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A Review of the Modern Methodological Approaches to Tracking Elephant Intrusion in Sri Lanka

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This review aims to address the prevailing issues of elephant intrusion and the subsequent Human Elephant Conflict (HEC) in Sri Lanka, particularly in villages where the seasonal concentration of elephants can be observed in agricultural and surrounding wetlands. The episodic gatherings of elephants in these specific areas are a serious concern due to the lack of integrated control measures. The incidents of elephant gatherings are increasing in rural villages, especially during the off-season of paddy cultivation or nearing the harvesting period, as well as during the blooming times of fresh grass in the riverbeds. These interactions with people along their range lead to the onset of HEC scenarios. If these elephant gatherings are left without solutions, it could pose a significant threat to the affected areas, settlements, and economic values, making them highly vulnerable. Therefore, this paper suggests a holistic approach that integrates modern techniques with a literature review to explore and assess existing methods and identify viable ones to control elephant intrusion and mitigate the impacts on the affected areas and Sri Lanka as a whole.

KEYWORDS: Elephant intrusion, human elephant conflict, seasonal concentration, holistic approach

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INTRODUCTION

Human Elephant Conflict (HEC) is defined as complex interactions between humans and elephants that result in negative effects on human social, economic, or cultural life and/or on elephant conservation and the environment (Parker et al., 2007). It is a situation in which elephants cause problems for people by damaging agriculture, settlements, and properties and threatening their lives in retaliation. Humans also react against elephants by considering them as elephant vermin, a term that denies society's understanding of the nature of wildlife, thereby allowing their killing and ultimately leading to HEC.

HEC cases have been documented in regions across Asia and Africa, presenting a critical issue that requires sustainable solutions. It has multifaceted impacts on human life, including mortality, crop raiding, and property damages. Additionally, it leads to the death of elephants due to poaching and killing for tusks (Anni and Sangaiah, 2015). In India, 100 elephants and 400 people die annually during conflicts, impacting around 500,000 families socioeconomically. Annually in Sri Lanka, over 70 people and around 200 elephants die during conflict incidents (Fernando and Pastorini, 2011; Shaffer et al., 2019). Between 2007 and 2011, there were 1,123 elephant deaths and 335 human deaths (Kuruwita, 2022), averaging 225 elephant and 67 human deaths per year. From 2012 to 2016, there were 1,169 elephant deaths and 361 human deaths recorded due to HEC. According to Prakash et al. (2020), around 405 elephant deaths were reported in Sri Lanka in 2019, along with around 121 human lives lost in the same year. Based on the 2022 Environmental Statistics in Sri Lanka, an average of 134 elephant and 60 human deaths occurs each year. It is evident that human-to-elephant deaths are occurring and increasing due to HEC in a roughly 1:3 ratio. Most of the elephants live outside protected areas, where the land has been converted to agriculture, restricting their access to water and other resources as well as their movement through traditional corridors. Furthermore, during the dry season, elephants intrude into human settlements in search of water resources (Anni and Sangaiah, 2015). Deforestation, habitat fragmentation (Thennakoon et al., 2017), and agricultural expansion in Sri Lanka have contributed to the loss of forest habitats for wild elephants (Dombois, 1972). Asian Elephants *(Elephas maximus)* mostly prefer lower visibility habitats to avoid humans due to the prevailing conflict (Pastorini et al., 2015; Prakash et al., 2020). The massive agricultural development projects under the Mahaweli Development Scheme

in the past four decades in the dry zone of Sri Lanka have significantly increased habitat fragmentation and HEC incidents (Fernando et al., 2005).

Asian and African countries experience food shortages and displacement due to crop-raiding activity and the exploitation of elephants in slash-and-burn agricultural fields (Ville, 1995; Nelson et al., 2003). As the elephant population increases, habitat loss leads to elephants exploiting farmland due to food shortages in the wild. According to Fernando et al. (2021), elephants and people co-occur in approximately 70% of the current elephant range in Sri Lanka, and HEC arises in almost all areas where they intersect. However, the majority of HEC incidents have been reported in proximity to protected areas within a 5 km radius of a protected area (Rathnayake et al., 2022).

Historically, in Sri Lanka, the wet zone contained numerous elephants. During the colonial period from 1505 to 1948, the wet zone was converted into fields of commercial crops such as tea, coffee, rubber, and coconut, which led to elephants being considered vermin, and many of them were shot dead which resulted in their elimination from the wet zone (Jayewardene, 1994). Consequently, the elephants moved towards the dry zone, where their population and density increased due to the presence of numerous abandoned reservoirs that provided water sources (Fernando et al., 2011).

Several districts in Sri Lanka experience HEC cases, mostly in areas where agricultural lands are abundant. Significantly, elephants are living in eastern, northern, northwestern, southern, northcentral, and Uva provinces in the lowlands (Gunawansa et al., 2023). The availability of food determines the seasonal gatherings of elephants. Elephants prefer grass, and during the dry season, fresh grass grows in the riverbeds (Karunatilaka et al., 2021), leading them to travel long distances in herds.

In this context, the review aims to discuss the application of modern techniques that can be employed to manage HEC cases, minimise the loss of lives (human and elephant), minimise property damages, and maintain sustainable agriculture in Sri Lanka.

Contextual Methods

The main goal of this paper is to articulate modern and applicable methods, considering the context of various research studies implemented in other countries or partially in Sri Lanka. The prevailing issue of elephant gatherings in human settlement areas for crop raiding needs to be curbed in a holistic

and integrated manner. The review has been designed as an approach to managing the HEC in Sri Lanka, suggesting several modern techniques to be used in different contexts. Accordingly, it aims to find a solution for the prevailing concentration of elephants in rural areas, considering the future consequences both for the human environment and the elephant population, which are the royal symbols in Sri Lanka (Köpke et al., 2021). Finding a solution to the Elephants' intrusion and HEC in Sri Lanka is a challenging task that needs a long period of institutional engagement. However, the implementation of a holistic and integrated approach to address and find solutions to such problems is happening slowly or hardly at all mainly because of negligence. Many state-of-the-art techniques and methods that have mostly been used in various areas and countries have been discussed in the paper, and out of these, viable and modern methods have been discussed to provide insights regarding their viability. The prime expectation of the paper is to find a sustainable solution to the prevailing imminent hazard in the affected area through an integrated approach since agriculture is a major livelihood in several parts of Sri Lanka.

LITERATURE REVIEW

As humans and wildlife, particularly elephants, increasingly share land resources, competition arises. As the elephants' natural habitat shrinks, they are progressively compelled to confront humans, which results in severe damage to people and elephants alike (Shaffer et al., 2019). The major factors for declining wildlife are loss of habitats, land use changes, land ownership changes, and the growth of the human population (Kioko and Seno, 2011; Rathnayake et al., 2022). Many countries where the HEC prevails follow a few methods through which the targeted objectives cannot be achieved because of inefficiency, and they are futile methods to do so. HEC is connected with the behavioural changes of elephants and humans. It is important to compromise the HEC while understanding the behaviours of elephants when chasing or escaping humans from their territory. Many human lethal cases have occurred without any basic understanding of the elephants' behaviour. Also, as humans encounter the elephants without any understanding of their behaviours, the conflict becomes a serious situation where the losses are uncountable for both sides.

When the elephants enter with human-dominated areas, particularly agricultural and settlement areas, they are chased away by numerous methods. According to Fernando et al. (2011), farmers shoot them with

handmade guns to protect the crops and use hakkapatas, which are small exploding mines hidden in vegetables and fruits that harm the jaws of the elephants when biting (LaDue et al., 2021). It should be highlighted that many elephant deaths have occurred in several regions of Sri Lanka. According to the BBC (2019), in the year 2019, around seven elephants were killed due to suspected poisoning, and one elephant in that herd was pregnant, resulting in the death of the fetus as well.

The idea of constructing electric fences is also lethal to elephants and humans when it is used illegally or indiscriminately. In two ways, the electrocution cases occur that lead to the deaths of the elephants; one factor is when the electric wires sag and electrocute, and the second factor is the illegally formed high-power fences, which are immediately fatal (Kalam et al., 2018). The illegal electric fences erected by villagers near the forest and farmlands or to protect the settlement by farmers and/or villagers are fatal for the elephants. The elephants are trapped by such electric fences, causing death, and such illegal electric fences should be eradicated (Gunarathne and Premarathne, 2006) with the proper monitoring system by the respective authorities.

Every year, Sri Lanka loses a significant number of elephants due to electrocution caused by illegally erected substandard electric fences (Daily News, 2022). Also, in a couple of months in the year 2021, out of 100 elephant deaths recorded, 21 were from electrocution. There is no way to increase the number of electric fences, which are illegally formed and hooked up with the electric lines indiscriminately. Consequently, illegal set-up of electric fences causes fatal incidents for humans as well (Mongabay, 2021). Many people have so far been accidentally electrocuted by illegally formed electric fences that were indeed set up for the elephants. Measures are pivotal to monitor the elephants that are outside of the protected areas to curb the existing HEC (Compos et al., 2009).

Loss of Traditional Corridors and Consequences

The extirpation or partial loss of the elephants' corridor is a serious concern that should be discussed. Since there is fragmentation occurring in their traditional corridors, the consequences are dire for the HEC. The fragmentation of the protected areas has the potential to cause adversarial impacts on the animals, which tend to range for a long time and a long distance (Adams et al., 2016). The developmental activities in many countries pose threats to the traditional corridors through which elephants used to roam. According to Chakraborty and Paul (2021), the existence of the broad railway

through the elephants' habitat is a major inducing factor for HEC in West Bengal, India. Also, Sri Lanka is placed first in the row of deforestation in Asia (LaDue et al., 2021), destroying or fragmenting numerous traditional wildlife corridors that connect to the protected areas.

The elephants have broad home ranges within which they can move a long distance in a single day (Pan et al., 2009). Also, they tend to move to various habitats at different times (Kioko and Seno, 2011). Human-influenced changes in the physical environment have the potential to make the HEC (LaDue et al., 2021). The destruction of their traditional wildlife corridors due to developmental activities such as highway expansion affects the elephants seriously (Joshi and Singh, 2007). They tend to select another route that is not familiar to them, leading to the aggressive behavior of elephants, perhaps if the route is connected to agricultural lands (Kangwana, 1995; Nelson et al., 2003). The traditional corridors should be renovated or linked with the protected areas through corridors whereby the elephants can safely move within their ranges (Kikoti, 2010).

It is evident that the postwar development process, *viz*., major irrigation projects, has resulted in many habitat losses for the elephants. Also, agriculture for commercial purposes by the state and private corporations for fruits and sugarcane production and the encroachment activities of humans into the forest lead to the fragmentation of the elephants' habitat and resulting HEC (Fernando et al., 2011). Sustainable solutions are needed to protect the elephants living outside the protected areas. As the elephant population increases, the existing corridors are insufficient for them to move. Thus, it is important to identify corridors (Liyanage, 2012) that have not been declared yet to mitigate HEC.

Fernando et al. (2005) recognised that the protected area provided elephants with a refuge and food during the rainy season when the single annual crop was grown. During the dry season, elephants moved into slash-and-burn areas and utilised leftover crops and pioneer vegetation in fallow fields. Large, protected areas with traditional slash-burned agriculture practices facilitated co-existence, whereas monoculture agriculture practices led to year-round conflict. The study suggested that areas managed according to traditional land use practices should be part of an elephant conservation strategy where people and elephants must share resources.

Seasonal Gathering of Elephants

Understanding why elephants select specific times for crop raiding (Santiapillai and Read, 2010) and concentrate in particular locations after spending months in a particular area is crucial. Several factors influence the elephants' choices, including the availability of forage, water resources, vegetation, and topographic features of the land (Verdade et al., 2014; Garstang et al., 2014; Karunatilaka et al., 2021). In the past, people predicted rainfall when elephants appeared at the end of the dry season in Kenya, and in India, the advent of elephants was believed to bring monsoonal rainfall (Garstang et al., 2014). During the dry season, elephants tend to gather for food in areas where fresh grasses grow due to water released from reservoirs for irrigation and power generation (Karunathilaka et al., 2021). These seasonal gatherings at reservoir-bed grasslands involve various activities such as roaming, playing, fighting, and raiding. Additionally, when crossing main roads, elephants display alert behaviour to cross safely. One of the most significant seasonal gatherings takes place in Minneriya, where around 400 elephants gather (Karunatilaka et al., 2021).

Elephants at the Dumping Sites

Improper waste management poses a major environmental issue and threatens wildlife in their day-to-day lives. Many wild animals and birds mistake waste, plastic, and polythene for food, leading to health issues and mortalities among these species. Elephants, too, scavenge and rummage through waste at dumping sites in search of food. The dumping sites contain a variety of waste from different sources, providing a high-nutrition food source for elephants. Relative to their body size, elephants require a large quantity of food, consuming 150 kg to 300 kg of food while spending around 18 hours a day feeding (Liyanage et al., 2021).

Due to the improper waste management system, landfilling, combustion of waste materials, and lack of environmental awareness, protected areas for Asian elephants are under threat (Puri et al., 2020). Sri Lanka is no exception, as elephants are known to consume garbage in many parts of the country, including the Pallakadu area and Oluvil. Elephants scavenging at dumping sites tend to consume polythene materials, leading to several deaths, and food poisoning has also been identified as another cause of mortality among elephants rummaging at dumping sites (Mongabay, 2022).

However, it is important to note that according to Liyanage et al. (2021), the consumption of garbage is not a significant health problem for elephants. While elephants do spend some time at dumping sites, garbage consumption is not their primary activity. Nevertheless, incidents of toxic or food poisoning cases resulting from garbage consumption need to be identified through necropsies (The Morning, 2019).

Traditional and Modern Methods to Detect Elephant Intrusion

Various methods are employed to divert elephant intrusion and protect agriculture and settlements. These methods include igniting fires, drumming techniques, beehives, chili fencing, electric fencing, and early warning systems using different technologies (Hahn et al., 2017; Karidozo and Osborn, 2015). Electric fences are commonly used globally to control elephant intrusion; however, systematic operation is needed to make them more effective (Liyanage, 2012).

The existing electric fences are not entirely efficient, as elephants still intrude through them. Proper planning mechanisms should be considered when erecting electric fences, including ecological boundaries rather than administrative boundaries. Moreover, proper maintenance is crucial to ensure the efficacy of the electric fencing system (Global Wildlife Programme, 2017).

As modern techniques, satellite telemetry can form an early warning system to alert people, GPS tracking (Pastorini et al., 2015) allows monitoring elephant movement, seismic sensors accurately detect elephant movement where GPS trackers may not have access, hovering drones provide surveillance (Hahn et al., 2017), and counting the number of elephants are used in many countries.

Automatic early warning systems with infrared technology (Sugumar and Jayaparvathy, 2014; Rathnayaka et al., 2020; Chakrabort and Paul, 2021) are also commonly used. Unmanned aerial vehicles are employed to observe elephants' movements, providing real-time data (Hartmann et al., 2021). Satellite images combined with artificial intelligence are efficient for surveying and counting elephants, preventing double counting of the same elephants (Hahn et al., 2017; Livescience, 2021; The Hindu, 2021).

In summary, the issues of elephant intrusion and HEC cases continue to increase due to insufficient preventative measures. The existing techniques and methods are not fully effective, as reflected in the literature. Given the

significance of elephants in agriculture and socioeconomics, strategic conservation measures are necessary to protect and preserve these magnificent animals.

RESULTS AND DISCUSSION

In the Sri Lankan context, the major source of income for the villagers is agriculture. At the same time, elephant intrusion during the post-harvesting period is rife, where the reflection of human activities lowers and elephants directly intrude on the targeted places. Consequently, the socio-economic well-being of the people is under threat. Earlier, there was an issue with a few elephants or a single elephant's intrusion into villages or agricultural lands. Presently, the seasonal gathering of the elephants as a herd (more than 100) has several ramifications for the settlement area, agriculture, and even urban areas.

According to Karunarathne et al. (2021), a household survey in Ekgaloya in Ampara District indicated that 17% of Paddy *(Oryza sativa)* and 15% of Maize *(Zea mays)* were lost due to crop raiding within the cropping season. Whenever the elephants intrude on the agricultural fields and surrounding wetlands, there are several possibilities for accidental confrontation with humans, which leads to the HEC and causes deaths and injuries to humans and elephants. During the post-harvesting period, the ranging and gathering of more than 200 elephants, according to locals, takes place in paddy lands and surrounding wetlands in Nintavur and nearby villages. The gathering of the elephants lasts for over a month, which is an attractive scene along the areas where a part of the A4 road, i.e., the Colombo-Batticaloa highway, crosses from Akkaraipattu to Kalmunai.

There is a growing concern about the seasonal gathering of the herd of elephants in the Nintavur area because perhaps any incident, intending to disperse them or if they are provoked, would have an unimaginable result, particularly because the people would be endangered due to the elephants' attacks, and on the other hand, the elephants would also be threatened due to the retaliation of the people, which would finally result in the loss of elephants, where only around 5,879 elephants exist in Sri Lanka (öpkeetpkeet, 2021).

It is a tricky matter to consider that since a couple of years ago, the elephants' concentration has been on the rise in the particular area, and the reason why they gather and from where they travel should be investigated to control their

intrusion in a mindful manner. Diverting the elephants or driving them to another place is a challenging and life-threatening hazard because when they get angry, the result would be serious. Still, during the gathering period, several youths try to provoke the elephants because of their irritation and exasperation. The elephants chase them, which perhaps leads to the conflict. According to the locals of the area, during the gathering of elephants, the nighttime travels for emergency purposes, transportation from one place to another via the nearby roads, and the settlements close to the elephant's concentration point are challenging. Some of the individual elephants that are veering from the herd tend to roam the nearby villages, which is a major threat to the people living there.

It is also evident that in the range of the elephant, there are many local dumping sites, particularly in Kalmunai wetland areas and Nintavur, with the major dumping site being located in the Pallakadu Oluvil area. People reportedly say that the elephants come to find garbage in the areas, but there is no clear-cut evidence for this since they come to concentrate in nearby Nintavur. It is vital to know the movement of elephants when they move, why they move, and from where they move to successfully conserve and manage them and to minimise HEC cases (Bohrer et al., 2014). According to a study by Prakash et al. (2020) study, 479 HEC incidents have been reported in Ampara District from 2010 to 2019.

Dumping sites attract elephants when they range along their trails. At the Pallakadu dumping site, located in Ampara District, more than 10 elephants can be seen daily scavenging the garbage. Elephants tend to consume garbage (Liyanage et al., 2021) and according to the Voice of America (2022), since the last eight years, around 20 elephants have died consuming waste, including plastics (polythene), in the Pallakadu area of Oluvil. However, there is another counterargument by Liyanage et al. (2021) that feeding garbage to elephants in the Uddakandara garbage dump in southern Sri Lanka showed that elephants feeding on garbage had better body condition than non-garbage consuming elephants, indicating that garbage provides better nutrition than fruits and vegetables, which should be deeply investigated. It is important to identify whether the concentrating elephants in Nintavur area mingle or interact with the elephants in Pallakadu area in Oluvil or whether they are permanently occupying elephants at the dumping site. If they are permanently occupying elephants, it should be found out how the gathering elephants move along the dumping site area and how they behave with the already existing elephants in the dumping site.

Figure 1 shows the dumpsite in Pallakadu, Oluvil, in Ampara District. It is a pathetic situation where the treasure trove of the country is left to consume waste without any consideration, knowing the dangers of waste consumption. As shown in Figure 2, a wild elephant has died in an open landfill in Pallakkadu village in Ampara District. Thus, an integrated approach is a must to control the elephants' intrusion and HEC since many of the traditional corridors of the elephants have been modified due to human activities. Before the imminent issues arise in the areas of Sri Lanka where elephant seasonal gathering and intrusion occur, it is indeed needed to control them in a tackling manner. To do so, the tracking of elephants is important using GPS technology, which can give real-time monitoring of the elephants' movements and routes, with which the entire route of the elephant can be identified.

Figure 1: Pallakadu dump site, Oluvil area

Source: Voice of America, 2022

Figure 2: Dead Elephant in Pallakadu area, Oluvil

Source: Arab News, 2022

There is a vital need to conserve elephants as well as the socio-economic condition and lives of the people in Sri Lanka in a tackling manner. During the raids of the elephants, numerous varieties of crops such as banana, rice, corn, coconut, and home gardens consisting of fruits and vegetables (Köpke et al., 2021) were affected or destroyed completely. In the Ampara District, particularly in the coastal villages, agriculture is one of the major socio-economic sources of the people. However, the recent elephant gathering incidents harm the socio-economic system and the security of the inhabitants. A holistic approach is needed to minimise the present HEC incidents and future possible impacts mentioned earlier. The elephant's tracking is the utmost task to be done to pinpoint the movement of the elephants along the areas.

Tracking the Elephants' Movement

It is vital to find the source of the location in which the elephants come and concentrate in a particular area with the view to knowing the exact factors affecting the recent peak of the gathering of elephants. GPS (Global Positioning System) collars are the best method to track elephants' movements (Pastorini et al., 2015; Rajalakshmi et al., 2021). The GPS collaring process can be done for a few elephants from the gathering to track their real-time movement with the support of respective organisations, *viz.,* the Department of Wildlife Conservation, and the Forest Department. The GPS tracker SIM would give the movement data of the elephants all the way.

Also, the system is nowadays commonplace, whereby the movements of other wild animals and birds are also tracked (Allan et al., 2013).

Based on the tracking of the elephants, it can be found from where the elephants move, where their traditional corridor has been affected, and at which point the diversion of the elephants happens. Then, we can analyse the problems with the field visits to investigate what happened to their traditional corridors, why they ranged along the route, and what happened to the electric fences to control them.

Having identified the track of the elephants, early warning systems with modern technology and novel methods, which have been discussed below, can be applied to alert the area to the elephants' intrusion. Once the intrusion is known, the people will be aware of the alert messages and announcements to the villagers who are in the paddy field or perhaps heading to the hazardous zone. Generally, in Sri Lanka, the integrated and holistic approach to elephant intrusion to minimise HEC cases is lacking, as already discussed. In the HEC regions, the integrated ways to find elephants' intrusion and to control the HEC could be adopted as an exemplary method with the following state-of-the-art technology and the support of state and international agencies that are keen to support such purposes, particularly for socio-economic enhancement of society.

One of the existing methods to control elephants' intrusion is electric fences, which alone cannot control the elephant intrusions (Gunaratne and Premarathne, 2006; Nadeeshani and Perera, 2021), and it can be understood that the use of electric fences to control the elephant intrusions is not applicable since they are crossing over agricultural lands. Even for erecting electric fences, the source of the location from which the herd comes should be understood.

Also, the geofence biotelemetry system is a cutting-edge and novel technique to solve HEC. Coupling web-mobile applications and geofencing techniques is useful to detect the elephants' intrusion in HEC alert areas (Rajapaksa et al., 2022). The geofencing prototype model was tested in Udawalawe National Park in Sri Lanka to control the HEC and protect the elephants. Elephant movement and their home range can be detected using the biotelemetry system and unmanned aerial vehicle surveys, which are useful to delineate virtual boundaries in vulnerable areas.

Unmanned Aerial Vehicles (UAV) are nowadays used to study in many sectors. To monitor the elephant intrusions in the hard-to-reach areas, drone-based observation is performed. When the elephants raid from forest to agricultural lands, it is difficult for them to monitor until they reach proximity to human settlements. Using drones, they can be monitored from remote areas in order to instruct people to be alert and cope with the situation. Also, during the night, rough elephant hideouts can be detected using thermal cameras fixed on the drones. Also, satellite-based monitoring helps to detect the periodic movement of the elephants, which can be identified after analysing the satellite images (Gunawansa et al., 2023).

Early Warning Systems in Elephant Corridors

Modern technological instruments can be applied to mostly all sectors for observation, monitoring, management, and historic analysis. Likewise, globally, several technological inventions have been applied to control elephant intrusion and HEC too. The loss of crops, property, and human lives has so far been reported, mostly due to the sudden confrontation of elephants in agricultural and settlement areas. This situation can also be controlled using the early warning system in potential locations. In a few locations, the early warning systems are in practice, which is also challenging. According to Sugumar and Jayaparvathy (2014), it is recommended to form an early warning system along the areas where the elephants' intrusion happens, and for that, an algorithm-based elephant intrusion detection system can be used whereby the elephants' intrusion happens in a particular corridor.

Many researchers have introduced modern techniques to find the elephant intrusions in advance, to take immediate action, and to alert the people. eCameras and remotely functioning instruments and sensors are the best tools to transfer data from the source to the receiver, with which information can be obtained from faraway places. According to Sugumar and Jayaparvathy, (2014), with the use of cameras mounted on trees or towers, images can be captured of intruding elephants, which are then sent to the base station via a radio frequency (RF) network. The images can be processed on the computer at the base station and compared with the stored database. Every five (05) seconds, a snapshot can be taken and compared with the database. Then, once the images match, via the global system for mobile communication (GSM) connected with the computer, send a short message service (SMS) to the officials to alert them. The method can be

applied in the Sri Lankan context, particularly in areas where seasonal elephant intrusion takes place, with the view to minimising the impacts.

Rathnayaka et al. (2020) also developed elephant intrusion detection with IR (infra-red) beam detectors (100m) and Passive infrared (PIR) sensors (12m), deterrence; with speakers and mp3s of bee buzzing sounds to chase or threaten the elephants before intrusion and alerting with signal lights for wireless communication in the range of 1 km with the alert SMS with Google Maps and an online database and warning system. It can also be applied in places where the elephants have the potential to intrude, particularly in the corridors. This holistic approach for elephants' intrusion detection, deterrence, and warming system is an astonishing method in Sri Lanka, which is indeed a need in the locations where HEC is rife.

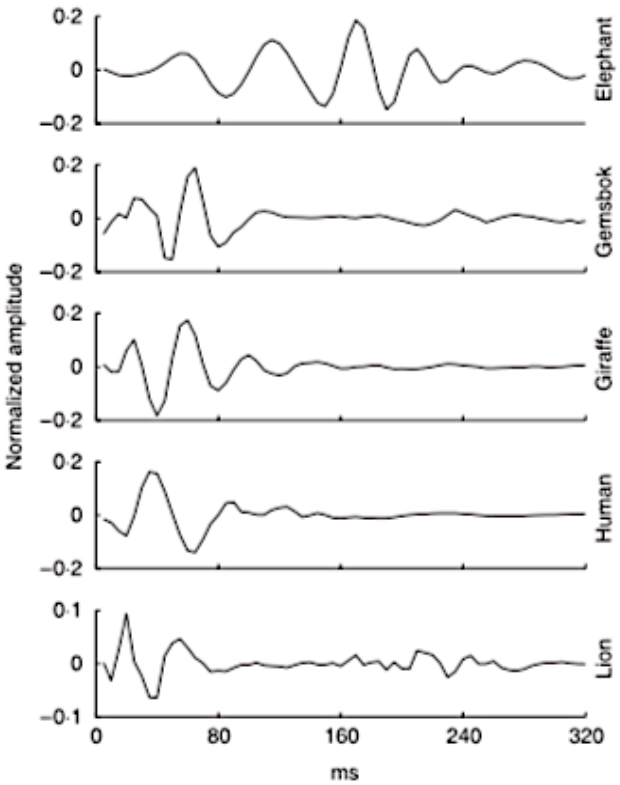
Seismic Sensors Application to Recognise the Elephants' Movement

Detecting elephants' movements with seismic waves is a more advanced method used in many countries. The large herd of elephants' intrusion should be carefully traced for precautionary activities and to minimise the impacts. Since the elephant's movement happens in thick forest areas where perhaps the signal for the GPS is inaccessible, seismic waves are a suitable method to detect the movement. If the movement is understood at an early stage within a forest area, then diverting or dispersing them without concentrating on their destination is a handy task to minimise the impact. For this process, the early stages of the elephant's movements should be detected and known. Wood et al. (2005) have conducted research based on the seismic waves to detect the animal's movement, within which they have distinguished the elephant's movement.

Seismic waves have the potential to pass through solid materials (University of Oxford, 2021). Historically, the geophone sensor system has been used for many purposes. During the Vietnam War, the United States military used geophone sensors to detect the troops and the movement of vehicles (Wood et al., 2005). Nowadays, seismic sensors are widely used to find the elephants' movements with the view of detecting the elephants' intrusion and to control HEC within the forest-settlement borders. According to Wood et al. (2005), seismic sensors were used to find the elephants' movements after comparatively studying the spectral differences of some selected species, *viz.,* lion, giraffe, Gemsbok, elephants, and including humans (Fig. 3). For this, a single 4.5 Hz geophone (vertical) was placed into the ground at around 1 m depth. Then, a preamplifier was used to enhance the recording and to

convert the signal from analogue to digital, a sound card was used. Consequently, it was recorded on a laptop with the Cool Edit Pro Software. Front footfalls were considered since rear footfalls have lower amplitudes. Then, the footfalls were uploaded to the Matlab software to create a power spectrum plot for each footfall with the Fast Fourier Transform. After processing, they have differentiated the species and the individuals with the integrated systems within which the elephant's footfall mostly differed from the other animals' spectral signature. Figure 3 shows the spectral variation of the selected animals (Wood et al., 2005), whereby the elephant's spectral signature can easily be understood compared to other animals. Therefore, the movement of the Elephants in the forest areas can be traced with the view of alerting and warning the people in advance, and if possible, they can be diverted within the forest environment with possible actions before they begin to intrude into unprotected areas.

Figure 3: Spectral differences within species



Source: Wood et al., 2005

Having tracked the route of the elephant and the location where tracking is impossible due to signal weakness and thick forest corridors where early warning systems cannot work, the seismic sensor method can be applicable in a place where the herds of elephants roam for a long distance.

CONCLUSION

Elephant intrusion and consequent HEC are escalating issues in Sri Lanka, particularly in the villages where agricultural land expands towards their traditional corridors. It is crucial to acknowledge that agriculture is the major socio-economic activity of the people in the villages, which must be safeguarded to meet their needs. Additionally, it is essential to protect the elephants. This necessitates a thorough investigation to trace the source-land of the intruding elephants, understand why they come along the areas and gather or concentrate in specific places, and determine what happened to their traditional corridors, all through a holistic approach. Various methods have been explored to find the source of the elephants' gathering and modern techniques to detect and control their intrusion to minimize HEC.

Furthermore, it is imperative to educate people about the behavioural changes of elephants when they encounter or confront humans. Many HEC cases have occurred without an understanding of the elephants' behaviour. As elephants are a vital resource that interacts with the human environment, especially outside of protected areas, raising awareness about elephant behaviour from the grassroots level is necessary. This can be achieved through community engagement, stakeholder participation, and institutional support, which can be applied to cases involving concentrating elephants in specific areas to mitigate potential threats and dangers.

In conclusion, a holistic approach is required to address HEC cases in Sri Lanka, considering that agriculture is a major livelihood. The review suggests several modern techniques that can be applied in different parts of Sri Lanka in a viable manner since relying on a single method to control elephant intrusion and manage HEC cases is not efficient and effective. For instance, in canopy areas where detecting elephant movements using GPS or aerial views is difficult, seismic sensors prove to be more effective. Similarly, geofences are more practical than physical electric fences, as the latter can be inefficient in various parts of Sri Lanka due to the intricate movement of elephants and fragmentation.

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