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REVIEW PAPER

The human-elephant conflict in Sri Lanka: history and present status

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Abstract
Human-elephant conflict (HEC) is a severe conservation, socio-economic and environmental issue of forests and ecosystems in elephant inhabiting countries, including Sri Lanka. Due to the rapid growth of human and elephant populations, both struggles to share limited land resources. The major causes and contexts of HEC in Sri Lanka include land use change, habitat loss due to human population growth, crop raiding behavior, problem elephants, and changes in agriculture practices. Since 2019, 125 people and 370 elephants have killed annually on average due to the conflict. Also, Sri Lanka has recorded the highest annual elephant deaths and second-highest human deaths due to HEC. The human death rate has increased by approximately 42% over previous three decades. The Sri Lankan government provides compensation for death and disability of the human caused by elephants and for elephant-damaged houses or properties. The Sri Lankan elephant (*Elephas maximus maximus*) is an endangered subspecies. It's home range is restricted to 50–150 km^2 and depends on the availability of food, water, and shelter of the habitat in which they live. Various management strategies have been developed by the government and villagers to prevent and mitigate HEC. Today, Sri Lankan elephants are protected under Sri Lankan law, with punishment by fines and jail terms. This article reviews the history, present status, and traditional conflict management of HEC in Sri Lanka. We suggest a satellite data fusion approach with GIS modeling to identify risk zones of HEC to develop further protective measures for humans and elephants.

Keywords Asian elephant · Human-elephant conflict · Crop and property damages · Traditional mitigation methods · Sri Lanka

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Extended author information available on the last page of the article

Introduction

More than 50 countries worldwide are home to the world's wild elephant, mainly in Africa and with just 13 in Asia (Perera 2009; Wijesekera et al. 2021; World Wildlife Fund, 2022). There are estimates of 51,000 to 66,000 elephants in Asia, but only 35,000 to 50,000 live in their natural habitats (Nakandala et al. 2014). Sri Lanka is home to 10% of Asian elephants living in their natural habitat, accounting for around 2% of the global range of Asian elephants (Fernando et al. 2011; Perera 2009). Asian elephants are classified into three subspecies: the Indian (*Elephas maximus indicus*), the Sumatran (*Elephas maximus sumatranus*), and the Sri Lankan (*Elephas maximus maximus)* (Animalia 2022; Fleischer et al. 2001; Sukumar 2006).

Currently, elephants live in five South Asian countries, Bangladesh, Bhutan, India, Nepal, and Sri Lanka (Fernando and Pastorini 2011). In Bangladesh, Bhutan, and Nepal, there are less than 500 wild elephants in the whole country (Fernando and Pastorini 2011; Sukumar 2006). According to the most recent estimate in 2017, mainland India has the largest population of Asian elephants, with 29,964 (Koshy 2021; Montez 2021). Sri Lanka has about 5,787 elephants, including 1,107 calves and 122 tuskers (World Wildlife Fund, 2019), according to the elephant census conducted in 2011. This contrasts starkly with the estimates of the population size in the 19th century, between 12,000 and 14,000 (Fernando et al. 2011; Katupotha and Sumanarathna 2016; Santiapillai and Read 2010). According to an elephant estimation conducted in 2011 by the Department of Wildlife Conservation (DWC), less than 10% of the Sri Lankan subspecies are tuskers, most likely due to selective hunting and poaching for ivory (Fernando et al. 2011; Köpke et al. 2021; Wikramanayake 2022). Sri Lanka has the second-largest population of wild elephants in South Asia (Menon and Tiwari 2019). When the estimated elephant population is divided by the land area, India had an elephant density of 0.0008 per km^2, while Sri Lanka had a density of 0.088 per km^2 in 2008 (Perera and Tateishi 2012).

Although wild elephants were once widespread throughout Sri Lanka, they are now restricted to the dry zone lowlands, Northern, Eastern, North Western, North Central, Southern, and part of Uva Provinces, as shown in Fig. 1 (De Silva and Srinivasan 2019; Menon and Tiwari 2019).

Except for the Sinharaja Forest and a few areas of Central Province, such as Wilgamuwa, Dambulla, and Laggala Pallegama, elephants live in the country's wet zone (Bandara and Tisdell 2005). Elephants are also found in Sri Lanka's major national parks, including Udawalawe, Yala, Lunugamvehera, Wilpattu, and Minneriya (Fernando et al. 2011). Apart from these areas, orphaned elephants are kept in Sri Lanka's Pinnawela Elephant Orphanage, which was established in 1975 to care for orphaned or abandoned baby elephants because of HEC (Fernando et al. 2011). Elephants often invade human settlements and cause damage to property, crops, and lives called problem elephants. In Sri Lanka, these elephants are captured and translocated to the elephant-holding ground in Horowpothana, North Central Province. This holding ground provides a safe and secure environment for problem elephants to be relocated to and receive appropriate care.

HEC is a severe conservation, socio-economic and environmental issue in elephant range countries' forests and ecosystems (Shaffer et al. 2019). Humans and elephants are under significant threat from HEC in various parts of Asia, including Sri Lanka (Thant et al. 2021). When elephants and humans interact, when elephants move through human settle-

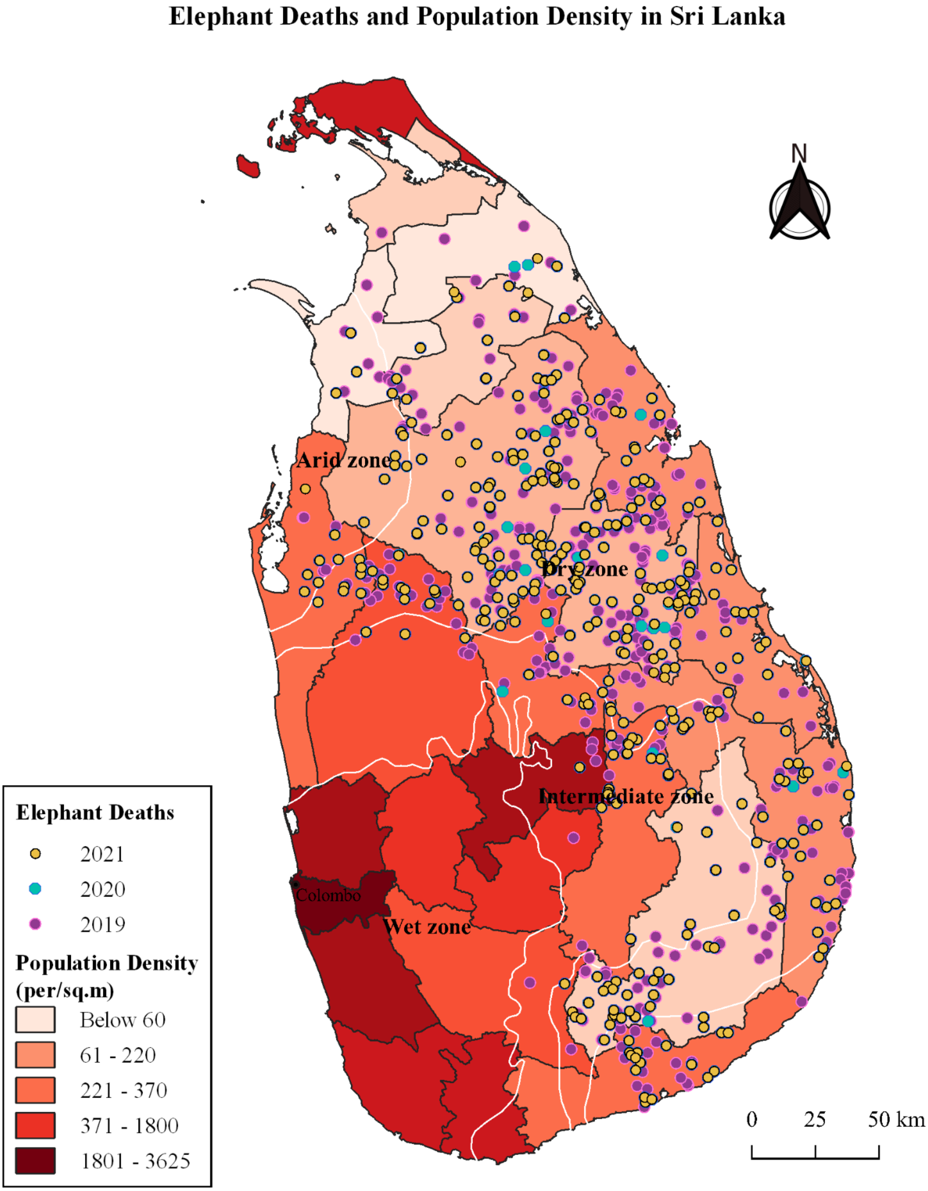

Fig. 1 Sri Lanka population density in 2019 and distribution of elephant deaths between 2019 and 2021. (Central Bank of Sri Lanka, 2019, DWC)

ments, there is a conflict due to crop raiding, household damage, injuries, humans killed by elephants, or vice versa (Billah et al. 2021; Das et al. 2014; Sitati et al. 2003). The intensity of HEC varies significantly due to ecological and socioeconomic factors such as food availability, size of protected areas, agricultural practices, human density, seasonal climate variations, and socio-cultural beliefs (Fernando et al. 2005). Furthermore, HECs are unavoidable in regions with a large elephant population due to the intense competition between elephants for resources such as food, water, and shelter (Tiller et al. 2021).

Crop raiding has a direct impact on the livelihoods of humans. It destroys crops and nearby properties, as well as poses a threat to human safety by causing injuries or killing people in some incidents (Pant et al. 2015; Vibha et al. 2021). This conflict primarily occurs where villages are located close to elephants' natural habitats (Enukwa 2017). People who contend with elephant depredation daily increasingly perceive them as agricultural pests, an unwelcome burden, and a threat to their own survival and well-being (Fernando et al. 2005). The local communities' negative perceptions of elephants in many cases strongly undermine conservation efforts for elephant populations (Vibha et al. 2021). African and Asian elephants are vulnerable to conflict because they spend a significant amount of time living near humans outside protected areas. Furthermore, their large size makes them more dangerous, increasing the risk of conflict (Tiller et al. 2021). Asian elephants are forest animals, and Sri Lankan elephants spend the day in low-visibility habitats such as scrub and secondary forests, only venturing out into the open at night (Fernando et al. 2021; Psaradelis 2021).

Asian elephants (*Elephas maximus)* are listed in the International Union for Conservation of Nature (IUCN) red data book as endangered species (IUCN 2020). Elephants may live for 60–70 years or more, depending on regular migration over large distances to search for food, water, and social and reproductive partners (Hart et al. 2008; Shaffer et al. 2019; Sukumar 2003). Also, elephants are intelligent animals with impressive memories (Katupotha and Sumanarathna 2016). Asian elephants have gained international attention due to an estimated 50% decline in their population over the past three generations, as well as the rapid shrinkage of their habitat range (Choudhury et al. 2008; Neupane et al. 2013; Williams et al. 2020). This study is a status investigation of the current level of HEC in Sri Lanka and the methods used to mitigate it. Several specific measures have been implemented and practiced at different scales for preventing and mitigating the problem. However, there is a lack of generic frameworks that provides a standardized approach to implementation. The relationship between the habitat of elephants and changes in land cover, particularly greenery, has not been established in Sri Lanka due to the lack of up-to-date and detailed information on forest cover changes. Therefore, identifying the HEC risk zone hotspot map is essential to reduce HEC in Sri Lanka. There is an extremely urgent need for a standard framework to monitor, identify and predict the hotspots of HEC risk zone. We suggest applying a satellite data fusion approach with GIS modeling to identify risk zones of HEC in Sri Lanka.

A previous study has been conducted assessing important to management of forest lands as well as to mitigate the risk of HEC in Sri Lanka. Satellite imagery used as an additional cost-effective approach to support ground-based studies, forest cover or green area monitoring (Perera and Tateishi 2012). Especially can use in remote or inaccessible regions. The successful applicability of Normalized Difference Vegetation Index (NDVI) products for forest cover change detection in Sri Lanka was presented in two previous studies (Perera and Tateishi 2012; Perera and Tsuchiya 2009). Based on those research findings, seasonal NDVI values of a selected location in south Sri Lanka (area including Udawalawe national park) was analyzed as a case study.

Satellite data fusion allows for long-term monitoring of HEC, facilitating the detection of trends and changes over time. By analyzing historical satellite images fused with recent data, researchers can assess the effectiveness of conservation measures. Satellite data fusion enhances the accuracy and precision of land cover classification and mapping.

The developed system will significantly contribute to managing HEC by identifying patterns of elephant movements using accurate changes in forest greenery and weather patterns. This system will encourage researchers to devise new methods for increasing the safety and well-being of people and elephants.

Study objectives

This review paper aims to explore the complex issue of HEC in Sri Lanka by providing a comprehensive overview of the historical context, examining the primary drivers of conflict such as habitat loss, changing agricultural practices, and land use patterns. Furthermore, identify the traditional methods people use to mitigate in Sri Lanka. The paper also seeks to identify gaps in the existing literature and research on HEC in Sri Lanka, suggesting areas for future investigation. In addition, the potential social and economic impacts of the conflict on local communities will be explored. Finally, the implications of HEC in Sri Lanka for broader conservation efforts, human well-being, and sustainable development will be discussed, highlighting the significance of this topic for both national and global audiences.

Literature review

Elephant species range and ecology

Elephants are the planet's largest terrestrial mammals, the African elephant (*Loxodonta*) being the largest (Bandara and Tisdell 2005; Naha et al. 2020; Sukumar 2006). Among Asian elephant species, the Sri Lankan is physically the largest of the subspecies and also the darkest in color (Bandara and Tisdell 2005). The host order and family of Sri Lankan elephants are Proboscidea, and Elephantidae (Cappellini et al. 2014).

Elephants are friendly social animals that live in groups known as a clan or a herd (Lakshmanaprabu et al. 2018). Elephants form deep family bonds and live in tight matriarchal groups of related females (Katupotha and Sumanarathna 2016). The herd is led by the oldest and often largest female, the matriarch (Rutherford and Murray 2021). The Sri Lankan elephant herd typically consists of 12 to 20 singles or more, and may include young juvenile, nursing, lactating, and other adult elephants (World Wildlife Fund, 2022).

Males leave the family unit between 12 and 15 years and may lead solitary lives or temporarily live with other males (Entertainment 2022). Elephants have a very structured social order, and male and female elephants have very different social lives (Katupotha and Sumanarathna 2016). Females spend their entire lives in tightly knit family groups of mothers, daughters, sisters, and aunts, and adult males live primarily solitary lives (Katupotha and Sumanarathna 2016). A typical Asian elephant family herd has a home range of 100-1,000 $km^{2,}$ but in Sri Lanka, it is more restricted to 50–150 km^2 (Shaffer et al. 2019; Sukumar 2006). Home range sizes depend on the availability of food, water for drinking and bathing, and shelter in the region (Sukumar 2006). Elephants mainly rely on water for cooling due to the evaporation of water from the skin (Dunkin et al. 2013; Williams 2019). More recently, elephants' home ranges have been disturbed by development activities such as roads, fences, and canals (Fernando et al. 2008).

Sri Lankan elephants can reach 6.4 m in length, and 2-3.5 m in height at the shoulder, and weigh 3,000–5,000 kg (World Wildlife Fund, 2022). Among other physical characteristics, their ears are small, not covering the shoulders, and they have two humps on their forehead (Bandara and Tisdell 2002; Grannan 2022). The trunk has one lobe at the tip, the front feet have five toes, and the back feet have four (Bandara and Tisdell 2005). Only male elephants have tusks, with the heaviest recorded tusk weighing 39 kg (Bandara and Tisdell 2005).

The elephant uses its trunk to release water and pick up and insert foods into their mouth when drinking and eating (Gruber et al. 2000; Racine 1980). While resting, the elephant stands up but does not make any specific movement (Bates et al. 2008; Pruett 2021). The elephant's trunk can draw water, spray it on its body, and throw mud or dirt on its back when grooming (Krishnan and Braude 2014). Because of these biological needs, elephants live in proximity to water sources such as lakes, irrigation tanks, and rivers (Pozo et al. 2018).

The elephant's digestive system is inefficient, and 40–50% of its food intake is passed through as undigested matter (Kingdom 2021; Sukumar 2006; Williams 2019). As a result, the elephant spends approximately 19 h daily eating and seeking a continuous and abundant food and water supply. Its diet is strictly herbivorous, with a daily food requirement of approximately 10% of its body weight (Krishnan and Braude 2014; Sitompul et al. 2013). Most elephants consume 100–150 kg of food daily, with mature adult males requiring more food than females (Fernando et al. 2022). Many types of grass, juicy leaves, fruits, small stems, and roots are included in the elephant diet, but grasses are only available seasonally in most Asian elephant habitats (Fernando 2015; Sukumar 2006; Zubair et al. 2005). In Sri Lanka, male elephants are mostly responsible for crop damage (Ekanayaka et al. 2011) since they search for more food compared to female elephants. Elephants can produce approximately 100 kg of dung per day while wandering around an area that can cover up to 324 km^2, and this helps to disperse germinating seeds (World Wildlife Fund, 2022). Therefore, elephants can be described as either eating machines or manure manufacturers, depending on their activity at the time (International Elephant Foundation, 2001). Elephants are always near a source of fresh water because they need to drink at least 80–160 L daily (Sajla and Famees 2022; World Wildlife Fund, 2022).

Elephants sleep about four hours per day, and about two hours of this are spent standing (Katupotha and Sumanarathna 2016). The Asian elephants can reach speeds of 40 km/hr while running and up to 6.4 km/hr when walking (Bandara and Tisdell 2005). They are excellent swimmers and have been known to swim for long distances. Reports reveal that one elephant swam about 2.5 km across the Trincomalee Harbor to Sober Island, and a 3.048 m high elephant swam across the Senanayaka Samudra Reservoir (Katupotha and Sumanarathna 2016). In 2017, the Sri Lankan navy rescued an elephant swimming in the ocean about 16 km off Sri Lanka's northeast coast (Guardian 2017).

Asian elephant species have one of the most extended gestation periods in the animal kingdom, lasting 18–20 months (Taylor and Poole 1998; Tuntasuvan et al. 2002). Sri Lankan elephants' gestation can extend up to 680 days, and they typically give birth to a single calf, which exits the womb weighing 90.7 to 136.1 kg (Animals 2021). Female elephants reach sexual maturity at ten years old and give birth once every four to six years (Animalia 2022). When a calf is born, it is raised and protected by the whole matriarchal herd. Elephants are an oddity among mammals because they grow until they die, usually around the age of 60 (Bandara and Tisdell 2005).

The loss of teeth is the leading cause of death among mature elephants. When an elephant's last set of teeth wears down, they lose the ability to chew and digest (CGTN 2020). Therefore, their natural cause of death is generally starvation or malnutrition (CGTN 2020). However, according to local reports, 70% of elephants died near water holes containing algal blooms, which can produce toxic microscopic organisms known as cyanobacteria (Weston 2020). All these biological, ecological, and behavioral facts about elephants have elevated the HEC in the island nation of Sri Lanka, where feeding grounds for them are extremely limited.

Causes and consequences of Human Elephant Conflict (HEC)

The HEC exists whenever and wherever humans and elephants coexist (Fernando et al. 2005). However, the conflict has recently intensified, due to the changing agricultural practices and land use patterns (Anuradha et al. 2019). Mattala airport has been established by clearing forest covers of approximately 2,000 ha (PEAD 2015), and the airport has fragmented wild elephant habitat and hindered the wild elephant corridors (Bandara 2020). The Department of Wildlife states that the wild elephant population in Sri Lanka has increased to 7,000 (Ministry of Agriculture 2023). In 2011, it had been reported that the number of those animals on the island had been around 5,787. Various human needs, including land utilization, have increased in response to the rapid growth of the human population (Fernando et al. 2021). According to World Bank projections based on the United Nations population division's world urbanization prospects, Sri Lanka's rural population has continuously increased throughout recent history (The World Bank Group 2022).

Due to the natural growth of the population and the advancement of the country's free healthcare system, the rural population of Sri Lanka has increased significantly from 8.25 million in 1960 to 17.8 million in 2020 (Perera and Tateishi 2012; The World Bank Group 2022). Figure 2 illustrates the national and rural population growth over the last six decades. Notably, this nearly doubled between 1960 and 2000.

However, agriculture is the primary source of income for rural communities in Sri Lanka. More land is being cleared for permanent agricultural activities for food production (Anni and Sangaiah 2015; Fernando 2015; Fernando et al. 2021). Due to the rapid growth of rural population, local communities are increasingly attracted to settle near areas of conservation or forests that are protected (De Silva 1998). While less productive compared to modern agro-methods, traditional farming practices allow for a more harmonious relationship between human and elephant through resource partitioning (Fernando et al. 2005). To increase the yield per hectare, new agricultural activities have emerged, with the potential for human and elephant coexistence decreasing rapidly, throughout Asia (Fernando et al. 2005).

Human activities have often expanded and encroached on elephant habitation areas (Fernando 2015; Fernando et al. 2021). The ongoing expansion of human settlements resulted in many infrastructure development activities, such as the Mahaweli Development Project (Dissanayake et al. 2018; Paranage 2019; Talukdar et al. 2022). This is a notable multipurpose development scheme with the primary objectives of human settlement, hydroelectricity generation, and farmland irrigation (Burchfield and Gilligan 2016). State interventions have led to both population increase and major land-cover transformations in the dry zone of northeast Sri Lanka (Paranage 2019).

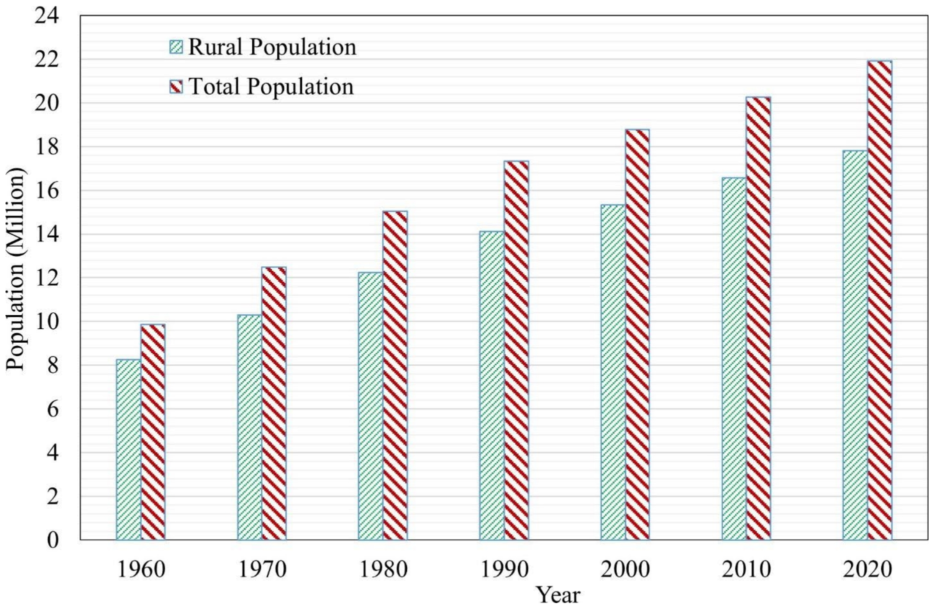

Fig. 2 Total population and rural population of Sri Lanka from 1960 to 2020 (https://data.worldbank.org/)

Human settlement areas are concentrated around permanent water sources because this facilitates agricultural expansion (Anni and Sangaiah 2015; Loarie et al. 2009). These expansions have led to a significant decrease in the size and range of elephant populations, as well as a reduction in the connectivity of elephant habitats in their historical ranges (Calabrese et al. 2017; Thouless et al. 2016). As their habitats have started shrinking, elephants are progressively forced into close contact with human, resulting to more frequent and severe conflict over space and resources, ranging from crop raiding to reciprocal loss of life (Liu et al. 2017). Consequently, farmers have become incompatible neighbors in many Sri Lankan elephant range areas, and these populations cannot coexist peacefully where agriculture is the predominant land use (Animals 2021; Bandara and Tisdell 2002).

The forest cover in Sri Lanka was reported to be 21.0% (1,377,799.1 ha) in 2019, down from 24.8% (1,624,757.5 ha) in 1992 (Ranagalage et al. 2020). Additionally, declining biodiversity and scarcity of resources, particularly food and water, have resulted in increased wildlife habitat fragmentation (Köpke et al. 2021; Shaffer et al. 2019). Forest loss and degradation bring wildlife closer to humans, competing for shared resources such as space and water (Mumby and Plotnik 2018). Consequently, wildlife such as elephants raid crops, damage property, and kill humans, leading to further escalation of the conflict, including retaliatory wildlife killings (Acharya et al. 2017; Haven 2019a).

The survival and continuation of elephants in their range countries are severely threatened by HEC. This is due to the development and well-being of human communities who coexist with these large herbivores (Shaffer et al. 2019). Habitat fragmentation increases the contact between elephants and agriculture, and conflict intensity is usually higher in more fragmented habitats (Sukumar 2003). During a drought, elephants require water to survive. However, when water becomes scarce, they may gather around village farm wells and other water tanks to access the limited supply of available water (Perera and Tateishi 2012). The degradation of elephant natural habitat resources such as water is also apparent in some regions, and severe droughts may force elephants to disperse into new habitats where conflict may escalate (Sukumar 2006).

The status of the HEC in Sri Lanka

HEC incidences are common in Sri Lanka, and over 59.9% of Sri Lanka's elephants are restricted to the lowland dry zone (Fernando et al. 2021; Rathnayake et al. 2022). Notably, approximately 69.4% of the elephant's range in Sri Lanka is in areas where people live, a problem expected to worsen in the future (Fernando et al. 2021). Therefore, HEC is a challenge to the Sri Lankan government for policymaking and planning (Prakash et al. 2020; Sukumar 2006).

In this country, HEC has commonly manifested as direct attacks on people, resulting in human injuries, deaths, crop depredation, property damage, elephant injuries, and deaths (Leimgruber et al. 2011; Santiapillai et al. 2010). Sri Lanka has the highest annual elephant deaths and the second-highest human deaths in the world, while India holds the first rank (Huaxia 2020; News 2020; Ranawana 2020). More than 600 humans and 450 elephants are killed annually during crop raiding in Asia, with India and Sri Lanka accounting for more than 80% (Sukumar 1990; Williams et al. 2020).

Elephants are being squeezed into smaller areas of their remaining natural habitat, surrounded by crops that elephants like to eat (Palita and Purohit 2008). Farmers experience risk losing their entire livelihood in one night due to crop raiding (Bandara and Tisdell 2002). Small-scale agriculture is the main economic activity in rural Sri Lanka. Banana, coconut, sugarcane, and seasonal crops are cultivated during the rainy season, including paddy, maize, pumpkin, green chili, bitter gourd, and watermelon (Campos-Arceiz et al. 2009; Ranaweerage 2012). Rice, banana, coconut, cassava, corn, papaya, and sugarcane are wild elephants' most preferred crops while they avoid lime, orange, sesame, and cashew (Santiapillai et al. 2010; Webber et al. 2011). It has also been observed that elephants tend to consume more nutritious crops like sugarcane, rice, and the tops of pineapples (Haven, 2019) Additionally, bananas are a preferred food for elephants due to their high nutritional value and ease of digestion (Haven 2019b). Interestingly, it appears that elephants are not fond of the smell of citrus trees (Rathnayake 2020).

It is known that elephants raid crops throughout the year, but their activities are intensified during certain months (Bandara and Tisdell 2002). Elephants raid paddy fields in January when the grain matures and continue until harvesting is completed (Ranaweerage 2012; Santiapillai et al. 2010). They damage bananas during every stage of the crop's life (Santiapillai et al. 2010). Mango trees are attacked during their fruiting seasons, from May to June and November to December (Bandara and Tisdell 2002). Elephants also attack perennial crops, such as jackfruit and coconut, when other crops are unavailable along their usual raiding routes (Bandara and Tisdell 2002; Campos-Arceiz et al. 2009).

Additionally, there is damage to the crops cultivated in home gardens, such as bananas and coconuts (Gross et al. 2020). Elephants enter home gardens more frequently because they can reach food with less effort than in the jungle, where food is scarce (Thennakoon et al. 2017). Once they become used to attacking villages for food, the behavior could continue even during the rainy season (Fernando and Pastorini 2011; Ranasinghe 2021).

The slash-and-burn farming system or "chena" is a local variety of shifting cultivation practiced in the villages in the vicinity of the forest (Lindström et al. 2012). The elephants influence chena cultivation because chena farmers occupy the forests around villages (Tsuji and Fujimura 2020). From October to the end of January, villagers guard their crops, prevent approaching elephants (Tsuji and Fujimura 2020). After harvesting, people limit their movement to the resulting forest patches and open areas, and elephants take advantage of this opportunity to move closer to the villages (Fernando et al. 2005). Since February, there tends to be a significant increase in raids on village dwellings, partially due to the end of chena activities (Campos-Arceiz et al. 2009).

Most HEC incidents are caused by small groups of elephants in Sri Lanka, usually one to three (Campos-Arceiz et al. 2009). Male elephants move alone or in small temporal groups, whereas female elephants move in larger family-based groups (Fernando and Lande 2000; McKay 1973). Damage to houses is determined by their proximity to elephant corridors, construction condition, dryness in elephant habitat regions, the amount of grain stored inside the house, and crops grown in the home garden (Bandara 2020; Perera and Tateishi 2012; Thennakoon et al. 2017). The extent of damage caused by elephants varies depending on whether the structure is a permanent or temporary dwelling (Galappaththi et al. 2020). Villagers believe a bump by an elephant can be enough to collapse a temporary house (Thennakoon et al. 2017).

Wild elephants damage houses regularly, especially when food, mainly paddy, is stored inside (Hedges et al. 2005). Elephants have a keen sense of smell, and they can detect paddy and other goods such as salt stored inside houses and knock down the walls to feed on them (Campos-Arceiz et al. 2009; Gunawardhana and Herath 2018). A few elephants may have become accustomed to raiding houses, doing so repeatedly in Sri Lanka (Campos-Arceiz et al. 2009). Therefore, keeping rice sacks in the same rooms where people sleep is common because it reduces the risk of elephant attacks (Ranaweerage 2012).

The year can be divided into four seasons based on elephant raiding frequency: the dry season with serious damage, the rainy season with low damage, the post-rainy season with serious damage, and the transitory season with low damage (Campos-Arceiz et al. 2009). During the dry season, typically from May and October, elephants tend to move in search of water. This movement often leads to an escalation in conflict, making it a period of increased anticipation for potential clashes (Gubbi 2012; Gubbi et al. 2014). In addition, paddy fields located far from the housing area are targeted by elephants because of their proximity to water sources such as lakes and tanks, as well as the surrounding forests (Ranaweerage 2012).

People attempt retaliatory attacks on elephants as a solution to elephants raiding and destroying crop fields regularly (Perera 2009). People have tried to kill elephants in various ways, including explosives such as "hakkapatas," poisoned foods such as pumpkins laced with chemicals, and gunfire (Gunawardhana and Herath 2018). Hakkapattas kill most elephant calves, and a total of 69 elephants were killed by these explosives in 2021, while 64 were killed by electrocution, 45 by gunfire, and four by toxic chemicals. In addition, 69 elephants were killed by these explosives in 2020, while 66 were killed by electrocution, 46 by gunfire, and two by poisoning (DWC, 2020). An average of 200 animals are intentionally killed annually, with 70 to 80 human casualties (Köpke et al. 2021).

Figure. 3 shows the changes in the number of human and elephant deaths in Sri Lanka since 1991. Although these were equal in 1991, the number of elephant deaths has con-

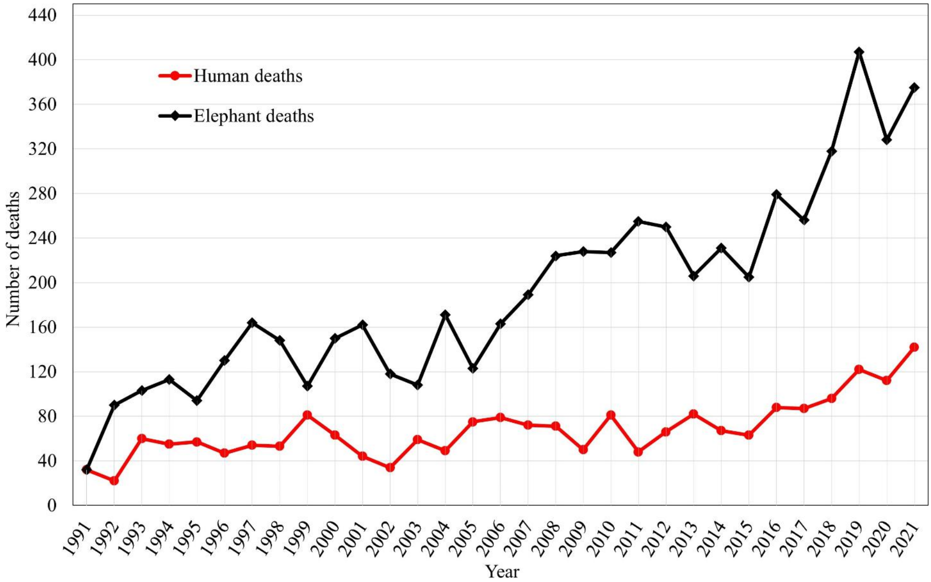

Fig. 3 Human and elephant deaths in Sri Lanka from 1991 to 2021 (DWC)

sistently been higher from that year onwards, with a sharp increase in recent years. The majority are due to HEC, indicating that violence against elephants has increased. This underscores the severity of the issue.

The average annual human death rate due to HEC from 2012 to 2021 was 93, from 2002 to 2011 it was 62, and from 1992 to 2001 it was 54. Therefore, the human killing rate by elephant has been increased by approximately 42% over the previous three decades, with the 2021 figure reaching 142, a marked increase. Despite fluctuations, the number of HEC caused human deaths has exceeded 100 per year over the last three years. Overall, within the last 30 years, 2,111 human and 5,954 elephant casualties were reported due to the HEC.

According to the DWC (Fig. 4), human deaths are more concentrated in the wildlife regions in Anuradhapura, Polonnaruwa, Ampara, Monaragala, Batticaloa, and Kurunegala, while elephant deaths are spread throughout the affected HEC region. The majority of human casualties are male since most HEC incidents occur at night when females in Sri Lankan villages generally do not go out (Galappaththi et al. 2020).

According to Fig. 5, the number of properties damaged has fluctuated but increased. From 2011 to 2021, this reached more than 1,000 per year, with a peak of 2,195 incidents recorded in 2020. Between 1991 and 2021, a total of 27,344 cases were reported, with the worst incidents occurring in Polonnaruwa, Ampara, Badulla, Monaragala, Anuradhapura, and Kurunegala (Fig. 4).

The Sri Lankan government has implemented some laws to protect elephants because killing elephants is illegal (Gardner 2008). These include a fine of between USD 756 (LKR 150,000) and USD 2,520 (LKR 500,000) or a jail term of two to five years, or both (Gardner 2008; Wikramanayake 2022) for killing an elephant.

The DWC of Sri Lanka manages the only scheme that compensates farmers for deaths, injuries, crop loss, property damage, and specific problems that vary from place to place

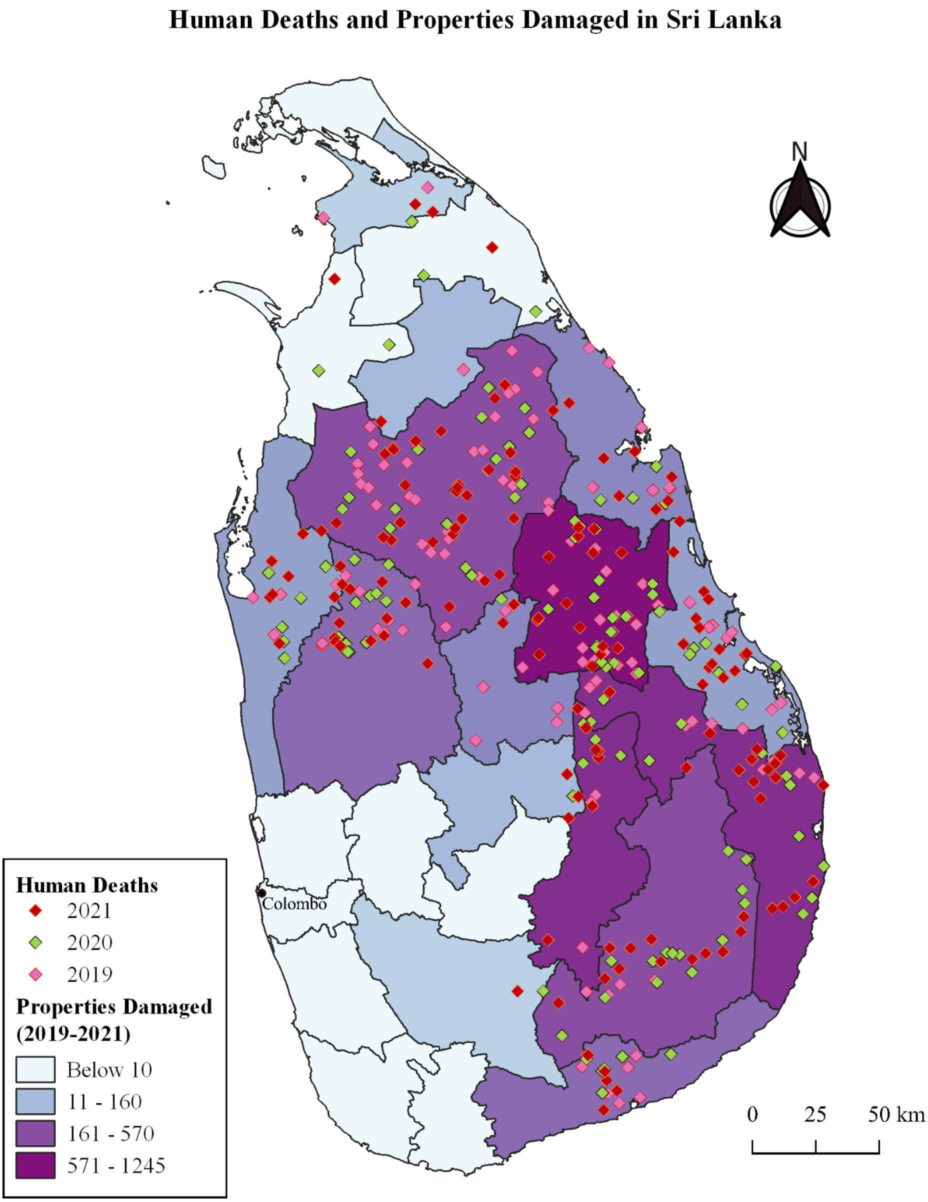

Fig. 4 Number of human deaths and properties damaged in Sri Lanka from 2019 to 2021 (DWC)

caused by elephants in the HEC area (Bandara and Tisdell 2003; Talukdar et al. 2022). Previously, there was also an additional scheme under the Department of Social Services to pay compensation for the damage caused by elephants. After 2nd August 2021, it was amended to make payment through district secretaries (Bandara and Tisdell 2002) to compensate for death, total or partial disability, and house and property damage caused by attacks by protected wildlife.

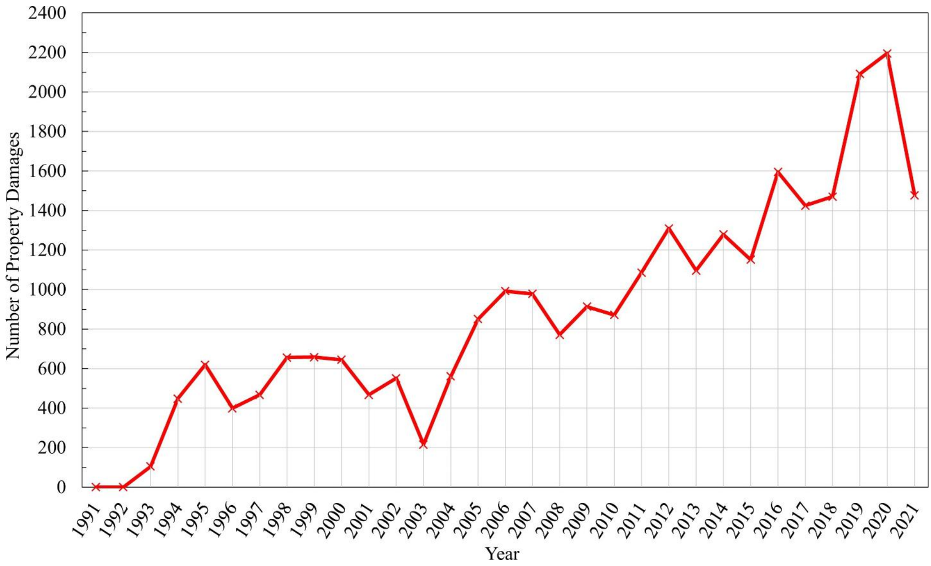

Fig. 5 Number of properties damaged in Sri Lanka from 1991 to 2021 (DWC)

According to the DWC, any victim of an elephant-related death will receive USD 5,040 (LKR 1,000,000) regardless of gender or age, with funeral expenses covered by USD 504 (LKR 100,000) and the remaining USD 4,536 (LKR 900,000) going to dependents or legal guardians. Also, the compensation for "complete disability" is USD 5,040 (LKR 1,000,000) regardless of gender or age. People who are partially disabled or have suffered physical injuries now receive up to USD 756 (LKR 150,000), including a daily hospital allowance of between USD 7.56 (LKR 1,500), and USD 252 (LKR 50,000). Partially disabled people who cannot work due to a medical condition will be compensated daily by between USD 4.03 (LKR 800) and USD 352.80 (LKR 70,000), after being released from hospital. In addition, all medical testing, equipment, and medication prescribed by the doctor must be obtained from a third party, with a maximum compensation of USD 151.20 (LKR 30,000). The compensation for systemic fracture management via traditional Ayurveda medicine is up to USD 50.40 (LKR 10,000). In addition, compensation for houses and properties damaged by wild elephants is up to USD 1,008 (LKR 200,000).

Economic losses due to HEC

HEC can be classified as direct or indirect according to its impact on people (Sampson et al. 2021). Direct HEC has a physical and economic impact on rural communities, whereas indirect HEC has a broad and indirect social impact on people and society (Nyumba et al. 2020; Shaffer et al. 2019). Such indirect costs may form a significant component of the conflict perceived by local people (Sampson et al. 2021).

Elephants cause direct economic damage in agricultural areas by destroying crops, loss of life, injury, livestock, and other property damage (Nyirenda et al. 2018). Although other wildlife species such as parrots, peacocks, wild boars, porcupines, monkeys, rabbits, and flying squirrels also damage crops, elephants are feared the most because of their ability to eat and trample a large number of crops in a single night (Gunawardhana and Herath 2018; Santiapillai et al. 2010). It has been estimated that a typical farmer in elephant-affected areas of Sri Lanka loses over USD 200 annually due to crop damage (Santiapillai et al. 2010).

The indirect impacts of HEC are less tangible than physical damage (Santiapillai et al. 2010). These include fear of attack, and disruption of livelihoods, community activities, and daily activities (Sampson et al. 2021; Tripathy et al. 2022). This may restrict people's movements between villages, mainly where attacks have recently occurred (Tripathy et al. 2022). Such fear among children may reduce school attendance or interfere with collecting fuel wood, wild fruits, or other resources such as wood apples and wild mango (Dharmaratne and Magedaragamage 2014).

Furthermore, resources are lost due to uncompensated activities such as guarding crops (Sampson et al. 2021). Farmers and their families are required to guard their crops and property during the crop raiding season, resulting in loss of sleep and energy, lost time, reduced opportunities for employment, increased exposure to infectious diseases, and psychological stress (Parker et al. 2007). Such indirect costs do not translate well to economic value and are difficult to calculate conventionally. Basically, people are living in fear.

The opportunity cost of different conflict management approaches can be calculated as the income forgone due to the farming households' commitment to dealing with the threat of elephants (Woodroffe et al. 2005). It can be identified as a percentage loss of annual income (Dharmaratne and Magedaragamage 2014).

The DWC spends funds annually for selected HEC mitigation activities for elephant thunder, compensation, capture and translocation, and elephant drives (Horgan and Kudavidanage 2020; Prakash et al. 2020). Sri Lanka spent USD 2.74 million constructing electric fences in 2019 and 2020, resulting in 4,756 km of electrified fencing (Köpke et al. 2021). According to statistics provided between 2011 and 2018, USD 0.76 million was paid as compensation for human deaths and USD 1.7 million for property damage (World Wildlife Fund, 2019). According to records, USD 0.05 million was paid for injuries in 2017 and 2018 (World Wildlife Fund, 2019).

Conflict prevention and mitigation strategies

Implementing HEC mitigation measures is imperative to enhance the sustainability of conservation efforts and improve the coexistence between people and elephants (Enukwa 2017). The advantages of implementing HEC mitigating measures may include improved attitudes and tolerance of farmers toward wildlife, a decline in crop losses, human death and injury, and a decline in elephant mortality (Jackson et al. 2008). A better understanding of the characteristics of HEC enhances the establishment of effective mitigation strategies and promotes the well-being of humans and wild elephants (Thant et al. 2021).

Multiple techniques have been implemented across the Asian and African elephant ranges to prevent them from entering crop fields and to scare them away when they are found feeding on farms (Shaffer et al. 2019). To protect crops from elephants, people shoot them away, use firecrackers and thunder flashes, acoustic deterrents, light-based devices, agriculture-based deterrents, electric fences, bee colonies at borders, protected areas and elephant corridors (Enukwa 2017; Gross et al. 2017; Köpke et al. 2021). Mathtala International Airport, Hambantota International Harbor, Magam Ruhunupura International Convention Centre, Hambantota Administrative Complex, and the International Cricket Stadium in Southern

Province, Sri Lanka, have fragmented the wildlife habitat, which has led to the formation of new corridors, such as the land belt connecting Mattala Airport and Malala Ara, Southern Province, Sri Lanka (Bandara 2020; PEAD 2015; Xinhuanet 2023). Sri Lanka's Road Development Authority design an elevated bridge, the underside of which would function as a corridor for travelling elephants (Xinhuanet 2023). Some artificial corridors, such as in the Andarawewa, Southern province of Sri Lanka, have also been constructed (Bandara 2020). Currently, wild elephants utilize this corridor to safely cross under the expressway. However, numerous incidents have been recorded where wild elephants, including calves have attacked the electric fence, broken the fence, and crossed to the other side from many places on the highway (Bandara 2020).

Traditional methods people use to mitigate HEC

Sri Lankan farmers use different traditional methods to mitigate HEC, frequently combining multiple techniques and changing strategies over time as elephants test the enacted measures to access desired resources (Hoare 1999; Perera 2009). Much of the effort to address the conflict has been focused on risk prevention by keeping humans and elephants separated (Shaffer et al. 2019).

The traditional conflict mitigation methods attempt to limit elephant movements into agricultural areas using barriers such as wooden fences, beehive fences, elephant watchtowers or guardhouses, and trenches (Enukwa 2017). Farmers' defenses in fields at night include chasing animals by banging on tins or drums, shouting, and throwing objects (Enukwa 2017; Sajla and Famees 2022). Chili peppers and fire are also used to scare elephants and keep them away from crop fields (Gross et al. 2017; Köpke et al. 2021).

Trench excavation

Physical exclusion methods such as trenches are commonly used to deter elephants from entering farmland and human settlements (Fernando et al. 2008). A trench must be broad and deep enough to prevent an elephant from stepping over it. Some communities have constructed elephant trenches along their boundaries, of approximately three meters deep and two to three meters wide (Mackenzie and Ahabyona 2012; Parker et al. 2007).

Trench excavation has been considered and proven as a potential and effective strategy for keeping elephants away from crops (Davies et al. 2011; Hedges and Gunaryadi 2010). These trenches serve as a physical barrier, preventing elephants from accessing human settlements (Nelson et al. 2003; Tchamba 1996). However, there are significant drawbacks associated with this method. One major challenge is the labor-intensive nature of trench construction and maintenance, which requires a significant amount of manpower and resources (Zhang and Wang 2003) in larger-scale applications (Enukwa 2017; Shaffer et al. 2019), and their presence creates defined boundaries that limit potential land use options (Nelson et al. 2003). Additionally, waterlogging in the trenches and the obstruction of rock boulders during excavation make the process more difficult (Zafir and Magintan 2016). Furthermore, elephants possess the ability to easily collapse trench walls using their immense body weight, especially in humid areas where they leverage their strength to render the trench ineffective (Enukwa 2017; Zafir and Magintan 2016). Moreover, trenches are susceptible to erosion and caving-in of side walls, which can fill up the trench and enable elephants to cross it (Fernando et al. 2008). Also, they limit potential land use options by creating defined boundaries (Nelson et al. 2003). These factors highlight the limitations and challenges associated with using trenches as a long-term solution for deterring elephants and protecting crops.

Acoustic deterrents

Acoustic deterrents are any noises used to discourage elephants, either through the shock value of an unexpected loud noise or specific noises that frighten elephants (Ball et al. 2022). Farmers scare away crop-raiding elephants by yelling, setting off firecrackers, hitting metal objects, and beating drums and tins. These are perhaps the most widely used methods throughout affected regions in Sri Lanka (Fernando et al. 2005, 2008; Gunaryadi et al., 2017; Shaffer et al. 2019). DWC provides "ali-wedi" which are specific firecrackers for elephants, approximately 25 cm long and 2.5 cm in diameter, to farmers in high HEC areas (Fernando et al. 2008).

Acoustic deterrents offer various benefits. They ensure the safety of elephants avoiding any harm to them, are a cost-effective method, and promote ethical and humane treatment of these magnificent creatures. Furthermore, this method has demonstrated promising results in efficiently deterring elephants (Zhang and Wang 2003).

However, there are significant drawbacks associated with using this repellent method. The absence of long-term adverse effects may raise concerns regarding sustainability and long-term effectiveness (Nelson et al. 2003). Furthermore, this method may only be effective over short distances (Shaffer et al. 2019), limiting its practicality in scenarios where elephants need to be deterred from larger areas. These techniques effectively keep elephants away from crops, and short-distance elephant repellents (Thuppil and Coss 2015; Wijayagunawardane et al. 2016). Additionally, the use of this repellent may disrupt the psychosocial well-being and livelihood activities of farmers (Shaffer et al. 2019; Tchamba 1996).

Light-based deterrents

Since ancient times, lighting fires has been a universal method of protecting crops from elephants and other wild animals (Fernando et al. 2008). Farmers may use flaming torches and light to protect ripening crops and deter elephant raids (Davies et al. 2011; Fernando et al. 2005; Shaffer 2010). Fires are also lit around the farms to improve visibility (Sitati and Walpole 2006). Farmers use light-based deterrents to keep elephants away when they detect them, especially at night (Shaffer et al. 2019). This kind of deterrent mitigates HEC as elephants tend to run away from massive fires. Controlling the fire regularly to prevent it from spreading into the surrounding area is a labor-intensive part of this method. Failure to properly manage the fire may destroy crops and surrounding vegetation (Enukwa 2017).

Most wild animals tend to avoid areas with fire (Nelson et al. 2003), making it an effective means of keeping elephants away from crop fields. Additionally, this method is relatively inexpensive (Enukwa 2017). Moreover, the use of fire as a repellent ensures that elephants are not harmed in the process (Fernando et al. 2008).

However, there are several disadvantages associated with using fire as a deterrent. Fire-based deterrents tend to be more effective in the short term but lose efficacy over time (Fernando et al. 2008; Zhang and Wang 2003). Elephants may adapt to the presence of fire or simply move to a different location (Sukumar 1991; Wijesekera et al. 2021), rendering this method less effective in the long run and serve as short-term measures, and their effectiveness may diminish as elephants adjust their behavior or find alternative routes (Shaffer et al. 2019).

Agriculture-based deterrents

Agriculture-based deterrents create barriers to wildlife entering subsistence farmland and consuming or damaging crops (Kolinski and Milich 2021). Farmers discourage elephants by using crops that are less attractive or palatable to elephants (Gross et al. 2017; Santiapillai et al. 2010). With this approach, they use citrus plant species such as orange and lime trees to create bio fences (Fernando et al. 2008; Sajla and Famees 2022). By planting these trees alongside their crops, particularly in the border areas adjacent to elephant habitats, they hope to decrease crop raiding (Dharmarathne et al. 2020).

Agriculture-based deterrents offer several advantages that make them a viable option in mitigating HEC. They are characterized as “low-tech” solutions that can be produced using locally available resources and techniques (Nelson et al. 2003). These deterrents can provide economic benefits to farmers. By implementing strategies such as intercropping or alternative crop cultivation, farmers can compensate for the reduced cultivation of main crops that are susceptible to elephant damage. Diversifying agricultural practices can lead to increased income and economic stability for farmers (Shaffer et al. 2019).

However, there are notable disadvantages associated with agriculture-based deterrents. One significant drawback is the requirement for consistent monitoring and maintenance. These deterrents often necessitate regular check-ups, repairs, and adjustments to ensure their effectiveness. This can impose a labor-intensive burden on farmers or communities already engaged in various agricultural activities.

Elephant watch towers/guard houses

An elephant watch tower, also known as a guard house, is a secure location for surveillance where a person can monitor elephant activities, and take appropriate precautions to prevent loss (Madzimure 2017). Elephant watch towers or guard houses are structures designed to provide elevated observation points for monitoring elephant movements and preventing HEC. Elephant watch towers are constructed in tall trees around six to nine meters high near the forest boundary, using wood, bamboo, a plastic cover, and tin sheeting with an easily climbable ladder (Madzimure 2017; Nakandala et al. 2014). At night villagers use these to detect elephants from a distance (Madzimure 2017; Nakandala et al. 2014).

These structures offer several advantages in mitigating conflicts. They ensure that elephants are not harmed during the monitoring process (Gunaryadi et al., 2017). Additionally, watch towers and guard houses can help minimize damage to crops, property, and infrastructure by providing early warning of elephant presence, allowing for timely intervention and preventive measures (Sugiyo et al. 2016).

However, there are certain disadvantages associated with the use of elephant watch towers. One notable drawback is the potential for these structures to scare away elephants due to their reliance on the fear elephants have towards human presence. Elephants may alter their behavior patterns or avoid areas where watch towers or guard houses are located, potentially impacting their natural movements and habitat use. This can lead to altered migration routes or the concentration of elephants in other areas, which may have broader ecological implications.

Beehive fences

Beehive fences are simple and inexpensive, made without cement and using only locally sourced materials (King 2019). Hives, or dummy hives, are hung every 10 m and linked together in a specific formation so that if an elephant comes into contact with one of the hives or interconnecting wire, the hives all along the fence line will swing open and release the bees (King et al. 2017). Elephants usually get scared of bees because the bees can quickly attack elephants when disturbed (Enukwa 2017; King et al. 2017). At present, Sri Lanka has beehive fences surrounding the small areas of crops in home gardens (Butler 2016).

Using beehives as a method to deter elephants from crop fields offers several advantages. It ensures that elephants are not harmed. Additionally, farmers can also earn by selling so-called "elephant-friendly honey" and bee products (Enukwa 2017; Shaffer et al. 2019), which can serve as an additional source of income for farmers. Moreover, this method is cost-effective, making it easily affordable for farmers (Sugiyo et al. 2016). Moreover, this method is cost-effective, making it easily affordable for farmers (Sugiyo et al. 2016). The implementation of beehives has also proven effective in reducing HEC by minimizing crop destruction (Enukwa 2017).

However, there are some disadvantages associated with the use of beehives as a deterrent method. Elephants may adapt and create new routes to avoid areas with beehives, reducing the effectiveness of this approach. Adequate training and management of the beehives are necessary to ensure their proper functioning and effectiveness (Sugiyo et al. 2016).

Traditional approaches for mitigating HEC have proven to be ineffective in adequately addressing the challenges posed by this complex issue. The limitations and drawbacks associated with these traditional approaches highlight the need for a novel and innovative method to effectively manage and reduce HEC. It is evident that relying solely on the existing techniques is insufficient in providing long-term solutions and achieving sustainable coexistence between humans and elephants. Therefore, researching alternative strategies and adopting a fresh approach becomes imperative to address the existing conflict and ensure the well-being of both human communities and elephant populations.

Methodology

In this review paper, a systematic approach was used to collect and analyze relevant literature on HEC, with a particular focus on the context of Sri Lanka. The methodology can be described in five steps, literature search, initial screening, focused search on Sri Lanka, study selection and data extraction and synthesis. A comprehensive search for relevant papers and data on HEC was conducted using various sources, including Google Scholar, ResearchGate, Scopus, Web of Science, websites, and newspapers. This search aimed to identify peer-reviewed journal papers, books, conference papers, and newspaper articles related to the topic. A total of 573 articles related to HEC were found, including 146 peer-reviewed journal papers.

In the first phase of screening, the focus was on collecting review papers related to HEC to establish a solid foundation for the analysis. The most important and relevant papers were manually filtered from this initial set of review articles, ensuring that this analysis would be grounded in a thorough understanding of the existing literature. In the next phase of the methodology, papers and data specifically related to HEC in Sri Lanka were searched. After identifying a comprehensive set of relevant papers and data, criteria were applied to select the most relevant studies for inclusion in the review. This included considering factors such as the quality of the research, the relevance to research questions, and the contribution of the study to our understanding of HEC in Sri Lanka. For this paper, 152 papers and websites were used including 75 peer-reviewed journal papers.

Key information was extracted from the selected studies, focusing on the aspects most relevant to the research questions. This data was synthesized, organizing it into categories that aligned with research objectives, and enabling a comprehensive and coherent presentation of findings. By employing this systematic and targeted methodology, a diverse range of literature were gathered and analyzed on HEC in Sri Lanka, ensuring that the review paper is both comprehensive and focused on the most critical aspects of the issue.

Results and discussion

This review presents an overview of the history, present status, and traditional approaches to preventing and mitigating HEC in Sri Lanka. Despite various efforts, HEC remains a pressing issue, highlighting the need for innovative strategies that prioritize both human and elephant safety for the long-term conflict resolution.

The major complexes of HEC are multidimensional, involving social, economic, and environmental aspects. They can be divided into several key areas, crop raiding, property damages, human injuries and death, elephant injuries and death, habitat losses and fragmentation, mitigation methods and their challengers and lack of effective policies and regulation.

In Sri Lanka, recorded a distressing number of elephant deaths, reaching a total of 439 in the year 2022. A significant proportion of these deaths were a direct result of HEC. Among these, 60 elephants were tragically killed by humans through gunshot wounds, reflecting the severity of the conflicts between local communities and these majestic creatures. Similarly, 59 elephants met a tragic end due to the use of explosives such as Hakkapatas, indicating the aggressive measures adopted to mitigate the HEC. Furthermore, electrocution caused the demise of 51 elephants, demonstrating the risks posed by the overlap of elephant habitats and human infrastructure. Man-made transportation systems also contributed to elephant mortalities, with 14 elephants dying due to train accidents and another 3 due to road accidents.

In response to the escalating HEC in Sri Lanka in 2022, the government found itself obligated to pay a substantial sum as compensation for the substantial human and property losses. The total compensation sum reached USD 946,553.34 (LKR 345,255,330), reflecting the severity and magnitude of the crisis. This amount was disbursed in recognition of 160 human fatalities, 192 injuries, and a staggering 2,741 instances of property damage caused by elephant encounters.

This enormous financial burden serves as a stark reminder of the urgency and necessity to address and mitigate the ongoing conflict, to not only reduce the cost to human life and livelihood but also to promote sustainable coexistence with the elephant population. These figures starkly underscore the urgent need for effective strategies and policies to mitigate the escalating HEC in Sri Lanka.

To mitigate the HEC, various measures have been employed, ranging from traditional measures like thorn branches and wooden fences to more innovative approaches like beehive fences, elephant watchtowers, guardhouses, and trenches. However, these methods come with their own set of challenges. They can be expensive, require regular maintenance, and often provide only short-term and limited-distance deterrence.

However, there is a lack of generic frameworks that provides a standardized approach to implementation. In Sri Lanka, the correlation between elephant habitats and changes in land cover and land use, especially greenery, has yet to be established due to the lack of up-to-date, detailed information and precise data on forest cover changes. Therefore, identifying the HEC risk zone hotspot map is an essential step in mitigating HEC in Sri Lanka. There is an extremely urgent need for a standard framework to monitor, identify and predict these HEC risk zone hotspots.

This paper suggests that prospects of incorporating satellite data fusion with GIS modeling in future research. This approach can facilitate more effective management and mitigation strategies by providing valuable insights into the spatial distribution of conflict hotspots. Satellite imagery can be used to prepare accurate and updated land use and land cover maps. Combining maps with GIS modeling to analyze elephant habitats and land-use patterns will identify risk zones and hot spots of HEC in Sri Lanka. The information of hotspots will significantly contribute to HEC management by identifying patterns of elephant movements using accurate changes in forest greenery and weather patterns. This information can be used to prioritize areas for intervention and allocate resources more effectively.

Using satellite data and GIS modeling to develop early warning systems can alert communities to the presence of elephants. Such systems will help prevent HEC incidents by giving communities time to take appropriate precautions and reduce negative interactions between humans and elephants.

Furthermore, integrate satellite data and GIS modeling into the development of adaptive management strategies and land use planning. This will help ensure that future infrastructure projects, agricultural expansion, and other development initiatives consider the spatial dynamics of HEC, minimizing potential conflicts. This approach can contribute to the development of targeted, effective, and sustainable strategies for mitigating HEC, ultimately promoting a more harmonious coexistence between humans and elephants in the region.

Conclusion

Sri Lanka is home to 10% of Asian elephants and 2% of the world's elephant population. The estimated elephant population divided by the land area, elephant density of India and Thailand, is 0.0008 and 0.006 respectively, while Sri Lanka's density is 0.088. However, their numbers have dwindled, with around 5,787 elephants in 2011. Elephant habitat loss, degraded forage, reduced corridors connectivity between forest areas, and a significant decline in elephant populations relative to their historical size and range have been caused by new human settlements and expansion of agricultural land use due to the rapid increase of rural human population.

Elephants confront more frequently with humans and people have attempted to kill elephants with explosives, poisoned foods, and gunfire. As a result, human and elephant deaths have increased in the last 30 years. From 1991 to 2021, there were 5,954 elephant deaths, and 2,111 human deaths. The highest number of elephant deaths, with 407 incidents was recorded in 2019. In HEC mitigation efforts, Sri Lanka spent USD 2.47 million on electric fences in 2019 and 2020, with a total length of 4,756 km, as part of HEC mitigation measures. The DWC also spends annually on elephant thunders, compensations to affected people, capturing and, translocating elephants, and drives elephants from villages into the forest. Also, traditional mitigation methods attempt to limit elephant movement into agricultural areas by using barriers such as thorn branches, wooden fences, beehive fences, elephant watchtowers, guardhouses, and trenches.

This article reviewed HEC's history, status, and traditional prevention and presently practicing mitigation methods. A variety of specific mitigation measures are used, but there are no generic frameworks to implement. HEC management has to be integrated into a long-term land use planning that recognizes elephants as an economic and cultural asset. Using high spatial resolution satellite data and GIS modeling to develop early warning systems can alert communities about movement of elephants according to the seasonal fluctuation of greenery of feeding grounds. Such systems will help prevent HEC incidents by giving communities time to take appropriate precautions and reduce negative interactions between humans and elephants. To find sustainable solutions to HEC, scientists, wildlife managers, policymakers, wildlife enthusiasts, government authorities, and local communities must actively work together.

Recommendation

Authors of present study suggest applying a satellite data fusion with GIS modeling to identify risk zones of HEC in Sri Lanka. Satellite remote sensing has the capability to classify land cover types with high accuracy and this fact has proven by thousands of researches throughout the world (Xie et al. 2008). GIS applies to integrate land cover data with other spatial data layers such as elephant movement records, HEC recorded spots, seasonal variations on vegetation, spatial distribution of human activities, and climatic data. Different land cover classification methods including random forest classifier and support vector machine will be used to classify land cover types to produce the most accurate land cover maps (Qin and Liu 2022) to obtain high accuracy in forest boundaries. GPS data can be used to observe, identify, and record the routes and movements of elephants and integrate field observations with GIS database. Through the GIS data analysis, it will be possible to reveal elephant movement routes, corridors, and entry points into human settlements or crop fields. The resulting HEC zone and elephant hot spots were then visualized on a map using GIS software. This system will inspire researchers to find new ways to protect people and elephants.

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Declarations

Competing interests The authors declare no conflicts of interest.

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