



REVIEW ARTICLE

Human-wildlife conflict in South Indian agriculture: Causes, impacts and mitigation strategies

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Abstract

Human-wildlife conflict is a persistent and widespread issue affecting rural areas in developed and developing nations and urban outskirts. These conflicts lead to significant financial losses, including reduced crop yields, property damage and adverse effects on farmers' livelihoods. This study reviewed incidents, reports and research from the past 20 years, utilizing web-based search engines like Scopus and Google Scholar. The focus was on human-wildlife conflict in agriculture, particularly in South India's biogeographic regions. This article explores the causes and consequences of these conflicts, analyzing farmers' vulnerability and resilience and examining the mitigation strategies employed in the past and present. Tamil Nadu, a state in South India alone, witnessed 36 human fatalities caused by elephants and seven by gaurs, 2560 crop damages and 81 household property damages done by both animals between 2016 and 2017. Most studies on human-wildlife conflict in India are region-specific or focused on individual species, often neglecting agriculture. This study bridges that gap by examining South India's agricultural sector and the harmful interactions between humans and wildlife, particularly their impact on farmers' livelihoods. Additionally, the article reviews the efficacy and limitations of the strategies implemented to address the issue. The findings provide insights into the driving factors, consequences and potential mitigation strategies to reduce these conflicts. It emphasizes that the well-being of wildlife and the goals of agriculture are not inherently contradictory. Encouraging stakeholders to adopt sustainable, economical and wildlife-friendly solutions can foster peaceful coexistence. Addressing human and wildlife needs, this approach aims to reduce conflicts, secure farmer livelihoods and promote conservation efforts. The study explores potential strategies for mitigating human-wildlife conflicts while highlighting the importance of a sustainable, balanced approach that ensures the coexistence of wildlife conservation and agricultural activities.

Keywords: agriculture and crop losses; farmers' vulnerability; human-wildlife conflict; mitigation strategies; South India

Introduction

Any encounter between humans and wildlife that causes suffering to humans or wild animals, in addition to destroying property and crops, is called human-wildlife conflict. Human-wildlife conflict has emerged as a prevalent occurrence on a global scale, happening in rural areas and on the outer edges of towns in developed and developing nations (1). Human-wildlife conflict (HWC) is a worldwide problem that will only grow as humans and wildlife share growing numbers of landscapes (2). Human-wildlife conflict is on the rise globally due to several other issues, including the growing human population, more significant pressure on natural assets and land and changes in the climate (3, 4).

There are more fallow lands as a consequence of discouraged cultivation and households losing their food supply due to crops being eaten by wildlife. Fallow fields near human populations serve as shelters for wild animals, exacerbating the prevalence of human-wildlife conflict (HWC) and thus reducing the production of food (5). Natural wildlife habitat is lost as human settlements grow into areas used by wild animals. Wild animals search for other kinds of nutrition as their natural prey and food sources become less accessible and their habitat shrinks. Conflicts between humans and animals arise when new feed supplies produced by humans next to the forest floor entice wildlife to move willingly to the non-forest area (6). Large predators' propensity for roaming exposes them to impact from edges

outside the designated regions, like wildlife reserves, which may result in conflicts between humans and other animals and pose a risk to livestock (7). Attacks significantly impact peoples' food security, means of subsistence and psychological wellness of human beings and livestock, increasing crop raiding incidence (8). Disputes over valuable resources often occur due to the shared living spaces of humans and elephants (9) (Fig. 1).

The Western Ghats, located in southern India between 1920 and 1990, experienced severe deforestation, with vast forested areas cleared for agriculture, leading to an estimated 40 % habitat loss. The expansion of monoculture plantations, mainly tea and coffee, further intensified habitat fragmentation by reducing the size of forest patches by 80 % while increasing their number by 400 %. Developmental activities such as hydroelectric projects, mining and resource extraction have significantly altered the landscape. Large mammals in the region face growing threats from illegal activities, including poaching through snaring, electrocution and poisoning of livestock carcasses (10, 11). Another ongoing challenge is the unauthorized grazing of livestock within protected areas by herders (12). The primary species frequently involved in human-wildlife conflicts in this region include the Asian elephant, gaur, wild pig, leopard, tiger and sloth bear. These are the primary reasons for increased conflicts, particularly in South India.

Human-wildlife conflict (HWC) is a global concern, though its patterns differ based on ecological, socio-economic and cultural factors. In South India, conflicts primarily involve elephants (*Elephas maximus*), leopards (*Panthera pardus*) and wild boars (*Sus scrofa*), leading to crop destruction, livestock predation and occasional human fatalities (13). Similar challenges are observed in Africa, where elephants and lions (*Panthera leo*) frequently raid farms and attack livestock, often resulting in retaliatory killings (14, 15). Meanwhile, in Southeast Asia, extensive deforestation has heightened conflicts with tigers (*Panthera tigris*) and primates, which increasingly enter human settlements in search of food (16). Despite regional variations, common issues include habitat destruction driven by agricultural expansion, climate-induced shifts in wildlife movement and economic hardships for rural populations (17). However, South India's HWC is uniquely influenced by cultural and religious beliefs as many communities revere elephants and leopards, shaping conservation initiatives. In contrast, African conflicts are characterized by large-scale livestock losses, requiring stricter anti-poaching policies and community-based deterrents. In Southeast Asia, urbanization and deforestation intensify human-wildlife conflicts, necessitating innovative land-use planning (18). Global mitigation strategies could strengthen South India's conflict resolution efforts, such as beehive fences in Africa and eco-tourism incentives in Southeast Asia (19, 20). Integrating

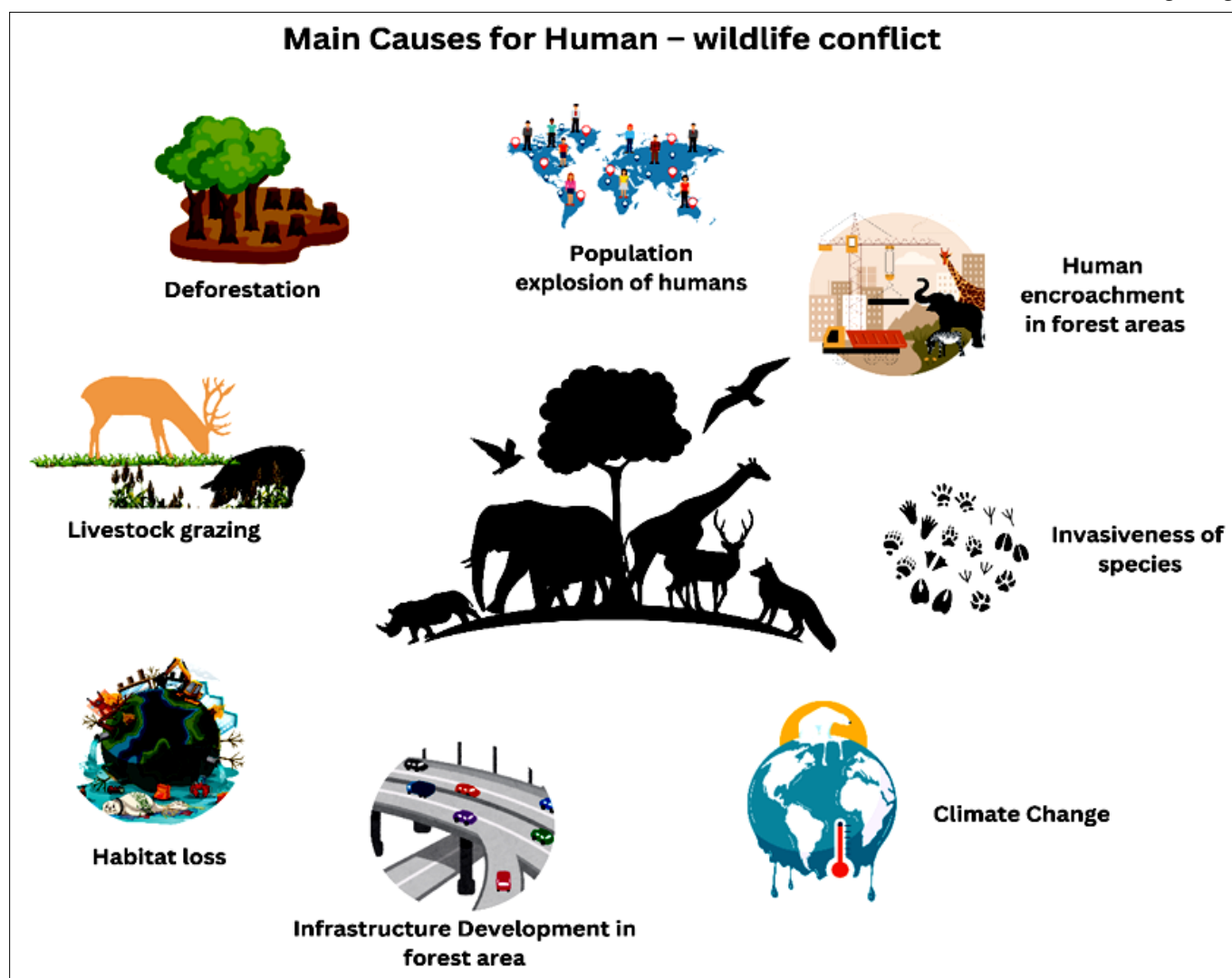


Fig. 1. Main causes for human-wildlife conflict.

localized approaches like community-driven conservation and technology-based wildlife monitoring can further enhance sustainable management.

Forest regeneration on abandoned agricultural land expanded wildlife habitats, enabling wild animals to come within reach of human settlements, which increased the likelihood of HWC events (21). Various preventive and mitigation strategies have been suggested, developed and adopted due to growing knowledge regarding wildlife behaviour and the spatial-temporal variations in human-wildlife conflict (22, 23, 24, 25). Many crop-raiding animal mitigation measures have been developed by farmers (26). Conversely, small-scale farmers in low-income countries are primarily restricted to labour-intensive crop safeguarding, a typical HWC mitigation approach and traditional and inexpensive technological solutions such as hunting, frightening and erecting rock or timber fences (26). Fencing and other preventative measures are examples of pre-conflict mitigation, whereas compensation for animal losses is an example of post-conflict mitigation. Both methods may reduce confrontations between farmers possessing livestock and wild animals. India and several African nations have employed the latter strategy (27).

Any interactions between people and wildlife that negatively impact the farming community are included in this article's description of human-wildlife conflict. The majority of HWC studies conducted in India are either region - or single-species-focused and do not take agriculture into account. To complete the current study, a thorough review of South India's agricultural sectors, the detrimental interactions between humans and wildlife and how these interactions affect the farmers' ability to secure livelihoods were taken for the study. In addition, this article discusses the causes, consequences, efficacy and drawbacks of the strategies used to deal with the problem.

Materials and Methods

The literature reviewed was from peer-reviewed publications, reports and newspaper articles across a vast database. The search focused on pertinent literature from previously recorded incidents, reports, case studies, research and review publications and the inclusion and exclusion criteria are mentioned in (Table 1). Literature about human-wildlife conflict in agriculture, its associated causes and consequences and mitigation strategies were acquired using web-based search engines such as Scopus and Google Scholar. The review prioritized the past 20 years' publication of studies from 2004 to 2024 to ensure empirical evidence from previous and present events occurred. The primary field data were included to validate findings from

published literature. Combination of relevant keywords such as "Human-wildlife conflict" AND "Agriculture", "Human-wildlife conflict" AND "South India", "Human-wildlife conflict" AND "Crop raiding", "Human-wildlife conflict" AND "Crop losses", "Human-wildlife conflict" and "Mitigation strategies" were used (Table 2). The key term used in this study is mentioned in Table 2. Studies were confined mainly to South India, India and a few around-the-world searches were conducted using key terms based on biogeographic zones, states and nation names. The first screening phase focused on collecting review papers related to Human-Wildlife conflict to establish a solid foundation for the analysis. A total of 603 articles related to HWC were found, including 154 peer-reviewed journals. For this review paper, 107 papers from 56 peer-reviewed journals, reports, newspaper articles and websites were used for the study. The acquired materials were thoroughly analyzed for key conflict animals, the agricultural economic loss caused by different conflict occurrences and the measures to prevent them. The study mainly focused on human-wildlife conflicts associated with agriculture.

Indian scenario

India has a vast climatic and topographic range, making it a mega-diverse nation. Despite making up just 2.4 % of our planets' geographical area, it is home to about 8 % of the worlds' known species, comprising 45000 plants and 91000 animal species (36). 17.5 % of the global population resides in India. India had 1210.6 million people living there as of March 2011 (37). Negative interactions among people and big mammals are expected to worsen due to the countrys' high population density (382 people/km²), especially in rural regions (38, 39). According to the study, the wildlife protection group generally believes that the nations' protected areas do not provide adequate water, food, or even a place to support thriving populations of elephants despite herds extending as far as 1000 km² (40). In India, elephants kill roughly 400 individuals on an annual basis on average and approximately 100 elephants get killed annually in retribution. Moreover, they typically have a yearly impact on crops spanning 0.8 to 1 million ha, affecting the livelihoods of a minimum of 500000 farmers (41). The primary causes or motives for the conflicts among humans and animals across India are habitat degradation, species invasion or succession resulting in the decline of herbivorous grazing land, scarcity of carnivore prey, depletion of forest water sources, raised cultivation of livestock and agricultural expansion resulting in exorbitant grazing, disputes among wild and domesticated animals and development-related initiatives (42).

Table 1. Inclusion and exclusion criteria

Parameters	Inclusion criteria	Exclusion criteria
Study time frame	Published between 2004-2024	Publications before 2004
Literatures' searched	Peer-reviewed journals, reports and credible newspaper articles	Duplicates or non-peer-reviewed
Study topic	Focus on human-wildlife conflicts	Not related to human-wildlife conflicts
Study topic	Studies related to agriculture	Studies unrelated to agriculture
Research locations	Relevant geographic focus (South India, India and global cases)	Studies with insufficient data or anecdotal evidence
Study language	English language sources	Non-English language sources

Table 2. Main terms or concepts associated with human-wildlife conflict

S. No.	References	Associated terms with human wildlife conflict	Explanation
1.	28	Crop Raiding	The term "crop raiding" refers to wild animals causing damage to human-cultivated crops by feeding on them or trampling them
2.	29	Deforestation	Deforestation is another significant driver of human-wildlife conflict in. It is primarily caused by tree cutting to expand farmland, collect firewood and provide grazing areas for livestock
3.	30	Habitat loss / Habitat encroachment	Habitat loss plays a significant role in human-wildlife conflict, occurring when natural ecosystems are disrupted or destroyed due to human activities such as agriculture, urban development, or logging. It results in habitat loss and degradation
4.	31	Invasiveness of species	The introduction of non -native species which disturb the native ecosystems acting as a threat to indigenous wildlife results in human-wildlife conflict
5.	32	Livelihood loss	The increasing human-wildlife conflicts in rural areas, fueled by growing human populations encroaching on natural habitats, severely affect human safety and livelihoods. These conflicts arise when wildlife negatively impacts agriculture, fishing, or livestock activities, decreasing income and resources for agricultural and related communities
6.	33	Translocation	Translocations of problematic species typically focus on the species that cause problems to crops or humans and involve relocating a small number of individuals
7.	34	Compensation	The monetary assistance or reimbursement provided to the communities or the individuals who had experienced human-wildlife conflict in the form of losses in crop damage or livestock attacks is termed as compensation
8.	35	Livestock predation	Livestock predation linked to human-wildlife conflict refers to wild animals attacking and killing domesticated animals such as cattle, sheep and poultry raised by farmers. Both crop foraging and livestock predation harm the local communities and the individuals' perception towards wildlife conservation efforts

The scenario is likely to worsen due to climate changes' consequences. Human-wildlife conflict has been primarily caused by the expanding human population and their integration with existing wildlife regions (43). Among the most deadly creatures that cause significant harm to people are tigers, leopards, elephants, monkeys and wild

boars. Human-wildlife conflict is ubiquitous in India and takes many different forms. The most common type of conflict between humans and wildlife in the nation is crop raiding, which includes the threat posed by monkeys in urban centres, crop raiding through mammals and wild boars and elephant devastation (44) (Fig. 2).

**Fig. 2.** Consequences of human-wildlife conflict.

There have been reports of crop raiding by wildlife from multiple protected regions in India, a significant source of conflict between humans and wildlife. The breadth of this issue is also increasing due to increased worries about habitat destruction, forest fragmentation and agricultural development (45). Crop loss was correlated with being closer to the conservation area and having more cropping periods annually. Livestock grazing within the conservation area and their closeness to it were linked to livestock losses (46). The Wildlife Protection Act of 1972 gave the species an elevated degree of protection, partially responsible for driving the rise in conflict. Another factor is that locals lack the power to control elephants on farmlands (47). Studies have employed compensation claims to farmers for losses resulting from wildlife devastation to analyze the trends and severity of conflict between humans and elephants in India across different periods and spatial scales (21, 48). Therefore, implementing systems for equitable financial compensation for crop or property damage, in addition to well-built and frequently checked barriers, can enhance cohabitation (49). The possibility of conflict among humans, animals and livestock in communities rises with the change of area for arable agriculture and the spread of alien tree species. A "green corridor" for terrestrial wildlife movement, a "blue corridor" for aquatic wildlife motion and viable human livelihoods can all coexist when the environment conversion is stopped and reversed in specific locations, potentially reducing human-wildlife conflict. It can be accomplished by managing exotic species, regulating land utilization in a community-driven, updated and cooperative manner and regenerating the areas' water reserves (50).

Therefore, a decentralized approach or enhancing local involvement in the decision-making process for governing forests in the region is recommended. Effective conflict mitigation depends on offering chances to those in charge of forest administration (51). Other approaches to addressing the issue have been created as a consequence of innovations in technology, including early identification and caution, radio collaring problematic elephants to monitor their movements, cognitive IoT systems with intelligence approaches and border intellect systems utilizing Wireless Combined Sensing Networks (52, 53). Sociologists contend that, regrettably, this isn't the case and that to manage human-elephant harmony, social scientific skills effectively must be integrated with conservation biology using an interdisciplinary basis (54).

Human-wildlife conflict from the South Indian context

The southern portion of the Deccan Plateau in the Indian subcontinent, which includes the Indian states of Andhra Pradesh, Telangana, Karnataka, Kerala and Tamil Nadu, in addition to the union territories of Lakshadweep and Puducherry, is referred to as South India, or peninsular India (Fig. 3). These regions account for 19.31 % of the nations' total area (635780 km² or 245480 mi²) and 20 % of its human population. The Western and Eastern Ghats constitute two mountain ranges surrounding the plateau heartland, contributing to the regions' varied topography. Designated as a UNESCO World Heritage Site, the Western Ghats represent some of the globes' "hottest hotspots" for ecological richness. The hills lie in the heart of the Western Ghats-Sri Lanka biodiversity hotspot and the UNESCO Nigiri Biosphere Reserve (55). Among the Asian elephants

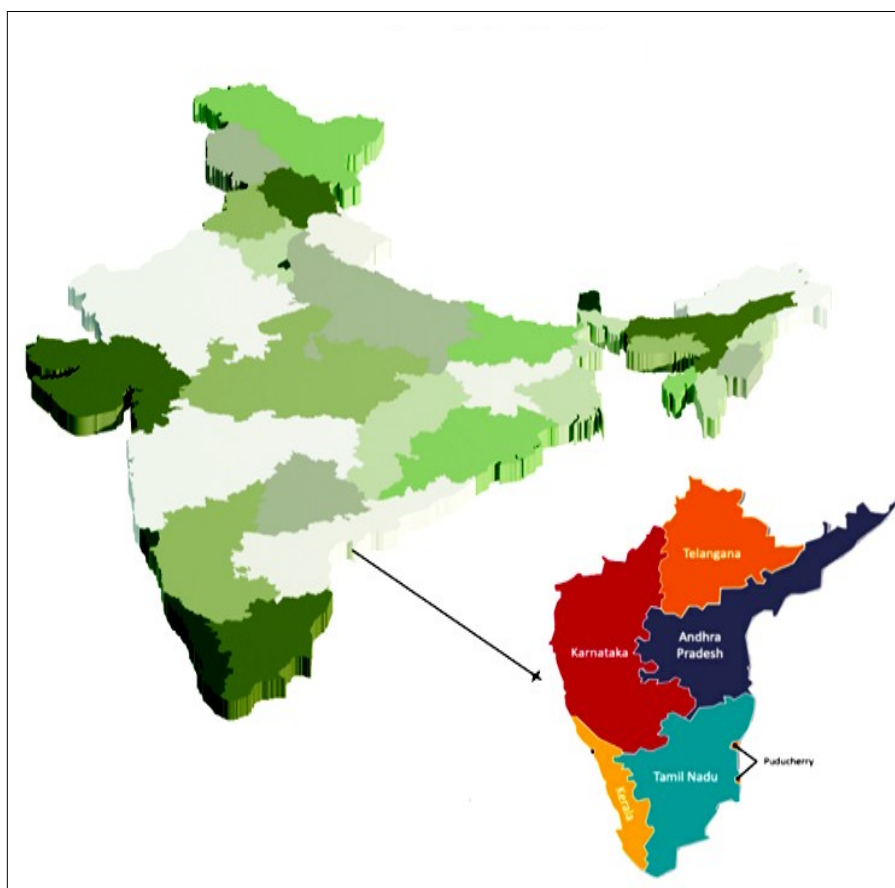


Fig. 3. South India map.

living in the wild, around 25 % are found in the Western Ghats biodiversity hotspot. At least 10000 elephants live in the Ghats, spread throughout four terrain configurations (56). The world's most significant populations of "endangered" Asiatic elephants (more than 50 %) and "vulnerable" gaurs (more than 85 %) are found in India, where they frequently coexist with indigenous communities within their territory (57). Negative human-large mammal interactions are anticipated to worsen due to the country's high population density, even in rural regions; such interactions include the decline of food resources, the extraction of biomass that sustains regional livelihoods, deterioration of habitat from extending agricultural development and the dissemination of invasive plants (58, 59). One of India's most significant elephant and gaur protection areas is the Western and Eastern Ghats Part of Tamil Nadu (WEGPTN) in southern India.

According to earlier research, elephant conservation in dispersed regions may be facilitated by the significant impact of the Western Ghats agricultural areas on migration and meta-population trends (60, 61). Studies have shown that elephants occupy about 60 % of their habitat outside protection areas (62). Elephant conflict occurrence in the vicinity of India's Nagarahole National Park was found to be non-linearly correlated with factors like population density, the number of livestock and the size of the hamlet (21). There might be other explanations underlying this diversity in conflict throughout the terrain. Initially relative to the western side, the eastern forest sections contained more non-forest features, including agricultural land and human habitation sites. Elephants may come into touch with agriculture in significant populations during their periodic travels due to habitat degradation and disintegration, extending the forest areas' outer limits for farming (63). Second, as noted elsewhere, elephant crop raiding may become increasingly prevalent in this area due to increased human activities that harm the eastern side of the forests, including cattle grazing and firewood gathering. In Southern India, for instance, the natural pastures that were essential habitats for reducing or preventing human-mega-herbivore conflict have been substituted with growing coffee and tea estates (64).

The spreading of lantana (*Lantana camara*), wattle (*Acacia sp.*), pine (*Pinus sp.*), as well as eucalyptus (*Eucalyptus globulus*) through native grasslands alongside ecosystems has decreased the natural food accessibility for these mega-herbivores within the southernmost distribution spans for Asiatic elephant (*Elephas maximus*) and gaur (*Bos gaurus*) in India (58). The Western Ghats are among the world's hotspots for biodiversity because of their exceptional ecological endemism and variety. The Western Ghats are home to an estimated 10000 wild Asian elephants, according to census data from 2002 to 2005 and 2007 to 2010. Of those, about 5900 are residents of the Nilgiri Biosphere Reserve, established to preserve biodiversity (56). Previous studies have suggested that elephants may travel periodically across the Kodagu

districts' eastern and western regions, traversing the areas' coffee fields and human settlements (61). Furthermore, specific elephants seek sanctuary and food year-round in coffee estates, the areas encircling acacia, eucalyptus plantations and patches of forests (65, 66). Nevertheless, insufficient research has been done on the movement patterns of elephants across Kodagu Districts' agroforestry areas to mark these areas accurately (67).

In the Western Ghats, the Nagarahole Tiger Reserve, the Bandipur and Mudumalai Tiger Reserves and the Wayanad Wildlife Sanctuaries comprise a significant continuous forest region (21). At the Bhadra Tiger reserve, each household lost roughly 11 % of its yearly production of grains (0.82 tonnes per family) to elephants and 12 % (0.9 head) of their entire holdings to big felines each year. The compensations covered only 5 % of the animal loss and 14 % of crop damage and the claims' adjudication procedure took a long time. In addition, creative livestock and crop insurance programs must be tried out as substitutes for compensation (68). Power fences sometimes block animals from travelling along their natural paths (69). According to the research study, the Indian crested porcupine became a nuisance to crops due to the habitat loss and fragmentation of forests. After researching the attack modes on various crop species, they developed a technique to lessen crop damage: they covered the coconut and arecanut seedlings using ceramic pipes (70). During the research, the scientist investigated the behaviour of arecanuts and fallen coconuts at the basal region of palm trees and their consumption. It was also suggested to apply coal tar on mature palms and seedlings to stop the debarking behaviour (71).

Human-wildlife conflicts in South India arise from several key factors. In the modern era, land use and cover change have reached unprecedented levels, particularly in developing nations like India (72). Protected areas within and near forest boundaries face considerable management difficulties due to these evolving land use and land cover change patterns (73). Climate variability, such as droughts and erratic rainfall, also impacts resource availability in natural habitats. This scarcity often forces animals to venture into human settlements for food and water, exacerbating conflicts. Consequently, South India has witnessed frequent human-wildlife conflicts as adverse interactions between people and wildlife.

The research, conducted in the Central Western Ghats of Karnataka, India, specifically in the Sakleshpur and Mudigere taluqs, focused on human-wildlife conflict and identified the main wildlife species responsible for crop damage as the Asian elephant (*Elephas maximus*), Indian Gaur (*Bos gaurus*) and Wild boar (*Sus scrofa*). The Asian elephant contributed to 90.06 % of the total crop loss, the Indian Gaur was responsible for 5.54 % and the Wild boar accounted for the remaining 4.40 % of the crop damage in the area (74). A study conducted in the coffee-growing Coorg region of Karnataka, which is close to Wayanad, revealed a high degree of violence throughout the jackfruit, paddy and coffee ripening seasons, as well as on more wet days (61). Over two years, the Mookambika

Wildlife Sanctuary in Kollur, Karnataka, was the site of a study on crop raiding by Gaur (*Bos gaurus*). March, April and May or summer had the highest number of crop raiding incidents (56.84 %), while June, July and August or monsoon season had the lowest number of cases (9.79 %). A medium-sized herd of nine to twelve animals did the most significant harm, with the paddy crop suffering the most tremendous loss. Relative to the crops on the sanctuaries' perimeter, those in the core region suffered the most damage. Most farmers (71 %) said manual guarding was their preferred method of crop security. Crop raiding and the parks' dry-season climate were directly correlated (75). Households in the Western Ghats are more inclined to report losses through "high-value species which includes elephants and tigers," the findings of the study revealed that while allegations involving "reported crop damage is severe or comprises injury or death to livestock and humans" are more likely to be verified by forest officials (76). Different perspectives of the issue, dangers, expenses and advantages of compensation are created by the discrepancy between what people feel is HWC and what the government recognizes as HWC.

The Tamil Nadu Forest Department made up for 36 human fatalities caused by elephants and seven by gaurs, 2560 crop damages and 81 household property damages done by both animals between 2016 and 2017 by paying residents' compensation. According to the report, there were 147 elephant attacks in the Coimbatore Forest Division between 2011 and 2022, which led to the death of 176 pachyderms due to various factors (77). According to a study conducted in the adjacent Gudalur region, recent migrants tend to be less tolerant of elephants than long-term native residents, who have been in the area for a more extended period (54). Thus, drawing up plans to foster cohabitation and lessen conflict is crucial to identifying the migratory routes used by elephants across agricultural regions (78). These results highlight the critical need for a more thorough investigation into how elephant crop raiding affects the food security and dietary requirements of the agricultural community in the HEC regions (79). The economic burden of farmers due to human-wildlife conflict is estimated to be the average cost per incident for crop and property damage in India, which was \$ 47. In comparison, compensation in the U.S. was significantly higher, with Colorado and Wisconsin reporting average payouts of \$ 1940 and \$ 3031 respectively (80).

Mitigation Strategies for Human-Wildlife Conflict

Both governmental institutions and villages employ the entire spectrum of conventional and contemporary methods for HEC mitigation, with differing degrees of effectiveness (81). The study clarified that human-elephant conflict has conservation in a range of countries. Growing know-ledge of wildlife behaviour and the spatiotemporal nature of conflict involving humans and wildlife has led to the proposal, development and adoption of several preventive and mitigation techniques, becoming a threat to biodiversity conservation. Managing it is crucial for elephant conservation in various countries (25).

Traditional measures of mitigation

Farmers defend their farms and prevent crop-raiding elephants by yelling, setting off fireworks or carbide cannons, beating metallic objects and throwing stones (82). Most farmers (71 %) said manual guarding was their preferred method of crop security. Since conflict exhibits trends that are distinctive to a specific region, knowing what is causing it will aid in developing suitable location-specific mitigation techniques (83). While elephant herds were primarily driven off by these means, removing habitual crop raiders from agricultural regions is difficult using traditional methods like crackers, torches, or loud noises (84). According to research in northern West Bengal, tea plucking near leopard areas of rest contributes to human-leopard confrontations by denying the animals a chance to flee (85). It appears that smashing pots and pans before plucking tea has improved the situation significantly and decreased the number of fatalities.

Modern measures of mitigation

Similarly, satellite surveillance of radio-collared elephants facilitates early identification of potentially problematic individuals and herds (86). According to the research, one technique for early elephant detection and warning is using mobile phones to swiftly communicate between farmers and local authorities, as well as between farmers. This allows people to work together to remove potentially harmful elephants. More research has shown that high-intensity electric fencing works better than any conventional technique for controlling wild animals (87, 88). In his study, the scientist discovered that trenches and electric fences are two popular physical exclusion methods for preventing elephants from entering agricultural regions and human communities. Studies report 70-90 % effectiveness of electric fences when well-maintained, but they also have limitations like high costs, maintenance challenges and power issues. Some wildlife adapts by breaching weak points (15). These physical barriers' high upfront and continuing maintenance expenses make them impractical for larger-scale deployment, especially in fragmented areas with extensive frontage among farms and forests (89).

Solar spotlights-which have already undergone limited testing for community fields to deter elephants from agricultural land. However, the upfront ownership costs prevent rural households and neighborhoods with lesser incomes from extensively utilizing these devices (82). The research revealed that early warning systems could also involve the placement of detectors at conflict-prone locations that monitor elephants' infrasonic screams, intending to assist in recognizing and tracking individuals over long distances (90) (Fig. 4).

Agricultural deterrent measures

In their study, the researcher examined the effectiveness of a barrier made of tobacco rope to deter crop-robbing elephants in southern India. Their findings demonstrated the efficacy of this management method during seasons with little rainfall (91). Elephant deterrent measures such as chilli-fence and spotlights have proven effective, but only when combined with noise (92). The study clarifies that exclusion,

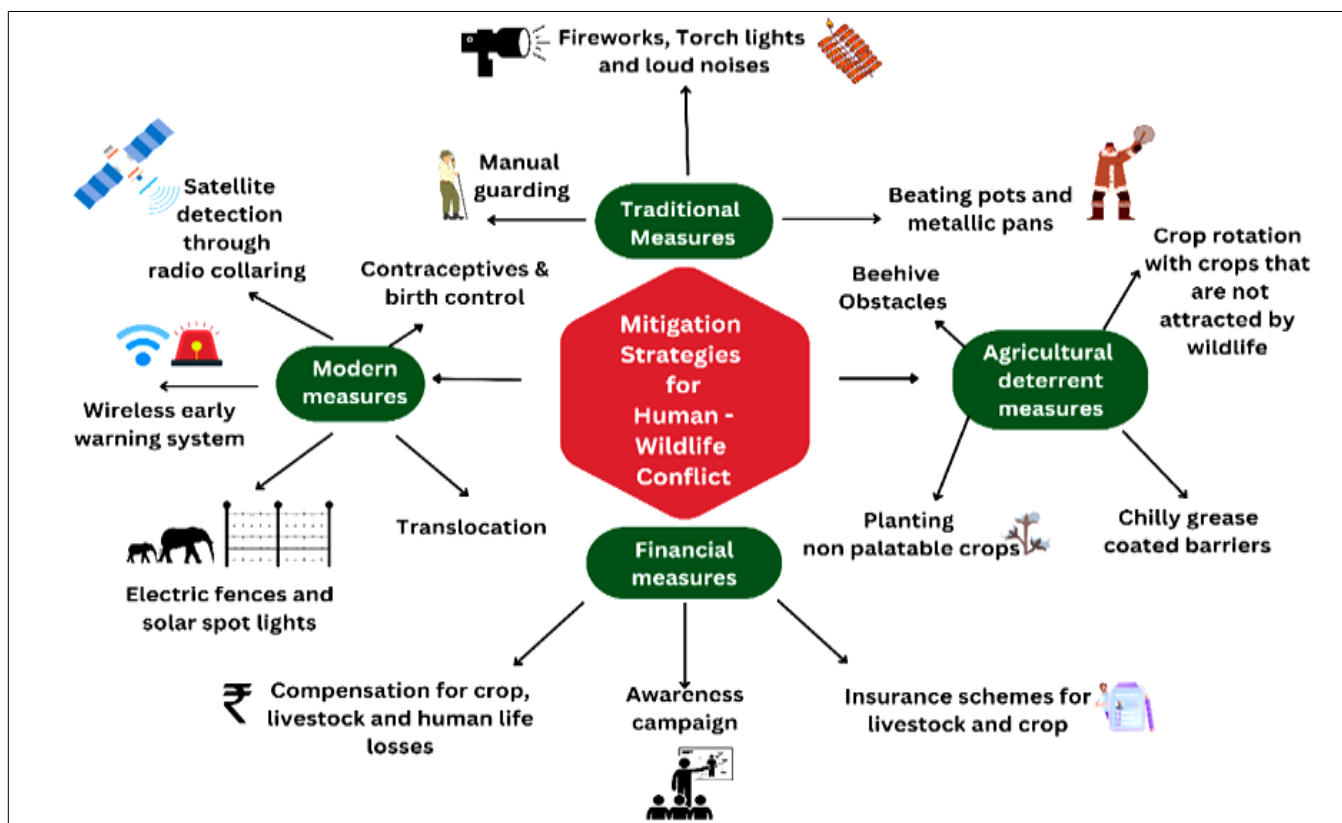


Fig. 4. Mitigation measures for human-wildlife conflict.

auditory and light approaches have been tested and applied more frequently than agriculture-based deterrents like chilli-grease-coated barriers and chilli dung (93). According to research studies, employing agriculture-based deterrents such as growing alternate crops like coriander, mint, ginger, onion, garlic, lemongrass and citrus trees helps reduce HEC. These techniques successfully reduce wildlife intrusion, especially with deterrent crops like chilli, but are also less effective against large herbivores and economic constraints may limit adoption (82). This can potentially discourage the elephants and give the farmers monetary aid (94). Research aiming at discouraging elephants has demonstrated that bio-acoustic approaches like beehive obstacles can provide encouraging results along with supplying honey and insect pollinators (95). To create food resources inside the jungles and reduce the number of elephants in their natural environments, the regional joint forest management organization has implemented a new initiative to roll fresh bamboo seeds to inaccessible forest regions (73). A study from the Coimbatore forest division revealed that crops like marigold, sapota, jatropha, eucalyptus, teak, etc., were found to be avoided by elephants (96).

Compensation

Due to its efforts to reduce the expense of in-person interactions and balance at least one of the drivers of Wildlife Conflict by acknowledging the financial implications of living close to PAs, India has accepted compensation as an approach to HWC (36). The research revealed that compensating the damaged parties is one of India's tactics to reduce HWC (97). In crop-raiding situations, it is more challenging to determine the proper compensation, although cases involving livestock predation are easier to figure out. Conflict among the public and park administrators occurs

after a crop-raiding event, according to (98). This is because the government officials' calculation of the crop raiding events' loss differs from the farmers' estimated loss. Many victims of conflict believe they are unwilling or unable to interact with the Indian wildlife damage compensation system because it is perceived as unduly complicated, opaque and delayed (99, 100).

Enhancing conflict resolution strategies in human-wildlife conflict

To mitigate human-wildlife conflicts, governments should enforce stronger wildlife protection laws against poaching and habitat destruction, implement timely compensation for affected farmers to prevent retaliatory actions and establish community-based resolution committees to address grievances and develop practical solutions. Sustainable land use planning, which includes creating buffer zones and wildlife corridors, could help minimize conflicts. At the same time, advanced technologies like AI-based monitoring and early warning systems can improve wildlife management. Additionally, climate change exacerbates these conflicts by altering habitats and reducing food and water availability by forcing wildlife into human settlements. Rising temperatures, deforestation and extreme weather also push animals into farmlands. Hence, practicing agroforestry, growing climate-resilient crops and reforestation are essential for restoring ecosystems, which will foster coexistence.

The effectiveness of South India's mitigation strategies depends on ecological similarities, local socio-economic conditions and government support. While solar fencing may be applicable in similar landscapes, solutions must align with community needs. Strong policies, adequate financial support and adaptive management approaches are crucial for scaling these interventions. Furthermore, education and

community engagement play a vital role in conflict reduction. Schools should integrate human-wildlife conflict resolution into curricula, while conservation initiatives can involve locals for habitat restoration and monitoring. Training programs on non-lethal deterrents and sustainable practices should be given to help farmers coexist with wildlife. Mass media campaigns will raise awareness and promote responsible behaviour. A more sustainable and balanced approach to human-wildlife conflict management can be achieved by integrating policy interventions, climate adaptation strategies, scalable solutions and community-driven conservation efforts.

Conclusion

Human-wildlife conflict poses a persistent and widespread threat to farmers' livelihoods and food security in rural agrarian communities across South India. With forests and protected areas near farmlands, crop-raiding by elephants, gaurs, wild boars and porcupines frequently results in substantial economic losses for smallholder farmers. The analysis of the causes, consequences and mitigation strategies of human-wildlife conflict in South India provides essential insights into the driving factors of the aftermath effects of human-wildlife conflict. From this, it is identified that habitat loss and fragmentation due to expanding agriculture drive animals into increased contact and competition with farmers over resources. It can be inferred that Crop-raiding exhibits seasonal and spatial patterns based on cropping calendars, water availability, forest food shortages and other factors. The review clearly shows that Community-based measures like guarding, barriers and deterrents had mixed results, while government compensation programs face limitations in adequately covering losses. Advanced technical solutions show promise but remain unaffordable and difficult to scale for many vulnerable agrarian communities. Understanding conflicts' ecological, social and economic drivers is key to designing appropriate mitigation strategies tailored to the local context. More research is urgently needed on cost-effective and socially acceptable means to foster human-wildlife coexistence and reduce the burden of conflict on rural farmer livelihoods in South India's biodiverse yet challenging agro-forest landscapes. The insights from this review provide a strong foundation to guide evidence-based policies and interventions to alleviate human-wildlife conflict in the region.

Human-wildlife conflict requires balanced solutions that support both conservation and human livelihoods. While existing mitigation strategies show promise, further research is needed to evaluate the long-term economic viability of mitigation techniques with cost-effective, sustainable and socially acceptable approaches. Future studies should assess the financial viability of low-cost fencing, bio-fencing and AI-driven monitoring while exploring community-based deterrents and agroforestry integration. Understanding local perceptions and enhancing participatory approaches will promote key findings in developing scalable and inclusive solutions for long-term coexistence.

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Authors' contributions

VP led the conceptualization and drafting of the original manuscript. MA contributed through conceptualization and oversight. SA and KB concentrated on developing ideas and providing reviews. VJ and RG were responsible for collecting the review data. NS and PP offered supervision, while SK managed the tasks of writing, reviewing and editing.

Compliance with ethical standards

Conflict of interest: The authors have no conflicts of interest to disclose

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