diverse and integrated approaches in managing human-wildlife conflict. It also emphasizes the importance of in-depth understanding of the contextual factors influencing vulnerability in each village and the implementation of tailored interventions to mitigate the negative impacts of such conflicts on local communities (Figure 6).

Through a more in-depth analysis, community vulnerability was categorized into five livelihood aspects: human vulnerability, social vulnerability, economic vulnerability, physical vulnerability, and environmental vulnerability. The data present findings from the survey related specifically to the human vulnerability aspect. In general, the level of human vulnerability was reported as very low in nearly all villages, with the exception of Seulekat. In detail, nearly half of the respondents in Seulekat (44.4%) reported a moderate level of human vulnerability, and approximately one-quarter of the total respondents indicated a relatively high level. Additionally, three other villages Pucuk Lembang, Durian Kawan, and Kapa Seusak also showed a notable proportion of respondents perceiving higher levels of human vulnerability. These findings underscore the need for a holistic and context-sensitive approach to managing human-wildlife conflict, recognizing the significant variation in human vulnerability levels across different locations. This emphasizes that conflict management strategies must account for local factors that specifically influence human vulnerability in each village (Figure 7).

Table 4. Vulnerability levels (Overall)

Category	Frequency	%
Low	109	40.70
Moderate	125	46.60
High	34	12.70
Total	268	100

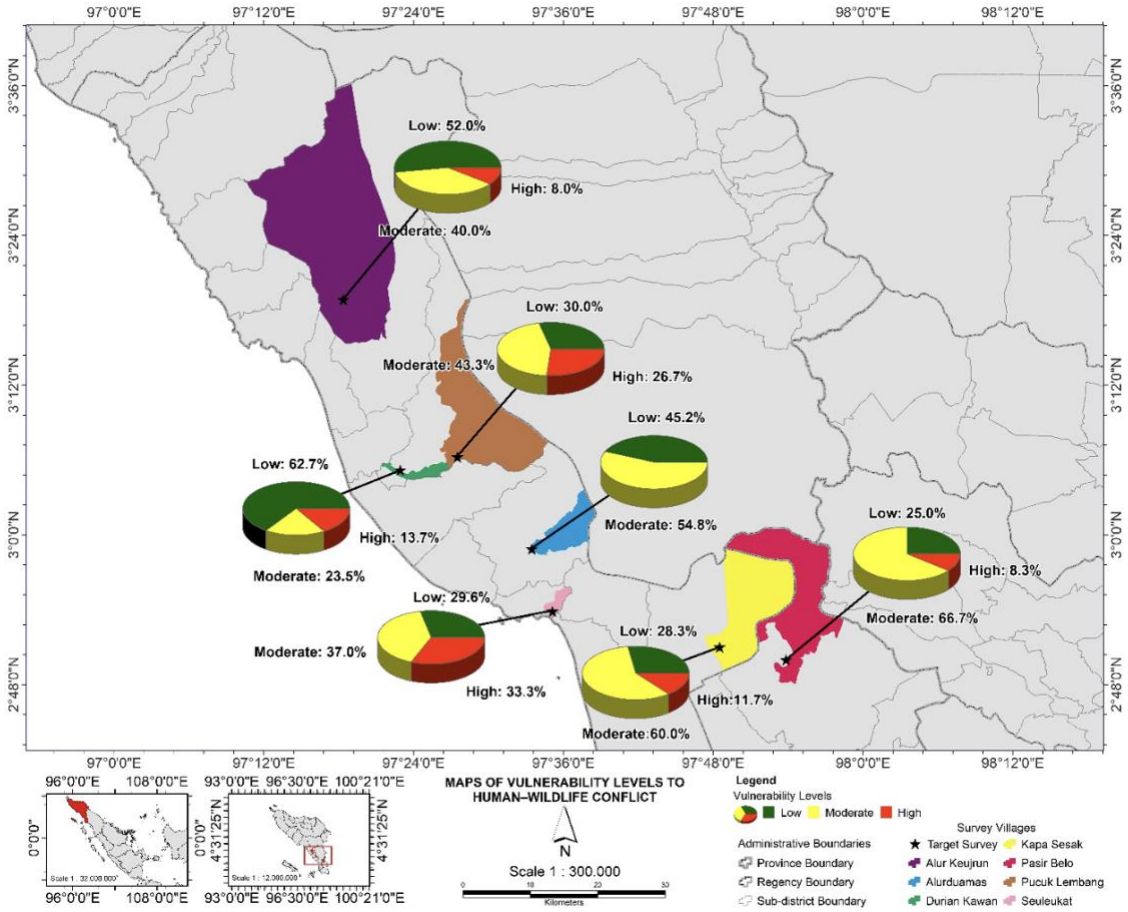

Figure 6. Assessment of vulnerability levels to human-wildlife conflict

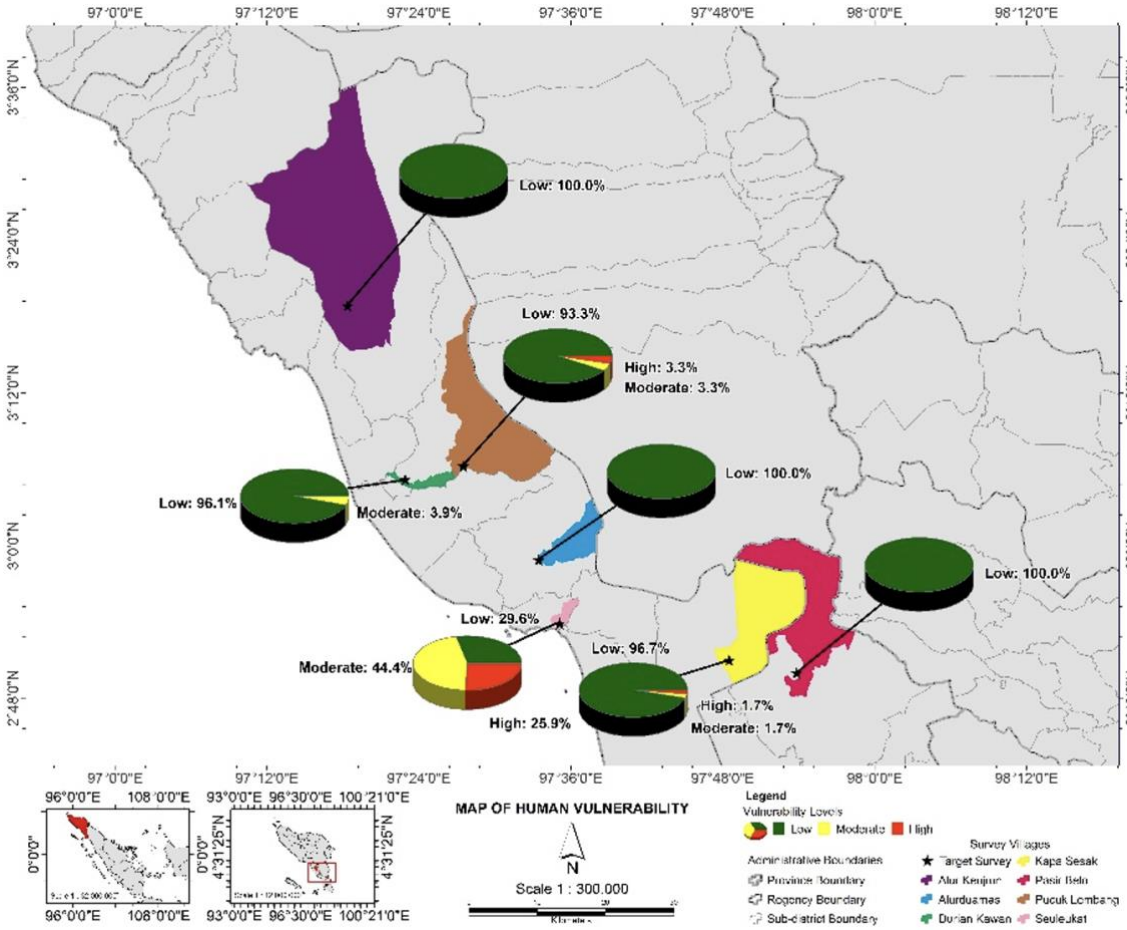

Figure 7. Assessment of human vulnerability

Based on the analysis of social vulnerability, each village under study exhibits a unique context in terms of social vulnerability levels. In Alur Dua Mas, the majority of residents (74.2%) reported a low level of social vulnerability. However, 16.1% indicated a moderate level of vulnerability, and 9.7% reported experiencing high social vulnerability. Similarly, the village of Seulekat showed comparable characteristics, with 25.9% of respondents indicating a high level of social vulnerability. The highest level of perceived social vulnerability was reported in Pasir Belo, where half of the respondents claimed to experience significant social vulnerability. Elevated levels of social vulnerability were also reported in the villages of Kapa Seusak, Pucuk Lembang, Alue Keujrueng, and Durian Kawan. Among all surveyed villages, Alur Dua Mas demonstrated the lowest proportion of respondents reporting high social vulnerability (Figure 8).

In this context, it is important to recognize that social vulnerability is closely linked to the strength of community social institutions, including kinship, mutual care, trust, social norms, and security. The observed variation in social vulnerability levels necessitates tailored approaches to community management, including initiatives for community empowerment and the provision of relevant resources. In conclusion, effective and sustainable resolution of human-wildlife conflict in each village must consider the unique social dynamics and conditions of the local population (Figure 9).

Based on the assessment of economic assets, household-level economic vulnerability across all surveyed villages is generally high. Durian Kawan shows relatively better economic resilience, with more than half of respondents (54.9%) reporting low levels of economic vulnerability, while 31.4% indicated moderate vulnerability and 13.7% reported high vulnerability. The highest levels of economic vulnerability were found in households in Pucuk Lembang (40%), followed by Kapa Seusak (30%), Seulekat (29.6%), Alue Keujrueng (20%), Alur Dua Mas (16.1%), and Durian Kawan (13.7%). In Pasir Belo, the majority of households (66.7%) reported moderate economic vulnerability. Therefore, wildlife conflict management in these areas should take into account its impact on local economic vulnerability, with an emphasis on strengthening household economic capacity and protecting resources for communities at risk (Figure 10).

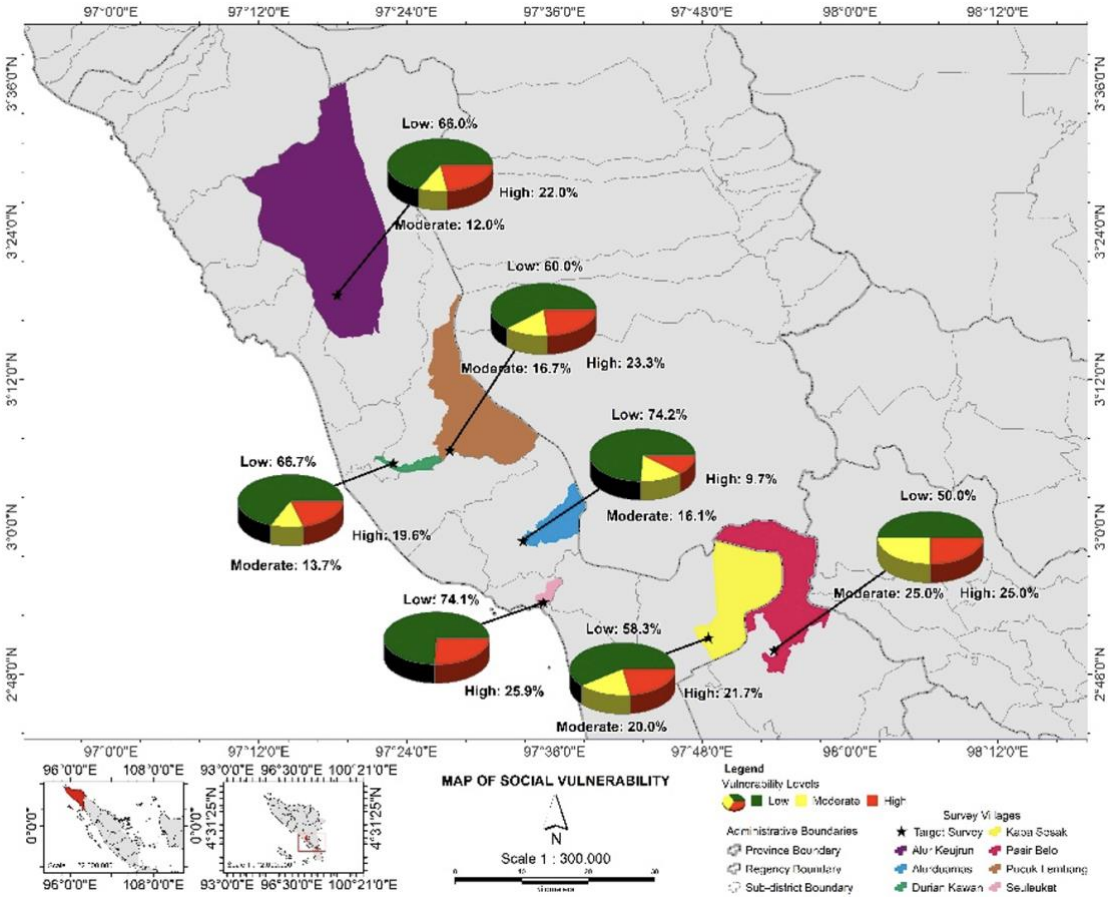

Figure 8. Assessment of social vulnerability

Based on the assessment of physical vulnerability, the community in Pucuk Lembang exhibits a significantly higher level of vulnerability related to physical aspects such as roads, bridges, housing, educational facilities, and healthcare services, with 70% of respondents indicating a moderate level of vulnerability and 16.7% reporting a high level. This suggests that the village faces considerable challenges in terms of physical vulnerability to wildlife conflict, potentially due to factors such as topography, wildlife population density, area accessibility, and the condition of local infrastructure, which may be inadequate or damaged. Conversely, respondents from Durian Kawan and Pasir Belo reported a higher capacity of physical infrastructure in their respective areas. Overall, physical vulnerability across all surveyed villages is generally low. However, four villages were identified a higher degree of physical vulnerability, ranked from highest to lowest as follows: Pucuk Lembang, Alur Dua Mas, Durian Kawan, and Seulekat. These findings highlight the need for targeted management strategies focusing on risk mitigation and infrastructure improvement in areas with elevated physical vulnerability (Figure 11).

Based on the analysis of environmental vulnerability, there appears to be a degree of complexity in the interaction between environmental factors and human activity across the surveyed villages. Overall, environmental vulnerability in these areas can be categorized as moderate, although some variations were observed in respondents' assessments. For instance, in Alur Dua Mas, the majority of respondents (67.7%) indicated a moderate level of environmental vulnerability. This finding provides a deeper understanding of the ecological challenges faced by local communities, particularly in maintaining ecological balance in areas susceptible to human-wildlife interactions. In contrast, Durian Kawan stood out as a positive example, where 58.8% of respondents reported low environmental vulnerability. This suggests that effective efforts have been made to preserve environmental sustainability in this village, which could serve as a model for similar conservation efforts elsewhere. Nevertheless, greater challenges remain in certain locations, such as Pucuk Lembang, where a significant portion of respondents (23.3%) perceived high environmental vulnerability. This highlights the need for enhanced awareness and the implementation of appropriate management strategies to mitigate the negative impacts of wildlife conflict on the natural environment in these areas.

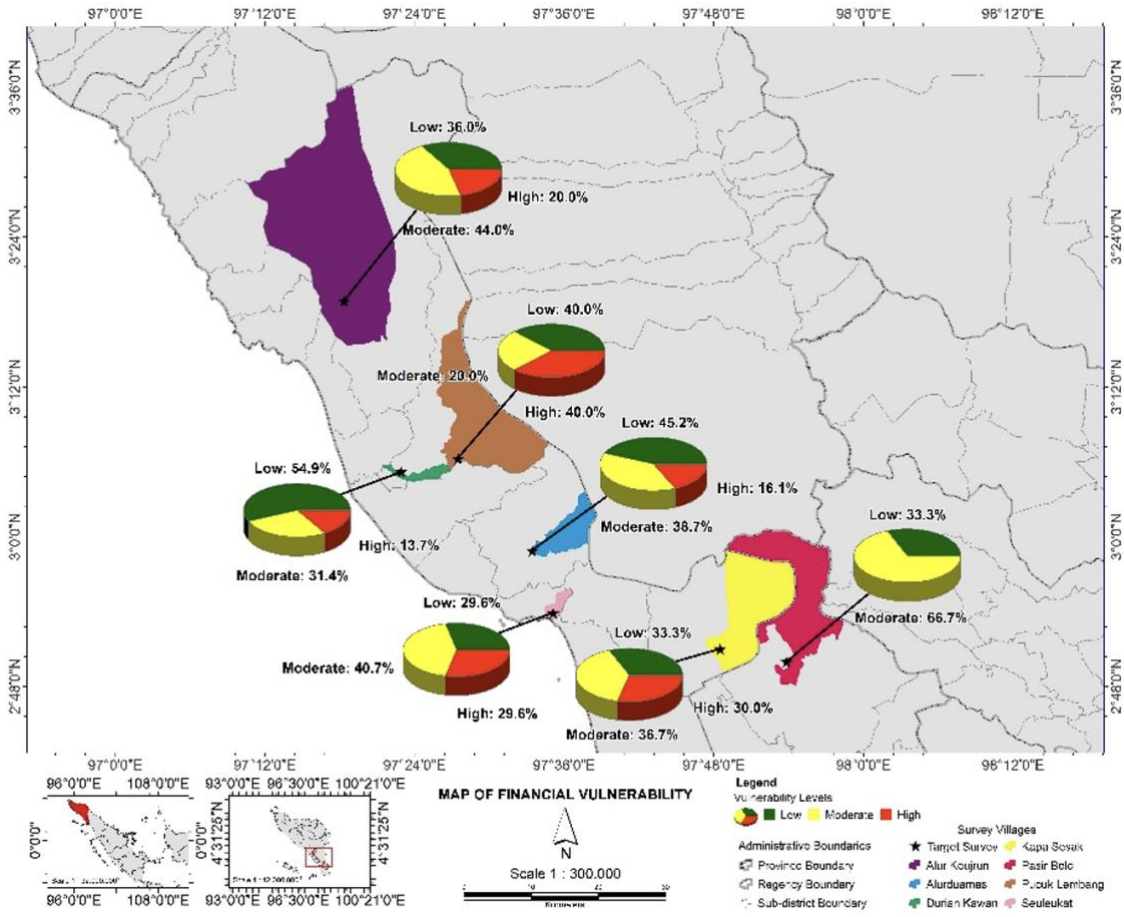

Figure 9. Assessment of financial vulnerability

From a scientific perspective, these findings underscore the complexity of understanding the human-environment interface, especially in the context of wildlife conflict. The variation in environmental vulnerability levels among villages emphasizes the need for an integrated and locally informed approach to natural resource management and environmental protection. In conclusion, only by recognizing local diversity and applying tailored strategies can we ensure environmental sustainability and community well-being in regions affected by human-wildlife conflict. Based on the data presented above, it can be concluded that the relatively moderate to high levels of social, human, physical, financial, and natural capital among communities in the seven villages contribute to a lower overall risk of human-wildlife conflict and its impact on local livelihoods. Furthermore, with continuous improvement and management of these livelihood capitals, risk mitigation efforts can be carried out more effectively.

Discussion

Wildlife Conflict Threat Risk Mapping (WCTRM) has been emphasized in recent studies as a critical tool for identifying areas vulnerable to human-wildlife conflict (Naha et al. 2019; Sharma et al. 2020; Stoldt et al. 2020; Abrahms 2021). This mapping approach does not merely focus on the spatial distribution of wildlife but also integrates key causal drivers such as land-use change (Bharathy et al. 2022), habitat loss (Braczkowski et al. 2023), and increased human activities in forest-adjacent areas (Hahn et al. 2023). For instance, Lubis et al. (2023) examined spatial patterns of forest conversion and the population status of several threatened mammal species within the Leuser Ecosystem. Similarly, Haidir et al. (2021) investigated the tropical rainforest landscape of Kerinci, mapping dispersal corridors for the Sunda clouded leopard (*Neofelis diardi diardi*), the Asian golden cat (*Catopuma temminckii*), and the marbled cat (*Pardofelis marmorata*), while simultaneously modeling future forest loss and fragmentation and its implications for landscape connectivity of these endangered populations. Together, these studies from Sumatra highlight the significance of risk mapping in elucidating the interplay between environmental conditions and anthropogenic pressures on wildlife.

However, spatial data alone are insufficient, as community experiences and perceptions may diverge from the outcomes of spatial mapping. This is where the Perceived Probability of Wildlife Conflict (PPWC) becomes particularly relevant, as it captures how local communities assess the likelihood of conflict. For instance, in a case study on human attitudes toward coexistence with Sumatran elephants, a survey of 660 respondents revealed that 62% were unwilling to live alongside elephants (Ardiantiono et al. 2021). Similarly, a study conducted in

South Aceh reported that 70% of respondents agreed that elephants should be driven away when entering farmland (Nurmaliah et al. 2024). Moving beyond elephants, research in Langkat District highlighted that communities perceived Sumatran tigers as having no direct benefit to their livelihoods, instead viewing them as a threat to public order (Patana and Rahmatika 2024). Perceptions of fear and anxiety toward the presence of tigers were further substantiated by Figel et al. (2023), who documented 96 cases of human-tiger conflict (HTC) in the lowlands of Aceh. Collectively, these studies suggest that community perceptions of wildlife conflicts whether with elephants or tigers are predominantly negative, framing these species as threats to safety and daily life. This underscores that conflict mitigation efforts require more than spatial mapping; they must also integrate community perceptions and lived social experiences.

Wildlife Conflict Threat Risk Mapping (WCTRM) provides insights into where human-wildlife conflicts are most likely to occur, while the Perceived Probability of Wildlife Conflict (PPWC) reflects how communities perceive the potential risks of such conflicts. Vulnerability analysis complements both approaches by addressing the critical question of who is most affected. For instance, studies have demonstrated that high livelihood vulnerability may compel communities to adopt coping strategies that inadvertently increase the risk of negative human-wildlife interactions (HWI), as observed in Quirimbas National Park, Mozambique (Pereira et al. 2021). Similarly, vulnerability assessments have been applied to map human-wildlife conflicts in the Hirpora Wildlife Sanctuary, Western Himalaya, Kashmir, using geospatial techniques, offering valuable insights for both local communities and conservation initiatives (Bharathy et al. 2022). Moreover, vulnerability analysis has proven particularly relevant in the context of climate change a global challenge that intensifies ecological pressures by identifying pathways for developing mitigation strategies and proactive policies aimed at minimizing the impacts of human-wildlife conflict on biodiversity conservation and human well-being (Abrahms et al. 2023).

The three complementary dimensions of WCTRM, PPWC, and vulnerability analysis provide an integrated framework for designing more effective mitigation strategies. Spatial risk mapping (WCTRM) can serve as a basis for establishing buffer zones and identifying ecological hotspots. PPWC captures local perceptions, thereby strengthening risk communication and community engagement. Vulnerability analysis, in turn, highlights which groups should be prioritized in terms of protection and support. The integration of these three tools ensures that the proposed solutions are not only technically sound but also socially inclusive. By combining WCTRM, PPWC, and vulnerability assessments, this study contributes to a more holistic understanding of human-wildlife conflict and offers policy-relevant recommendations that can be applied at the regional scale as mitigation efforts, particularly for the seven villages studied in designing future applications.

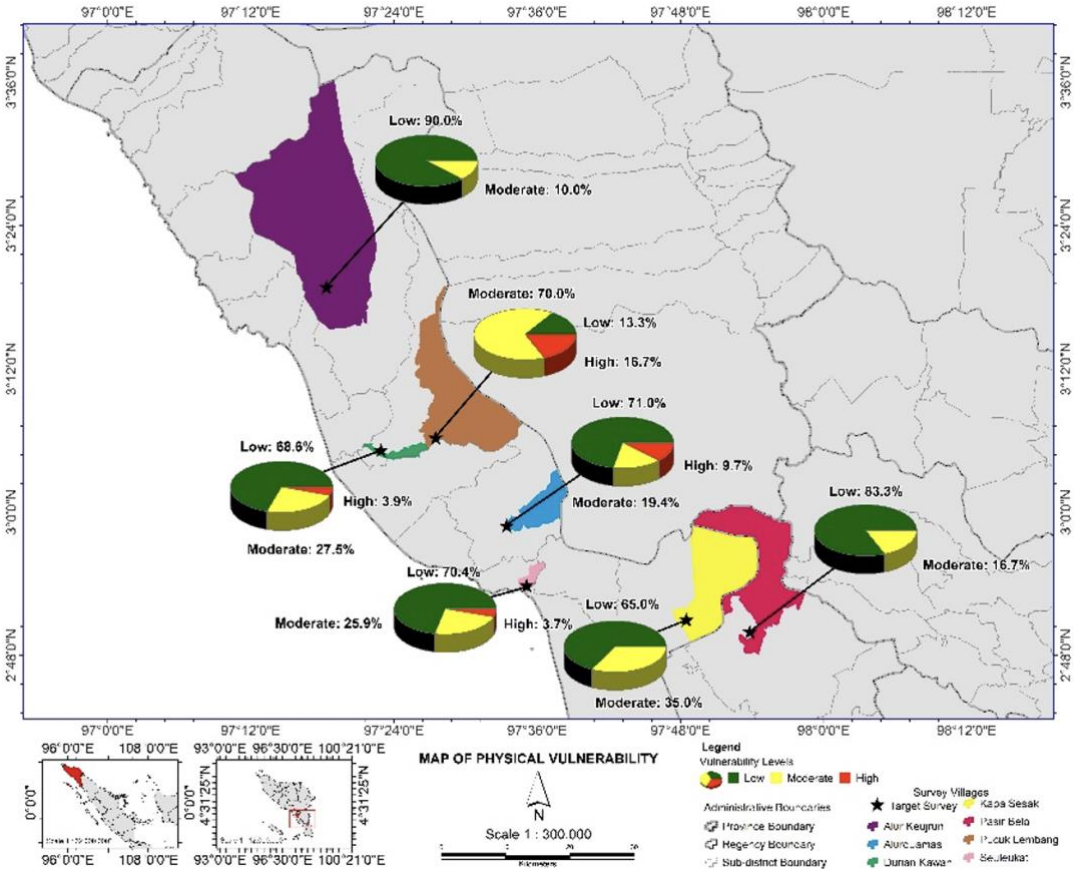

Figure 10. Assessment of physical vulnerability

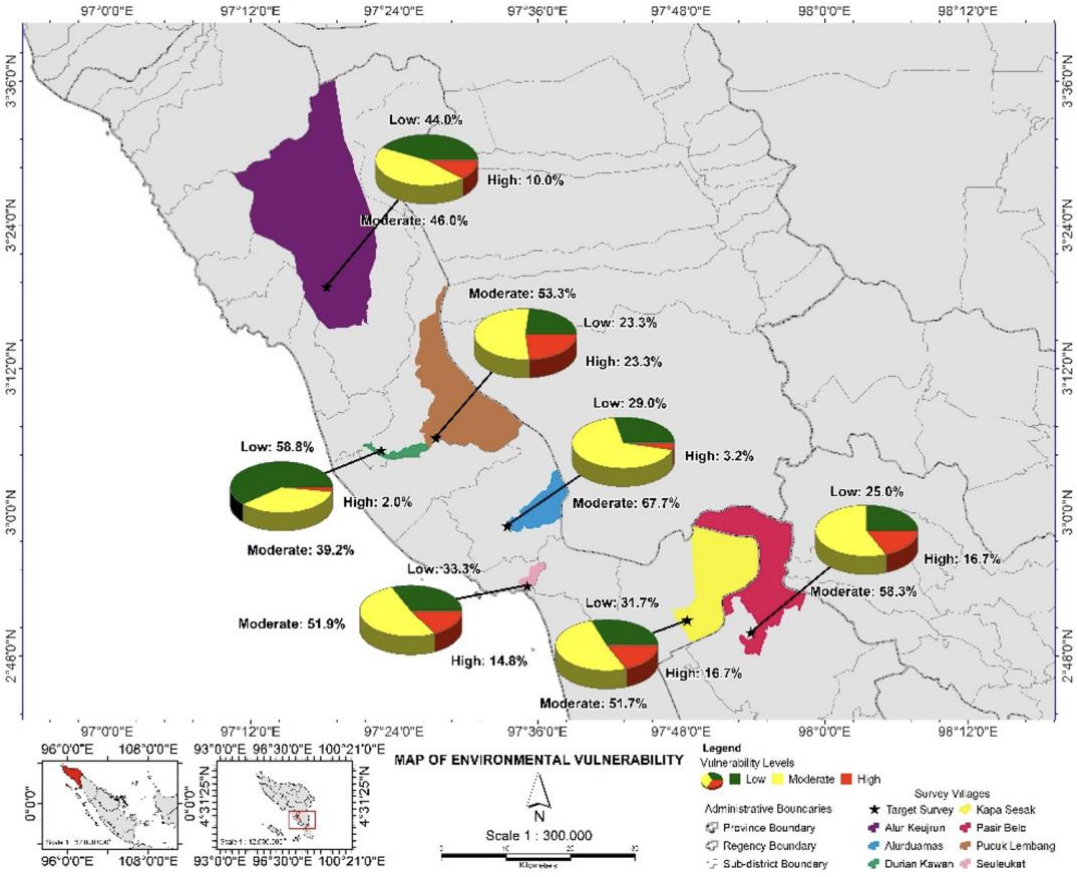

Figure 11. Assessment of environmental vulnerability

Figure 12. The presence of wild animals entering anthropogenic activities in the study area. A: Sumatran elephant (*Elephas maximus sumatranus*), B: Sumatran tiger (*Panthera tigris sumatrae*), C: Sun bear (*Helarctos malayanus*), D: Sumatran orangutan (*Pongo abelii*)

In conclusion, this study highlights that human-wildlife conflict (HWC) in the Leuseur ecosystem, Aceh, primarily involves key species such as the Sumatran elephant and the Sumatran tiger, bears, and wild boar. It assesses the risks of wildlife conflict to community livelihoods, with conflict hotspots concentrated at forest edges, plantation areas, and community agricultural lands. Key risks identified include crop damage, loss of household income, and increased fear and social insecurity at the community level. These impacts disproportionately affect smallholder farmers who rely heavily on subsistence agriculture, making them the most vulnerable group in the HWC context. In this context, of the seven villages we studied, Kapa Sesak and Alue Keujrung villages with level medium (as hotspot) were found to be more vulnerable than others.

These findings have significant implications for conservation management and sustainable development. Wildlife Conflict Threat Risk Mapping (WCTRM) provides a spatial basis for prioritizing intervention zones, while the Perceived Probability of Wildlife Conflict (PPWC) highlights the need for socially contextualized risk communication. Vulnerability analysis complements these dimensions by identifying population groups most in need of protection and support. Therefore, mitigation strategies should integrate technical approaches such as establishing wildlife corridors and patrols, along with social interventions, including the development of alternative livelihoods, compensation schemes, and building community capacity for conflict management. From a policy perspective, cross-sectoral coordination between government agencies, conservation organizations, and local communities is crucial. Evidence-based compensation policies, livelihood diversification programs, and educational initiatives on ecosystem balance are strategic steps to reduce conflict risk. At the community level, active participation in local conflict response units (e.g., Elephant Response Units) can enhance local management in mitigation. Through this integrated approach, HWC is reframed not simply as an ecological issue, but as a socio-ecological challenge requiring collaborative, adaptive, and context-sensitive solutions.

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