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Spatial Mapping of Mitigation Structures and Compensation Analysis to Understand Human–Elephant Conflict in Wayanad, Kerala

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Abstract

Objectives: Human-elephant conflict in India, intensified by habitat loss and encroachment, threatens biodiversity. This study assesses conflict patterns and intensity over five years (2018–2023) in Wayanad, Kerala. **Methods:** Data was collected from forest department compensation records and mitigation structures from January 2018 to November 2023. The mitigation structures established in Wayanad to address human–elephant conflict were systematically mapped through detailed field surveys. **Findings:** Results indicate a high prevalence of human-elephant conflict in Wayanad, with 9989 reported incidents, primarily involving crop depredation (94.69%), property damage (3.16%), and human injuries and fatalities. South Wayanad Division recorded the highest number of incidents (43.50%). Compensation totaling ₹690.012 lakhs was disbursed, predominantly for crop loss. The Kerala Forest Department has implemented various mitigation strategies, including solar fencing, elephant-proof trenches, and rapid response teams, which have contributed to stabilizing conflict incidences. Despite these efforts, underreporting of conflict incidents and delays in compensation persist, indicating a need for improved management strategies. The study underscores the importance of a landscape-level approach to conflict management, integrating early warning systems and media training for accurate reporting. Enhanced habitat restoration, fair compensation mechanisms, and increased employment opportunities for fringe communities are recommended to foster coexistence and reduce conflict. **Novelty:** Despite several studies conducted in the area, there is a lack of quantitative data on the spatial and temporal patterns of HEC, its ecological drivers, and its broader impacts on biodiversity and habitat quality in Wayanad. This study addresses the existing gap in quantitative data on the spatial and temporal dynamics of Human–Elephant Conflict (HEC) in Wayanad by analyzing compensation records from January 2018 to November 2023. It also examines the spatial distribution of mitigation structures, identifying key locations where elephants frequently breach barriers to access human settlements.

Keywords: Wildlife conflict; Wayanad; Property damage; Crop loss; Compensation mechanisms

1 Introduction

Human-elephant conflict is a major concern in Elephant range countries and despite numerous global efforts, its mitigation remains a significant challenge [1]. Negative human–elephant interactions (HEI) pose a serious challenge to the conservation of Asian elephant *Elephas maximus* and adversely affect the socio-economic and psychological well-being of local communities [2]. Human–elephant conflict arises when humans and elephants compete for space and resources, resulting in adverse consequences for one or both the species [3]. Increasing human–elephant conflict (HEC) has emerged as a major ecological and social issue due to habitat fragmentation, agricultural expansion, and the conversion of forests into monoculture plantations [4]. The Wayanad district of Kerala, part of the Nilgiris landscape in the Western Ghats, supports the largest and densest breeding population of Asian elephants, with the Wayanad plateau serving as an important dry-season refuge [5]. However, rapid habitat loss, settlement growth, and invasive species have intensified elephant dependence on farmlands, escalating HEC [6]. Although various mitigation approaches such as crop-guarding, barriers, deterrents, and compensation schemes are in use, their effectiveness remains limited. Despite the region's significance for elephant conservation and the escalating HEC, research on habitat dynamics and spatial patterns of HEC in Wayanad remains limited [7].

The ensemble species distribution modelling study in Wayanad revealed that human population density, distance from protected areas, and temperature were key drivers of Human–Elephant Interaction (HEI) risk. The results indicated that conflict likelihood peaked at moderate distances (4–15 km) from protected areas and intermediate population densities (350 people/km^2), with anthropogenic factors dominating seasonal risk patterns with dry-season conflicts concentrated in Kidanganad, Nulpuzha, and Pulpalli, and wet-season risks persisting in Tirunelli, Trisshaleri, and Payampalli [2]. Vineetha et al., 2024 studied the elephant habitat suitability in Wayanad Wildlife Sanctuary using geospatial analysis and the Analytic Hierarchy Process (AHP) and identified Sultan Bathery range as the most suitable area followed by Kurichiat and Tholpetti. Validation using human–elephant conflict data revealed that Kurichiat recorded the highest conflict (50%), highlighting the utility of the habitat suitability map for targeted management and conservation planning [7].

Anoop et al., 2023 assessed the spatial and temporal drivers of human–elephant conflict (HEC) in Wayanad by integrating questionnaire surveys, compensation records, and identification of crop-raiding elephants and analysed that conflict intensity was highest near forest boundaries and during the jackfruit–mango (May–August) and paddy (June–December) seasons, mainly involving bull elephants active at night. The increasing conflict, crop loss, and fear among residents have disrupted local livelihoods and tolerance toward elephants, while ineffective mitigation measures and inadequate compensation further aggravate the problem [6]. Over the past decade, 32 human fatalities have been reported due to HEC incidents in Wayanad, and a huge amount of money was paid as compensation for crop loss. The HEC is identified as a conservation challenge in Wayanad as the conflict situation leads to the death of several elephants, especially from illegal high-voltage electric fences and poisoning [8] and require better information on the pattern and distribution of HECs to mitigate them and conserve elephants [9].

However, there is a lack of quantitative data on the spatial and temporal patterns of HEC, its ecological drivers, and its broader impacts on biodiversity and habitat quality in Wayanad. We analyzed the intensity of human-wildlife conflict in Wayanad using compensation claims from January 2018 to November 2023 to evaluate its current status and changes in intensity. We also collected details on the spatial distribution of existing mitigation structures in Wayanad which serve to hinder the access of elephants to human settlements and identified key points where breaches commonly occur.

Table 1 provides a comprehensive contribution table summarizing the key aspects of the recent studies on Human–Elephant Conflict (HEC) in Wayanad.

2 Methodology

2.1 Study Area

The study was conducted in Wayanad district, located in northern Kerala, one of the ecologically sensitive biodiversity hotspots of the Western Ghats. The Wayanad district (11°27′–15°58′N, 75°47′–70°27′E) is nationally recognized for its rich biodiversity, tribal heritage, tourism potential, tropical crops, and human–wildlife conflict [5]. Covering a total area of 2,132 km^2, approximately 36.48% of Wayanad is under forest cover. The elevation ranges from 700 to 2,100 meters. The district shares borders with Kodagu and Mysore (Karnataka) to the north and northeast, Nilgiris (Tamil Nadu) to the southeast, Malappuram to the south, Kozhikode to the southwest, and Kannur to the northwest. Wayanad's forests are divided into three administrative units: North Wayanad Division, South Wayanad Division, and Wayanad Wildlife Sanctuary—the latter being a designated Wildlife Division Figure 1. The area's topographic diversity and climatic variation support multiple ecosystems that harbors globally important species such as the Asian elephant, tiger, and wild dog. Serving as the main watershed for the Kabini River, a key tributary of the Cauvery, Wayanad also sustains a human population of 817,420 with a density of 384 persons per km^2.

Table 1. Contribution Table of Recent Studies on Human–Elephant Conflict in Wayanad

Reference	Study Focus / Objective	Methodology / Data Used	Major Findings	Limitations / Gaps Identified	Contribution to HEC Research
(1)	To model and predict spatial and temporal patterns of Human–Elephant Interactions (HEIs) in Wayanad.	Ensemble Species Distribution Modelling (SDM) using environmental and anthropogenic variables.	Identified human population density, distance from protected areas, and temperature as key predictors of HEI risk; conflict likelihood was highest at 4–15 km from protected areas and 350 people/km^2. Seasonal patterns showed dry-season conflicts concentrated in Kidanganad, Nulpuzha, and Pulpalli.	Model-based predictions lacked field-level quantitative validation and real-time compensation or mitigation data.	Provided a landscape-level predictive model highlighting anthropogenic pressures as the dominant drivers of conflict.
(2)	To identify elephant habitat suitability and its relationship with conflict distribution in Wayanad Wildlife Sanctuary.	Geospatial analysis using Analytic Hierarchy Process (AHP) and validation with conflict occurrence data.	Identified Sultan Bathery as the most suitable elephant habitat, followed by Kurichiat (50% highest conflict) and Tholpetti. Demonstrated overlap between habitat suitability and high HEC zones.	Focused only within the sanctuary; did not incorporate socio-economic or compensation-related variables.	Introduced AHP-based habitat suitability mapping, aiding targeted conservation and conflict management planning.
(3)	To analyze spatial and temporal drivers of HEC and community perception in Wayanad.	Field-based socio-ecological approach integrating questionnaire surveys, compensation data, and elephant identification.	Conflicts peaked near forest edges during fruiting (May–Aug) and paddy (Jun–Dec) seasons; mostly male elephants active at night. Reported 32 human deaths and severe livelihood loss; ineffective mitigation and delayed compensation worsened conflict.	Did not provide quantitative landscape-scale assessment or evaluate structural mitigation systems.	Offered behavioural and temporal insights linking elephant activity patterns to crop seasonality and human responses.
(4)	To identify conservation challenges linked to elephant mortality and conflict escalation.	Qualitative assessment using field reports and official records.	Documented elephant deaths due to illegal electric fences and poisoning, emphasizing ethical and management failures in HEC zones.	Lacked quantitative data and spatial mapping of conflict trends.	Highlighted the ethical and mortality dimensions of HEC and need for improved conflict governance.
Present Study	To quantitatively analyse the intensity, spatial pattern, and economic implications of HEC in Wayanad and assess mitigation structure efficiency.	Empirical analysis using compensation claims (2018–2023), spatial mapping of mitigation structures, and field verification.	Recorded 9,989 HEC incidents, with 94.69% crop loss, 18 human deaths, and ₹690.01 lakhs (US$ 827,843.97) in compensation. Evaluated 644.35 km of solar fencing, 347.99 km of trenches, 22 km of walls, and 13.5 km of hanging fences, identifying breach-prone areas and underreporting.	Need for integration of elephant movement data and socio-behavioural parameters for predictive modelling.	Provides the first quantitative, landscape-level evaluation of HEC intensity, financial burden, and mitigation structure effectiveness, filling the critical data gap noted by previous studies.

The district's communities have distinct cultural identities, with many depending directly on forest resources for subsistence. The major crops grown here are coffee, pepper, tea and paddy. Crop depredation by Asian elephants has been identified as a prominent concern in Wayanad.

2.2 Data Collection

Research has utilized farmers' compensation claims for damages caused by wildlife to examine the trends and severity of human-elephant conflict across different periods and regions in India[10]. In the present study, we gathered data on human-elephant conflict incidents from forest department compensation records spanning five years, specifically from January 2018 to November 23. In addition, we also collected details on the prevailing mitigation structures in Wayanad, which serve to hinder the access of elephants to human settlements and identified key points where breaches commonly occur.

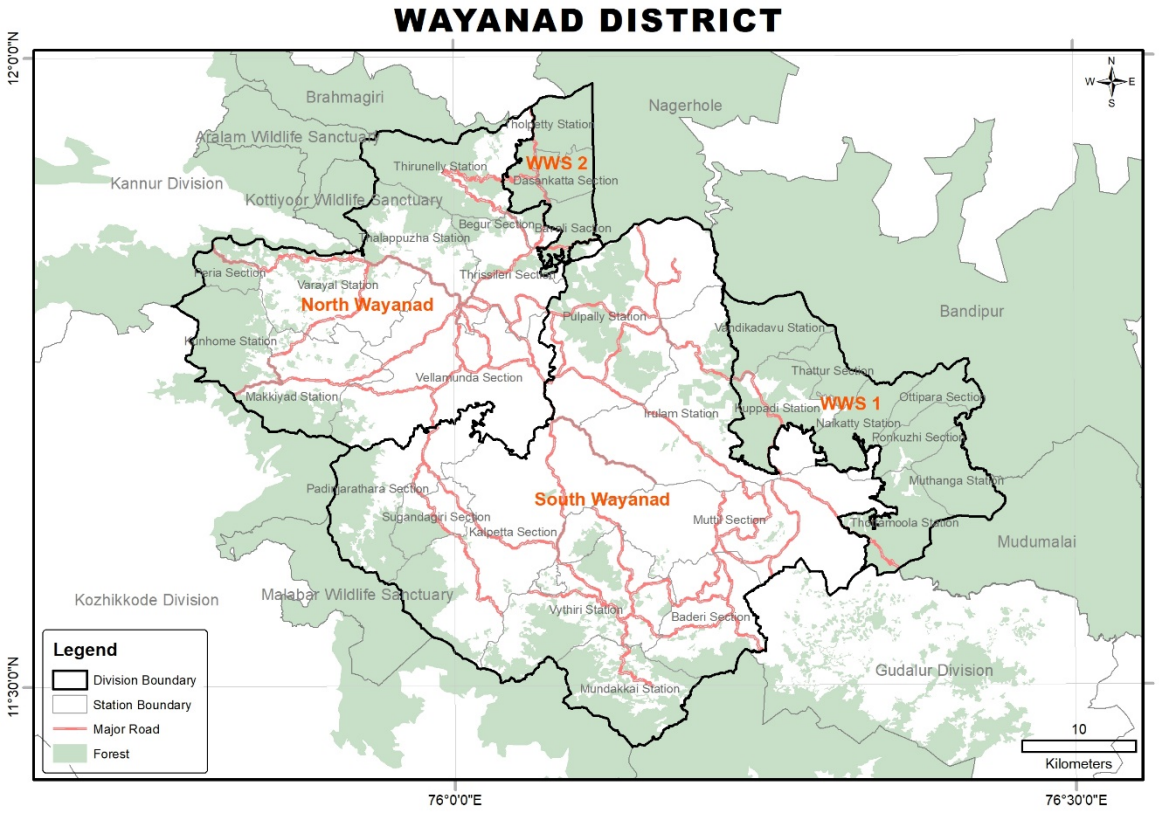

Fig 1. Map of the study area with adjacent protected area

3 Results & Discussion

3.1 Incidences of human-elephant conflict in Wayanad

Wayanad stands out as a significant region grappling with the challenge of human-wildlife conflict in India. The presence of wild animals poses a substantial threat to human settlements, agricultural fields, and domestic animals, causing considerable damage. Given that Wayanad is predominantly an agricultural district with a large population of farmers residing close to forested areas, the incidence of man-animal conflict is notably high in this region.

Over the last five years (2018-2023), Wayanad has recorded a total of 9989 instances of Human-Elephant conflict. Among these, 94.69% (n=9459) involved crop loss due to Elephant depredation. Property damage accounted for approximately 3.16% (n=316), followed by house damage at 1.28% (n=128) of the overall conflicts during this period. Human injuries constituted 0.580% (n=58), human deaths were at 0.180% (n=18), and 0.10% (n=10) of the conflict incidences involved the loss of cattle due

to Elephant attacks Figure 2. Elephants in Wayanad primarily target major crops like paddy banana, pepper, coconut, coffee, jackfruit, and areca nut. Property damage encompasses harm to vehicles, commercial structures, livestock shelters, as well as gates and walls of buildings. The loss of cattle during elephant attacks is primarily attributed to injuries sustained by the livestock when elephants assault their shelters. Out of the 9989 conflict incidences reported in Wayanad, South Wayanad Division has reported 4346 (43.50%) incidences of human-elephant conflict in the past five years followed by Wayanad Wildlife Division with 3500 (35.03%) incidences. North Wayanad Division has reported 2143 (21.45%).

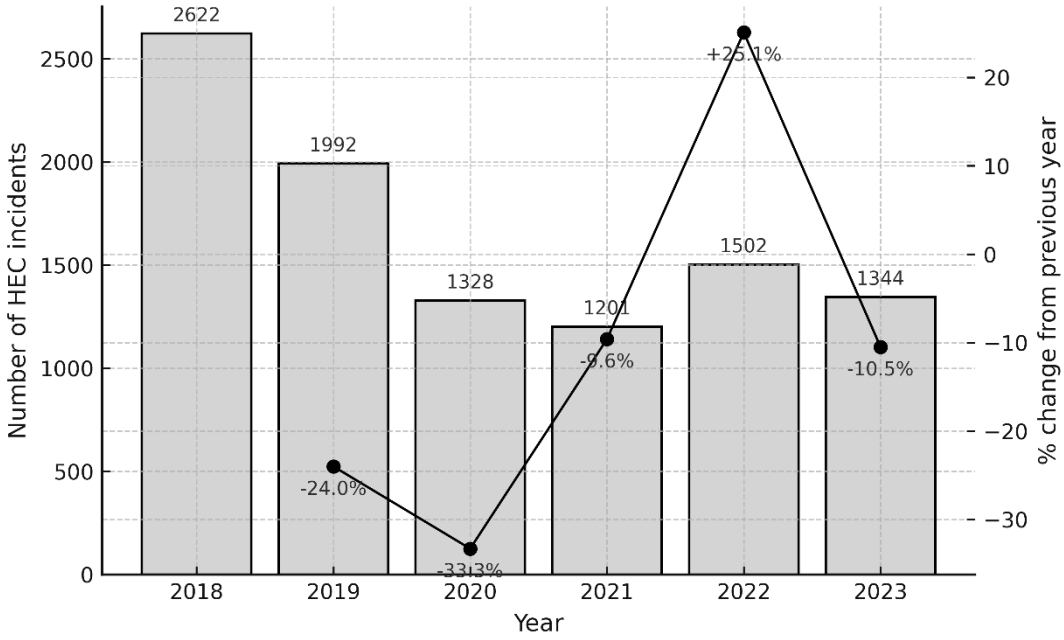

Fig 2. Incidences of HEC reported in Wayanad in 5 years

3.2 Ex – gratia Payments in Wayanad

Over five years in Wayanad, a total sum of 690.012 lakhs (US$ 827,843.97) was given as compensation for Human-Elephant conflict Figure 3. The majority of this amount was allocated for compensating crop damage, as elephants raid crops throughout all months and seasons in Wayanad. Specifically, 511.7904 lakhs (74.17%) were paid for crop loss, followed by compensation for human death, amounting to 130 lakhs (18.84%). An amount of 19.62846 lakhs (2.85%) was paid for property damage, 13.90355 lakhs (2.01%) for human injury, 12.02964 lakhs (1.74%) for house damage and 2.66 lakhs (0.39%) was paid for cattle loss. A total of 18 people lost their lives in Wayanad due to the Elephant attack between 2018 and 2023.

3.3 Existing mitigation structures to prevent human-elephant conflict in Wayanad

The Kerala Forest Department has been employing diverse strategies to alleviate the Human-Wildlife Conflict in Wayanad. Key measures include the installation of physical barriers such as solar fencing, Elephant-proof trench, Elephant-proof wall, Hanging power fence, and bio fencing. In addition to these structural interventions, successful initiatives involve the deployment of rapid response team and Elephant scaring watchers.

In Wayanad, Solar fencing has been installed across a stretch of 644.35 km, in which 363.55 km of fencing effectively operational. Additionally, Elephant Proof Trench (EPT) and Elephant Proof Wall, each spanning 347.99 km and 22 km, respectively, have been constructed in the region. The Elephant Proof Wall typically stands at a height of 2 meters. A recent development involves the adoption of hanging solar power fences, emerging as the most effective mitigation structure to prevent elephants from crossing into human habitations. The feasibility of installing this structure depends on the topography of the area, with steep slopes presenting challenges. Currently, South Wayanad and Wayanad Wildlife Division have constructed a hanging solar fence, covering a distance of 13.5 km. Additionally, there is an existing 10 km rail fencing in the Kurichiat Range

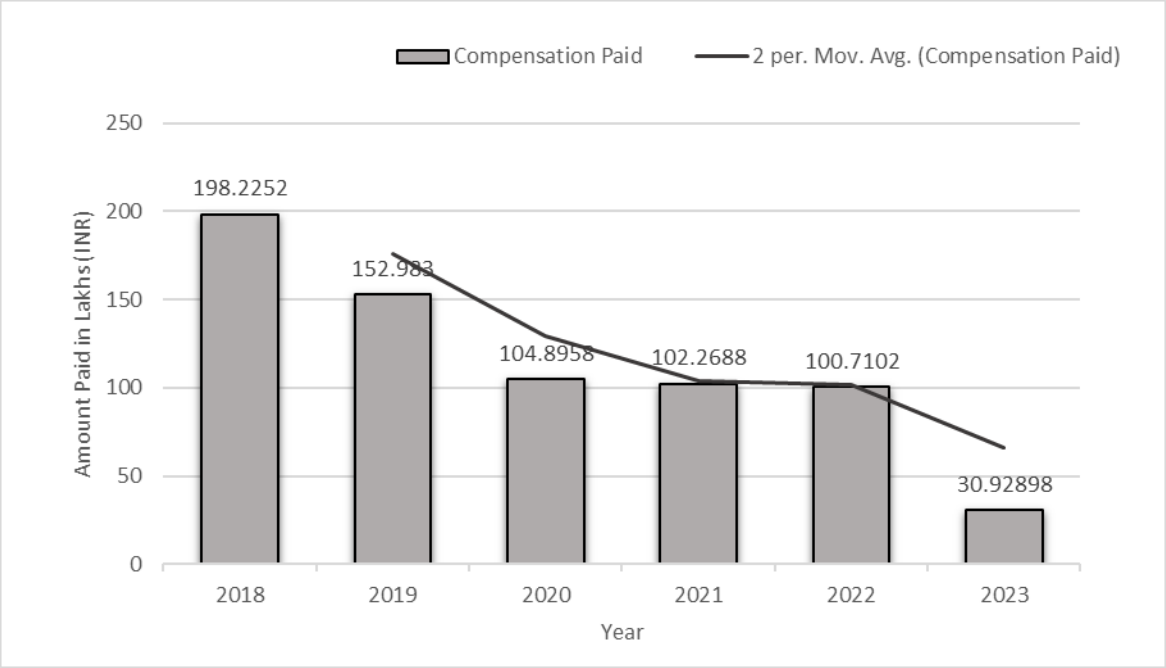

Fig 3. Compensation paid (In lakhs) in Wayanad due to HEC in 5 years

of Wayanad Wildlife Sanctuary Figure 4. Apart from these structures, Elephant scaring watchers are also engaged in conflict prone areas of the district to drive away Elephants from human inhabitations.

Previous research in Wayanad has primarily focused on modeling the spatial and ecological drivers of Human–Elephant Conflict (HEC), while the present study provides a quantitative, ground-based assessment of HEC intensity, compensation dynamics, and the functionality of mitigation structures across administrative divisions. Together, these studies contribute complementary insights into understanding and managing HEC in the Wayanad landscape. Our study findings indicate that human-elephant conflict is prevalent and significant in Wayanad, posing severe direct and indirect repercussions for both the local community and elephants. Among the various species in the landscape, elephants are the most challenging, with crop raiding being the primary source of conflict. This significantly impacts livelihood and household food security in the region [6]. The study area likely has an underreported count of conflict incidents, primarily due to farmers' hesitancy in applying for compensation because of the difficulty in the process of claiming compensation. Additionally, those lacking land records are ineligible to apply for compensation. Furthermore, the low payment amounts provided for commonly raided crops, such as paddy, coconut and banana contribute to underreporting. Moreover, the absence of compensation for non-commercial crops like mango or jackfruit further adds to the discrepancy in reported incidents [6]. Wayanad is an agrarian district where most people depend on agriculture for their livelihood. The Farmers endure substantial economic setbacks due to animal-related issues, leading them to discontinue farming and necessitating involvement in alternative non-agricultural pursuits. It affects the food security, livelihoods, and mental well-being of the people. Human–Elephant conflict in Wayanad is found to be stable in recent years. This can be assumed to be because of the effectiveness of various mitigation structures adopted by the forest department as well as local farmers to restrict the entry of Elephants into human habitations. However, none of these preventive measures or the compensation amounts proved sufficient to address the severity of the problem. Thus, a landscape-level approach is necessary to study the reasons and trends of Human- Wildlife conflict in Wayanad integrating behaviour and ecology at the individual level for effective conflict management in the future. Implementation of early warning systems to prevent conflicts and avoid fatal encounters can be considered. Examples include the use of technologies like the Wireless Integrated Sensor Network (WISN) based boundary intelligence system, incorporating multiple sensors for elephant detection, as well as automatic acoustic and visual detection methods [11]. The print and visual media, including social media platforms, play a significant role in the handling of human-wildlife conflict, influenced by how the media frames the conflict. The media holds a crucial position in shaping people's tolerance levels in human-wildlife conflict situations.

Recently, there has been a decline in people's tolerance towards wildlife management and conflict resolution. The media also brings attention to incidents of human-wildlife conflict. However, there has been no examination of how the media

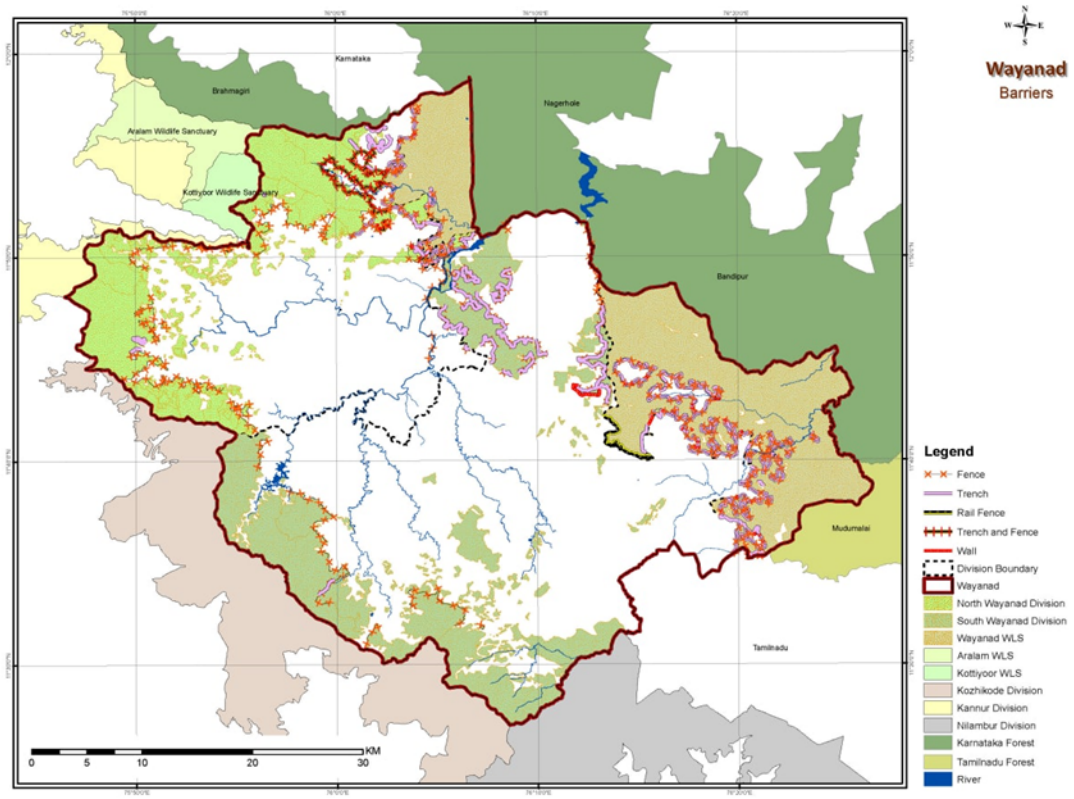

Fig 4. Map showing various existing mitigation structures in Wayanad

frames conflicts related to wildlife conservation and management [12]. Providing training to media professionals for ethical and scientifically accurate reporting of facts concerning human-wildlife conflict and wildlife conservation is essential. Additionally, training politicians in wildlife conservation and management is beneficial for effectively communicating the importance of wildlife conservation to local communities and addressing conflict incidents. Establishing a primary response team in conflict hotspots is essential to communicating conflict-related information and collaborating with forest officials. This team should work in conjunction with the Vana Samrakshana Samitis (VSS) in each area and must undergo comprehensive training and be equipped with protective gear. Additionally, habitat restoration activities, such as vayal management and removing invasive alien species, hold significant importance in Wayanad. Currently, *Senna spectabilis* has infested approximately 121 sq. km in the Wayanad Wildlife Sanctuary, particularly in the Muthanga and Tholpetty range. Lantana is the predominant weed in all eucalyptus plantations. The extensive weed infestation in natural forests suppresses natural regeneration and contributes to the deterioration of site qualities, intensifying human-wildlife conflict. The willingness of people to tolerate elephants is a crucial factor in any strategy for mitigation and elephant conservation [11]. Therefore, in addition to well- constructed and regularly maintained barriers, implementing fair financial compensation mechanisms for crop or property loss can enhance coexistence.

We observed an increasing trend in reported conflict incidences from 2018 to 2020, followed by a relatively stable graph with slight fluctuations between 2020 and 2023. This trend is attributed to the effectiveness of mitigation structures preventing wild elephants from entering human habitats. The Forest department staff and Elephant scaring watchers efficiently deter elephants from approaching human settlements. Additionally, local farmers in Wayanad predominantly employ a variety of cost-effective, non-lethal strategies for mitigating conflicts such as vocalizing, using tin cans and drums, throwing stones, and setting fires near farmlands as passive barriers. Nevertheless, one of the oldest and most effective approaches to reducing conflict involves farmers guarding their crops throughout the night. Currently, an approach by the forest department to reduce conflict is capturing persistent crop raiders and keeping them in captivity. People remain vigilant and actively repel approaching elephants using spotlights, firecrackers, and vocal warnings. On the other hand, we also observed that the conflict incidences in Wayanad are underreported due to the difficulty in the process of claiming and the delay in getting compensation. Additionally, those lacking land records are ineligible to apply for compensation. Furthermore, the low payment amounts provided for commonly

raided crops, such as paddy, coconut and banana contribute to underreporting. Commercial crops like Mango and Jackfruit are raided by Elephants in the season but are underreported due to the absence of compensation for such crops. The compensation amount given for the human-elephant conflict in Wayanad marked a sharp decline over the last five years, even though the conflict incidences have not marked such a sharp decline. This can be due to the rejection of many applications after detailed field and document verification by the forest department officials due to the absence of land records, absence of compensation for commercial crops such as jackfruit and mango, and failure to produce necessary documents.

The compensation awarded for the year 2023 is notably low due to insufficient funds, and there are hundreds of pending compensation applications, as indicated by forest department data. The disbursement of this amount to farmers is contingent upon the arrival of government funds allocated for compensation. In the case of compensation for human death, an immediate loan is provided from the Forest Development Agency (FDA) fund of the respective division.

4 Conclusion

The analysis of Human–Elephant Conflict (HEC) in Wayanad between 2018 and 2023 reveals the persistent and multidimensional nature of the issue, deeply affecting both human livelihoods and elephant conservation. A total of 9,989 conflict incidents were recorded during this five-year period, with 94.69% (n=9,459) involving crop depredation, followed by property damage (3.16%, n=316) and house damage (1.28%, n=128). Human injuries (0.58%, n=58) and deaths (0.18%, n=18) indicate the severity of human safety risks, while livestock loss (0.10%, n=10) underscores the broader livelihood implications. The South Wayanad Division reported the highest conflict incidence (43.50%), followed by Wayanad Wildlife Division (35.03%) and North Wayanad Division (21.45%), confirming the spatial heterogeneity of conflict intensity across the district.

Financially, over ₹690.01 lakhs (US$ 827,843.97) were disbursed as ex-gratia payments, primarily for crop loss (₹511.79 lakhs; 74.17%) and human fatalities (₹130 lakhs; 18.84%), demonstrating the substantial economic burden of conflict. Despite significant expenditure, delays in compensation, exclusion of landless farmers, and lack of coverage for non-commercial crops such as jackfruit and mango have contributed to chronic underreporting and farmer dissatisfaction.

The Kerala Forest Department has implemented a wide array of physical and operational mitigation measures, including 644.35 km of solar fencing (with 363.55 km operational), 347.99 km of elephant-proof trenches, 22 km of elephant-proof walls, and 13.5 km of hanging solar fences, complemented by rapid response teams and elephant scaring watchers. However, despite these extensive interventions, conflict incidents remain significant, suggesting that current mitigation strategies, though effective locally, are insufficient for long-term coexistence.

The persistence of HEC in Wayanad is influenced by ecological, socio-economic, and institutional factors. Habitat degradation, invasive species such as *Senna spectabilis* (covering 121 km^2) and *Lantana camara*, and agricultural expansion continue to push elephants toward human landscapes. The findings indicate a moderate stabilization in conflict frequency post-2020, likely linked to improved mitigation infrastructure, yet compensation disbursement has sharply declined due to financial constraints and procedural challenges.

The management of Human–elephant conflict must shift toward landscape-scale, data-driven planning that integrate elephant movement ecology, spatial risk profiling, and human behavioural dynamics. Investments in early warning and detection systems, coupled with scientifically engineered multi-layered barriers, are essential for minimizing high-risk interactions. Strengthening community-centered rapid response mechanisms through Vana Samrakshana Samitis (VSS), along with capacity building of frontline personnel, local leaders, and community responders such as primary response teams can enhance field-level preparedness. Strategic communication frameworks, including responsible media engagement and conflict-response training, are critical for improving public trust and tolerance.

Long-term coexistence requires habitat management eco-restoration, transparent compensation delivery, livelihood diversification, habitat connectivity enhancement, and where applicable, participatory and justice-ensured voluntary relocation. Management actions involving capture and relocation of identified habitual conflict individuals can be considered adhering to strict scientific, ethical, and welfare safeguards. Inclusive governance that prioritizes community participation, institutional accountability, and behaviour-informed adaptive management approaches can enhance tolerance and promote sustainable human–elephant coexistence.

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