ASSESSING THE EFFICACY OF SELECT PHYSICAL BARRIERS IN MITIGATING HUMAN-ELEPHANT CONFLICT IN THE HUMAN-ELEPHANT SHARED LANDSCAPE OF GOLAGHAT DISTRICT, ASSAM

Thesis submitted for the award of the Degree of

MASTERS

in

WILDLIFE SCIENCE

by

GITIMA DAS

to

SAURASHTRA UNIVERSITY
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DECLARATION

I, **Gitima Das**, hereby declare that the research work titled "**Assessing the efficacy of select conflict mitigation strategies in a human-elephant shared landscape of Golaghat, Assam, India,**" carried out as partial fulfilment of M.Sc. (Wildlife Science) degree under Saurashtra University, Rajkot is an original piece of work. This research work was carried out under the supervision of Dr. Gopi G.V, Dr. K.M. Selvan, and Dr. B.P. Lahkar at the Wildlife Institute of India from January 2021 to July 2021. I also declare that this work has not been submitted for any other degree of any university.

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CERTIFICATE

This is to certify that the thesis entitled **"Assessing the efficacy of select physical barriers in mitigating human-elephant conflict in the human-elephant shared landscape of Golaghat district, Assam"** is a bonafide work carried out by **Ms. Gitima Das** in partial fulfilment of the requirement for Master's Degree in Wildlife Science of the Saurashtra University, Rajkot, Gujarat. The study was carried out under my supervision from January 2021 to July 2021. I hereby certify that this work has not been submitted for any degree to any university.

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CERTIFICATE OF PLAGIARISM CHECK

It is certified that the M.Sc. thesis titled "**Assessing the efficacy of select physical barriers in mitigating human-elephant conflict in the human-elephant shared landscape of Golaghat district, Assam**" submitted by Ms. Gitima Das has been examined by us for plagiarism check as per UGC (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulations. The following inferences are drawn from this check:

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Today more than ever before, life must be characterized by a sense of universal responsibility, not only nation to nation and human to human but also human to all other forms of life," a memorable quote by the Dalai Lama is indeed compelling. The two 'C's, conservation and coexistence, should be given importance for a peaceful restoration of nature and bringing back the balance of life on earth. No matter how significant or pitiful, every art impacts the human brain, creating more curiosity. Realization about the beauty of any form of art is incomplete without the appreciation of its artist. Similarly, this piece of art, no matter how it performs, indeed would not have been even close to being realized and impactful without the help and guidance of a lot of creative minds and strong willpower to work.

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1.Project summary:

Human-Elephant Conflict (hereafter "HEC") is one of the most challenging issues both for elephant conservation and people's wellbeing in the elephant landscapes. Management of which becomes extremely difficult without the implementation of appropriate mitigation measures. Physical barriers, like solar fences, elephant-proof trenches, stone, or rubble walls are installed as mitigation measures in all elephant-occupied habitats at the edge of the forest and human-use areas, globally. However, installations of the same without a proper scientific rationale and assessing and analysing their site-specific efficacy in reducing elephant incursion in the human settlement areas often fail in doing its intended objectives. It is important to note that humans are also a crucial component of conflict, hence research focusing on social aspects are essential for finding solutions.

Keeping such concepts in mind, an assessment to determine the efficiency of two types of physical barriers, viz., solar fence and elephant-proof trench (EPT) was carried out in one of the prime elephant habitats of north-eastern India, in Golaghat district of Assam. Located on the southern bank of the Brahmaputra and home to Kaziranga National Park (KNP) on the west and Nambor-Doigurung Wildlife Sanctuary (NDWLS) in the south, Golaghat offers an ideal site for such study. It is realized that even after the presence of barriers in various areas of the district, conflict cases in the form of crop-raiding, human mortalities and human deaths continue to be reported. Handful studies on barriers and their effectiveness were done recently on the northern bank of Brahmaputra. However, no such appraisal on efficiency of barriers has been done in this landscape, where conflict levels are high. Hence, this study attempted to fill these existing research gaps.

This study looked at the historic human-elephant conflict records acquired from the Forest Department (FD) from 2010-2019 to check the spatial extent of the conflict and its dispersion in the district. Furthermore, an assessment on the efficacy of two physical barriers viz. EPT and solar fence was carried out by evaluating the encounter rates of elephant signs and other covariates at both barrier and non-barrier sites, parallelly along the barrier and the forest edge, respectively. The study also assessed the local people's perception on the barriers and overall conflict in their area based on their willingness to pay (WTP) used as a proxy.

An optimized hotspot analysis of HEC was done using historic conflict data from 2010-2019 for the district. The highest conflict occurred between 2016-2017, making up 25% of the total conflict. An average of n=86, 71 and 70 villages are found to be high conflict hotspots based on *z*-score $\geq$1.96 ($\geq$ 95% CI) for crop/property damage, human mortalities and elephant deaths in the district, respectively. However, it was noticed that the extent of these hotspots were concentrated in the same areas throughout the decade and there was no evidence suggesting the dispersion of conflict to other areas.

The output from Welch's ANOVA states that there is a significant difference in the encounter rates of elephant signs between solar fence and no-barrier sites, with solar fence showing relatively lower encounter rates of elephant signs than the trench. A generalized linear model shows that encounter rates are influenced significantly by availability of barriers (i.e., solar fence and trench), and distance from the forest.

Further, a total of n=249 semi-structured interviews in six villages were done to understand people’s views on the human-elephant conflict. For a better understanding of variables’

relationships, a multinomial logistic regression was run to evaluate people's perception on the barriers. Their perception was evaluated for two possible situations, i) the sites already having a barrier or ii) whether they would want to have a barrier installed in the non-barrier sites, based on their willingness or unwillingness to pay for construction/maintenance of the barrier. Interestingly, it was observed that people’s perception on barriers was affected by various conflict-related variables instead of their socio-economic status. Of the seven explanatory variables, i) the persistence of HEC cases, ii) whether compensated or not, iii) time delay in compensation, iv) change in elephant incursion, and v) change in crop-raiding by elephants significantly explain their perception on barriers.

These results concur with previous studies done on human-elephant conflict. Nevertheless, results from this study impart important site-specific management implications. Emphasis on traditional mitigation measures, improvisation in compensation schemes, support from government authorities, and further reduction on the conflict extent, conservation in mosaic landscapes beyond protected areas, ensuring safe passage, and implementation of site-specific modern practices of conflict mitigation can help in promoting human-elephant co-existence in this landscape.

Keywords: Human-Elephant Conflict, Golaghat, spatio-temporal pattern, solar fence, elephant-proof trench, people’s perception, optimized hotspot analysis, willingness to pay.

2. Introduction:

The negative interactions between humans and elephants arising from diminishing space and overlapping food availability is commonly known as Human-Elephant Conflict (HEC) (Fernando et al., 2008). The words “negative interaction” here are often used as an umbrella term for loss of life of both animals and humans, damage to property as well as monetary losses (Tchamba, 1995). The global populations of most Asian and African elephants are affected by human-elephant conflict (Blanc et al. 2003) and regions, where human settlements are close to elephant habitats have seen an intensification in conflict incidences (Naughton et al. 1999). HEC is most common in areas where former elephant habitats have been reclaimed, encroached, and converted into farmlands (Osborn & Parker, 2002). Human–elephant conflict also serves as an increasing limitation for elephant conservation. It creates resentment towards elephants among people as it pressurizes means of daily livelihood, survival and causes human life threat in severe cases (Omondi et al. 2004).

The Asian elephant (*Elephas maximus,* Linnaeus, 1758) is one of the leading flagship species' for biodiversity conservation in Asia (Fernando et al., 2008). India, being a country with an average human population density of 455 persons per km^2 (World Bank, 2018) and holding essential elephant habitats, is among the HEC hotspots in the world. In India, the top three high conflict states are Assam, Chhattisgarh, and West Bengal (The Times of India, 2017). The rise in HEC cases is often due to crop raiding in villagers' agricultural fields by elephants that fall within the elephant ranges (Fernando et al., 2008). Asian elephants are estimated to damage around 0.8 to 1 million hectares of people’s land by crop-raiding (Bist, 2002). These sudden encounters result in the injury and death of both humans and elephants.

According to Rangarajan et al. (2010), the intensity of HEC has increased and dispersed over the last two decades. Hence, it is vital to understand the spatio-temporal dispersion patterns by collating and comparing the past decade's conflict instances concerning various negative interactions possible, viz., crop losses, loss of life, property damage. With the increasing intensity of conflict, effective mitigation is vital for the conservation of this endangered species. A lack of clear understanding of the principles of implementation and maintenance of tools such as barriers and guarding methods is often found leading to a failure (Desai & Riddle, 2015). However, in the Indian context, there is a lack of monitoring and assessing the effectiveness of the implemented management approaches, including physical mitigation tools like electric fences, trenches, and walls (Rangarajan et al., 2010). Therefore, rigorous testing of these mitigation measures is direly needed, similar to instances in the conflict areas of Africa and Asia, for successful and long-term management of conflict (Nelson et al., 2003).

The state of Assam supports a population of around 5719 elephants (Sukumar et al., 2020), second only to Karnataka, and is among the high conflict regions in India, where 69 people succumbed to elephant attacks within the span of three years from 2015-2017 (The Times of India, 2017). The evident reason is that in Assam, forests are highly encroached (Department of Environment & Forests, 2011). Also, Assam has diffuse boundaries between human use areas and elephant habitats; this makes the implementation of physical barriers complex (Rangarajan et al., 2010). As a result, conflict turns severe and should be tested to deter elephants away from human settlements. A general observation suggests that the persistence of conflict in an area affects people's attitudes and perceptions towards wildlife and conservation efforts that heavily influence their willingness to engage in any conflict mitigation process (Karanth & Kudalkar, 2017).

In recent times, only a few studies have examined the social aspects of human-animal conflict (Inskip & Zimmermann, 2009; Campbell-Smith et al., 2012). This research attempts to overcome these knowledge gaps by assessing the effectiveness of the implemented physical mitigation methods, understanding people's perception of HEC, and learning the reasons behind these perceptions, which often affect their decision-making process on the deployed mitigation measures.

3. Literature Review:

Human-wildlife conflict is a rising topic of concern for many endangered species worldwide, being another threat in their race of survival. Species ranging from large to small mammals are currently under this threat, such as Sumatran tiger (*Panthera tigris sumatrae*), Asian lion (*Panthera leo persica*), African elephants *(Loxodonta spp.)*, Asian elephant (*Elephas maximus*), Snow leopard (*Uncia uncia*), and Red colobus monkey (*Procolocus kirkii*) to name a few (Distefano, 2005). Human-wildlife conflict occurs when species' habitat or preferences overlap with human requirements (World Park Congress, 2003). The regions in and around protected areas often serve as conflict hotspots. As a matter of convenience, animals tend to stray into these regions due to better resources (Distefano, 2005). The raiding of cultivated fields and livestock depredation are common forms of human-wildlife conflict. However, human deaths caused by an animal are a severe form of conflict that elicits a negative attitude towards the concerned species in people's minds; this imposes many conservation challenges.

A report by Distefano (2005), looking at the global human-wildlife conflict cases, states that multiple contributing factors amplify the same. Some factors include land-use changes or conversion over the years, wildlife population explosion simultaneous to increase in human population, vanishing species habitats due to continuous loss, degradation and fragmentation of forested areas, changes in climatic factors, and various stochastic events, etc.

In the current context of conflict, one such animal among the world of pachyderms, i.e, elephants, the African elephants *(Loxodonta spp.)*, and the Asian elephant (*Elephas maximus*), both clinging onto an endangered status need adequate conservation attention to find effective solutions for mitigation of Human-Elephant Conflict (HEC) for a peaceful co-existence with humans. As elephants require larger areas for their home territories and migration, increasing densities of human and elephant populations struggle and compete for similar resources like land, water, and privacy (Distefano, 2005). Globally, wild populations of all the elephant species are found in 50 countries, out of which 13 lies in Asia and 37 are in Africa (Perera, 2009).

3.1. Global context for Human-elephant Conflict:

In Africa, only 4,15,000 out of 10 million elephants are now left since 1930; their numbers have declined significantly by 111,000 elephants since the last decade, contributing factors being increased demands for ivory, habitat loss, and HEC (WWF, 2018). The African elephant populations are found to cause twice the havoc and aggression amongst the local people as they attack larger areas than African lions (Distefano, 2005). The estimated total economic loss due to crop damage by the elephants in the mighty African continent between 1991-1995 was around US$ 39,200 (O'Connell-Rodwell *et al.* 2000). Reportedly, Africa saw an increase in the number of crop damages by *Loxodonta africana* by 49% between 2000-2015 (Tiller & Smith, 2021).

The population of Asian elephants is estimated to be 41,410 to 52,345 individuals scattered in the highly fragmented habitats of 13 range countries in Asia, currently occupying 5% of their historic geographic range (Sukumar, 2006). The International Union for Conservation of Nature (IUCN) lists extant Asian elephants as Endangered and under their Appendix I (Perera, 2009; Choudhury et al., 2008). The various threats that affect the conservation efforts for Asian elephants include habitat loss, fragmentation of their habitat, human-elephant conflicts (HEC), and illegal killing. In Asia, these 13 countries are called the "Asian Elephant Range State" (AsERSM, 2006).

There are different forms of HEC including, loss of human and elephant lives and damage to properties. Still, crop-raiding is considered the highest form of loss as it remonstrates the means of survival of the concerned peoples (Desai & Riddle, 2015). Studies have suggested that crop-raiding instances accelerate during the harvest time, often promoting retaliatory killings of elephants in response to high crop losses (Chen et al., 2006; Graham et al., 2010; Webber et al., 2011; Gubbi, 2012). The most commonly reported, publicized, and enraged conflict costs include crop depredation and human casualties (Ngure, 1995; Lahm, 1996; He et al., 2011; Nath et al., 2015). However, other essential costs such as reduced psychosocial well-being and disrupted social activities are always unaccounted for (Jadhav & Barua, 2012; Barua et al., 2013). This adds to the generation of antagonistic feelings and low tolerances for elephants among local communities, serving as a limitation towards elephant conservation efforts (Desai & Riddle, 2015).

In southeast Asia, during 2001-2002, HEC reportedly occurred in 28% of the elephant range in Bangladesh, resulting in thirty-eight human and three elephant deaths. This had estimated damage of US$ 86,000 in terms of crop loss and property damage (Feeroz et al., 2004). In Nepal, the intensity of HEC is not severe, instead of on a moderate level in the conflict areas around the elephant habitats. The HEC related number of deaths in Nepal until 2008 summed up to be 66 humans and 18 elephants (Perera, 2009). For Bhutan, being a low human dense country, the occurrence, and intensity of HEC are reportedly low (Perera, 2009; Murdoch, 2008). However, Indonesia faces a high intensity of conflict due to many resident elephant populations of 2000-2500 individuals and increasing human density. Local people faced a financial loss of US$ 12,000 as a result of crop-raiding by elephants between the years 2000-2002, which also includes three reported human deaths (Hedges et al., 2005). Sri Lanka also documented over 70 human and 200 elephant casualties due to conflict till 2010 (Santiapillai *et al.,* 2010; Fernando & Pastorini, 2011).

3.2. National context for Human-elephant Conflict:

Currently, India is home to the highest surviving populations of Asian elephants, with the latest counts reporting about 27,312 individuals (Perinchery, 2020). However, with a simultaneous increase in human density around the elephant habitats reports estimate the death of 600 humans and 300 elephants annually, which affects 600,000 resident families and their one million hectares of land due to crop-raiding by these pachyderms alone (Fernando et al., 2008; Pokharel et al., 2018).

India is an agronomic and elephant range country with a net sown area covering more than 51% of the country's total geographical area (ICAR, 2021). However, the forest and tree cover of the country is relatively lower, covering 24.56% total geographical area in 2019 with a negligible increase of 0.17% since 2017 (Hindu, 2020). This suggests the reason behind the rise in crop-raiding cases over the years by the elephants. Subsequently, with the decline and increase in fragmentation of forest patches throughout the elephant habitats in the country, elephants are bound to venture out from the protected areas to agriculture and human-use areas for survival (Anand, 2020; Naha et al. 2020).

In addition, the compensation system by the forest departments in the majority of the states has a lengthy and time-consuming process. This is a major contributor to people avoiding the application of compensation altogether (Anand, 2020). This may also be one reason behind less or no conflict reporting, which creates a gap in the proper implementation of management implications in areas with high conflict.

3.3. Importance of this research in the context of the current status:

Conflict resolution is possible only by minimizing its effects to a point where it becomes tolerable to local communities. The first step towards this goal could be a thorough understanding and visualization of the HEC trends (Desai & Riddle, 2015). The spatially explicit analysis is an appropriate tool that could help in understanding modulations in conflict, as the distribution of HEC is often uneven across different elephant habitats and landscapes (Lenin & Sukumar, 2011; Gubbi et al., 2014). Studies in India suggests that the spatial patterns and distribution of HEC are positively related to human use areas, the presence of settlements, and agricultural lands (Sukumar, 1991; Gubbi, 2012). These are found to be influencing the extent and intensity of HEC (Wilson et al., 2013). In Asia, however, only a handful of studies assessed the spatial patterns of HEC (Wilson et al., 2013). Nevertheless, development in remote sensing and geographical information systems (GIS), predicting spatial and temporal patterns of conflict in crop-raiding or livestock depredation by large mammals, have been relaxed and used often (Ahearn et al., 2001; Treves et al., 2004). Assam lost 3,555 km^2 of its forests to encroachment owing to increased human density and increasing numbers of land riots. More than 70,000 households are found to inhabit areas around or within the forests earning either low or marginal incomes, mostly through agriculture, and are hence, involved in the conflict (Treves, 2009; Department of Environment & Forests, 2011). Therefore, understanding the spatio-temporal trend of conflict over the years, especially tracing out how these patterns are dispersing in terms of their extent to project the changing intensity of conflict, is vital for Assam. Moreover, understanding the spatio-temporal patterns would lead to develop and adopt appropriate, replicable, and effective mitigation approaches to counter HEC (Baruch-Moro et al., 2013; Hoare, 2015).

The long-term future of elephants and their conservation depends on the effectiveness of the measures taken to mitigate the conflict (Sukumar, 2006; Hedges & Gunaryadi, 2010). It is observed through studies that most of the HEC mitigation measures implemented are often reactive and done impulsively (Parker et al., 2007). However, HEC mitigation efforts tend to fail due to a lack of knowledge of available tools or application of the tools and the absence of a critical review through pilot surveys on the mitigation methods (Desai & Riddle, 2015). To counter increasing conflict, increased technical and sophisticated measures with higher costs are now implemented (Fernando et al., 2008). Physical barriers to control HEC involve electric or solar fences, elephant-proof trenches, and walls. The success of these barriers depends on people, environmental conditions, habitat characteristics, resource availability, and elephant behavior (Shaffer et al. 2019; Panda et al., 2020). However, elephants are highly intelligent and adaptable animals (Poole & Granli, 2008); they are found to circumvent and defeat many mitigation measures. Studies suggest that barriers may lose their initial effectiveness over time. Therefore, no mitigation measures last forever, hence, finding a solution becomes difficult (Fernando et al., 2008). Nevertheless, in such scenarios, information and knowledge of the locals on the area and the species becomes essential for selecting apt measures (Fernando et al., 2008).

In highly fragmented landscapes like Assam, higher expenditure, maintenance cost, and effort impose multiple challenges on large-scale application of these physical barriers (Kioko et al., 2008; Perera, 2009; Wijayagunawardane et al., 2016). Furthermore, effectiveness for a longer term could be hindered by various parameters such as the quality, design, responses of authorities towards fence breaks, overall protected area enforcement, and management (Graham et al., 2009; Massey et al., 2014). A study by Lee and Graham (2006) suggests that physical barriers also harm the elephant's survival by isolating already fragmented elephant populations, restricting their movements, and deterring access to seasonal food and water resources. Therefore, continuous monitoring and appropriate management based on results from research are critical for successful human-elephant conflict mitigation (Fernando et al., 2008).

In their study, Sampson et al. (2019), suggest that the socio-economic context of HEC is of equal importance, and should be kept in mind while designing efficient, long-term conservation and management plans for Asian elephants. Active involvement of local people in mitigation programs is essential to ensure such programs' sustainability and success over a while (Carter et al., 2012; Bruskotter & Wilson, 2013; Ripple et al., 2014; Treves & Bruskotter, 2014). It is essential to address the locals' concerns and needs to incorporate them accordingly into these efforts.

It is crucial to keep in mind that people living near or in the conflict zones are often a heterogeneous mix of multiple ethnicities having varied traditions and religious beliefs, making some communities more tolerant of wildlife than others (Karanth & Kudalkar, 2017). Hence, local people's perceptions and attitudes on HEC could often differ based on cultures, beliefs, and traditions (Dickman, 2010). One major challenge that persists while developing and implementing adequate conservation policies is to earn support from the local communities and engage them in long-term conservation efforts (Mulder & Coppolillo, 2005). It is considered a cumbersome process as it requires sufficient patience to gain the confidence of local people to understand the complexity of HEC issues that have to be faced before initiating

HEC mitigation programs (Sampson et al., 2019). Therefore, surveys and interviews of local communities affected by conflict could act as means of communication to reveal the main issues associated with HEC that are often unique from place to place. This eventually helps the researchers to develop better effective HEC mitigation and elephant conservation initiatives (Sampson et al., 2019).

Moreover, Golaghat is a prime elephant habitat, key for the resident and migratory elephant population of Assam. It facilitates the movement of elephant herds by connecting Kaziranga National Park to the forests of Karbi Anglong and Nagaland hills (Das et al., 2012). Due to the interstate position, there is complexity in understanding HEC in this district. The increase in development projects, such as Numaligarh refinery, the expansion of National Highways (NH37,NH39), and emerging tea estates, has led to fragmentation of elephant habitats and vanishing natural corridors (Talukdar et al., 2006), making it a conflict hotspot, ideal for this study.

4. Research Questions:

1. Is the extent and intensity of HEC in Golaghat district concentrated or dispersing spatially over time?
2. Are the physical barriers effective in restricting elephants' movement from their habitat to the human-use areas of Golaghat?
3. How do local people perceive the mitigation strategies involving physical barriers?

5. Hypotheses:

1. Increasing cases of HEC leads to dispersion of the spatial extent of conflict over time (derived from Sukumar, 1991; Gubbi, 2012; Wilson et al., 2013).
2. a. Intensity and frequency of human-elephant conflict is reduced in presence of physical barriers (derived from Kioko et al., 2008; Tibesigwa, 2013).

   b. Elephant incursion depends on the types and placement of the barrier (derived from Perera, 2009; Massey et al., 2014).
3. Conflict-related (incursion rates, breaches, damages/losses, etc.) and socio-economic variables (income level, gender, educational qualification, etc.) affect perception towards the barriers (derived from Dickman, 2010; Karanth & Kudalkar, 2017).

6. Study Area:

Golaghat district, located in central Assam is a homogenous plain and low-lying area on the south bank of the river Brahmaputra. Located between 25°50’48’’N–26°58’35’’N and 93°19’11’’E–94°14’24’’E, Golaghat covers an area of 3502 km^2. The altitudinal gradient of this site ranges from 40-360 meters ASL. The river Brahmaputra acts as a boundary in the north, Nagaland and Karbi-Anglong in the south, Jorhat in the east, Karbi-Anglong and Nagaon districts in the west. It is home to two protected areas, viz., –Kaziranga National Park (KNP; 380 km^2) on the west and the proposed Nambor Doigurung Wildlife Sanctuary (NDWLS), divided into Lower Doigurung RF (13.54 km^2) and Upper Doigurung RF (9.30 km^2) on the south. Fringe villages of Kaziranga National Park and Lower Doigrung RF served as two study sites in the district (Map 1). The mighty Brahmaputra runs through the district with its tributaries, mainly Dhansiri, Disai, Diphlu, Kakodonga, Rengma, Daigurung (Census of India, 2011).

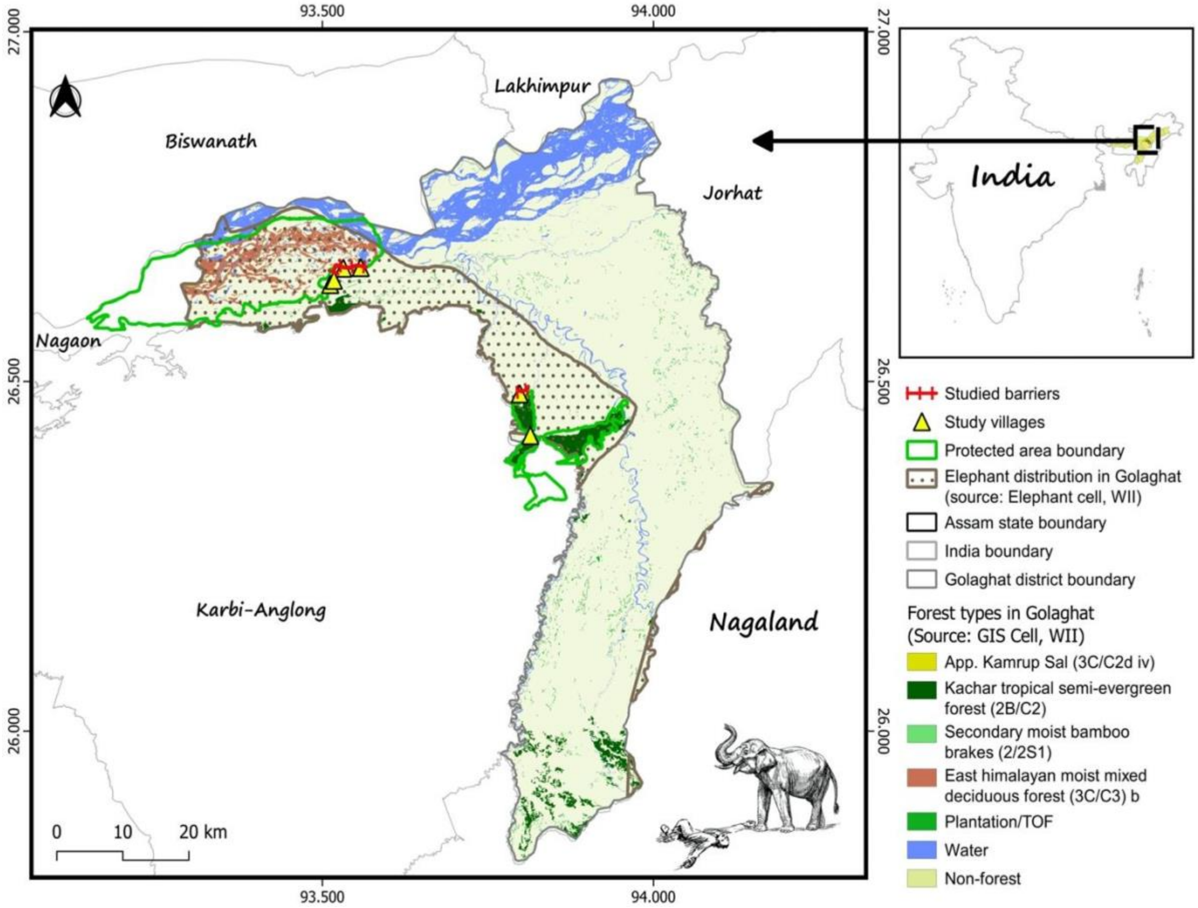
The climate of Golaghat is highly humid, with a mean annual rainfall up to 1960 mm (Climate-Data, 2020), and the mean annual temperature varies from 9.8℃$_0$ (49.6°F), reaching up to 31.8℃ (89.3°F) (Census of India, 2011). The forest cover of Golaghat spread over 43.0% of the total area equalling 1522.94 km^2 (Census of India, 2011). These forests hold landscape providing elephant habitats constituted by one Elephant Reserve (ER), i.e., Kaziranga-Karbi-Anglong ER and seven Reserve Forests, viz. Diphu, Rengma, Doyang, Nambor North, Nambor South, Upper Doigurung, and Lower Doigurung, covering 308.9 km^2 area (Das *et al.*, 2012). This district is a part of two major elephant corridors in north-eastern India, viz., number 20 (Kalapahar to Doigurung) and number 21 (Kaziranga to Karbi-Anglong and Panbari) (Wildlife

Trust of India, 2019). This district has three major forest types, i.e., Tropical Wet Evergreen Forests, Tropical Semi-Evergreen Forests, Grassland, and Savannahs (Champion & Seth, 1968). The forests have climax vegetation such as *Tetrameles nudiflora* (Bhelew), *Dipterocarpus retusus* (Hollong), *Artocarpus chama* (Sam), *Mesua ferrea* (Nahor), *Magnolia gustavii* (Sopa), *Dillenia indica* (Outenga), patches of *Bombax ceiba* (Simalu), and *Albizia procera* (Koroi), providing forage for wild elephants and rhinos (Census of India, 2011). The main varieties of grasses found in the area are *Apluda mutica, Phragmites karka, Sclerostachya fusca, Saccharum sp*, etc. (Biodiversity of Assam, 2019).

The district's total human population is 10,66,888, with a density of 305 people per km^2 (Government of Assam, 2021). The villages of study in Golaghat are composed of various ethnic communities, including Ahoms, Assamese, Tea-tribes, Mishing, Tamangs, and Karbis. A small population of migrants like Marwari, Bengali, Biharis, immigrants from Bangladesh and Nepal are among the other inhabitants too (Area Profiler, 2020). The majority population are practitioners of Hinduism, followed by Buddhism and other local tribal practices.

Agriculture serves as a significant livelihood option for people of this area, mainly cultivating *Oryza sativa* (Paddy), *Camellia sinensis* (Tea), *Brassica juncea* (Mustard), *Curcuma longa* (Turmeric), and some vegetables (Census of India, 2011). Local people hold agricultural land ranging from 0.5-18 bighas. Paddy is the staple crop of the state. Both sites have different periods of planting based on the availability or non-availability of water and the commencement of the annual monsoon. In some areas, *Boro* rice (Rabi season) is sown in December and harvested in April or May, whereas the *Khali* rice (Kharif season) is sown in May and harvested in November (*pers. comm*. with local farmers).

Crop-raiding by animals such as Asian elephants (*Elephas maximus indicus)*, wild water buffalo (*Bubalus arnee)*, various cervids, wild pig (*Sus scrofa*), and Indian rhinoceros (*Rhinoceros unicornis)* are very common in these agricultural areas, along with very few records of Gaur (*Bos gaurus)*. Traditionally people opt for night guarding in *tongi* (watchtower) to protect their crops. They also use flashlights/torchlights, fire, crackers, personal low voltage solar fencing, and nets as mitigation measures for driving animals away. In terms of physical barriers, medium to high voltage solar fences are installed in the park boundary of the Agoratoli and Kohora ranges of KNP by the Forest Department. Similarly, a stone wall is constructed by the Numaligarh refinery in the Numaligarh area. Elephant-proof trenches are also present in some tea estates and crop fields near Nambor Reserve Forest by various departments (*pers. comm*. with Dr. Bibhuti. P. Lahkar). This study includes two barriers, viz., a 4.2 km long solar fence in the Agoratoli range of KNP and an elephant-proof trench of 2 km in length in the Bokial range of the NDWLS (Figure 1,2). These barriers are noted to have non-uniform configurations at various parts.



Map 1: The study villages with and without barriers representing its forest types along with the elephant distribution in the Golaghat district

Figure 1: Solar fence in Agoratoli range of Kaziranga National Park; Figure 2: Elephant-Proof Trench in Bokial range of Nambor-Doigurung Wildlife Sanctuary

7. Methodology:

7.1. Study design:

This study was conducted between January 2021 and July 2021. Records of HEC from 2010-2019 for the Golaghat district were obtained from the respective forest divisions in an appropriate format both in soft and hard copies. Later, an *apriori* reconnaissance survey was conducted in both the proposed study sites after identifying villages based on four criteria, i) absence/presence of physical barriers, ii) high HEC instances reported, iii) similar habitat characteristics on the part of the reserves, and iv) accessibility. After consultation with the forest department officials and local experts/professionals familiar with the regions, the sites were selected. The location coordinates of the barriers were recorded using GPS Garmin etrex30. Post-reconnaissance, six villages adjacent to the protected areas, i.e., four (04) near KNP, and two (02) near NDWLS were chosen. Two of the villages near KNP have barriers (i.e., Solar fence), and the rest do not. Similarly, one of the villages near NDWLS has barriers (i.e., Trench), and the other does not. Elephant sign surveys were conducted along the forest-village edges in the chosen villages.

Simultaneously, systemic interviews of households were done, and few were avoided if located continuously or were tightly spaced. The interviews were done in Assamese, Mishing, and Adivasi languages. Trained local field assistants and the village local were recruited to monitor and translate the interviews whenever needed to avoid exaggeration of instances for establishing a reliable and authentic conflict reporting system (Siex & Struhsaker 1999; Davies et al., 2011).

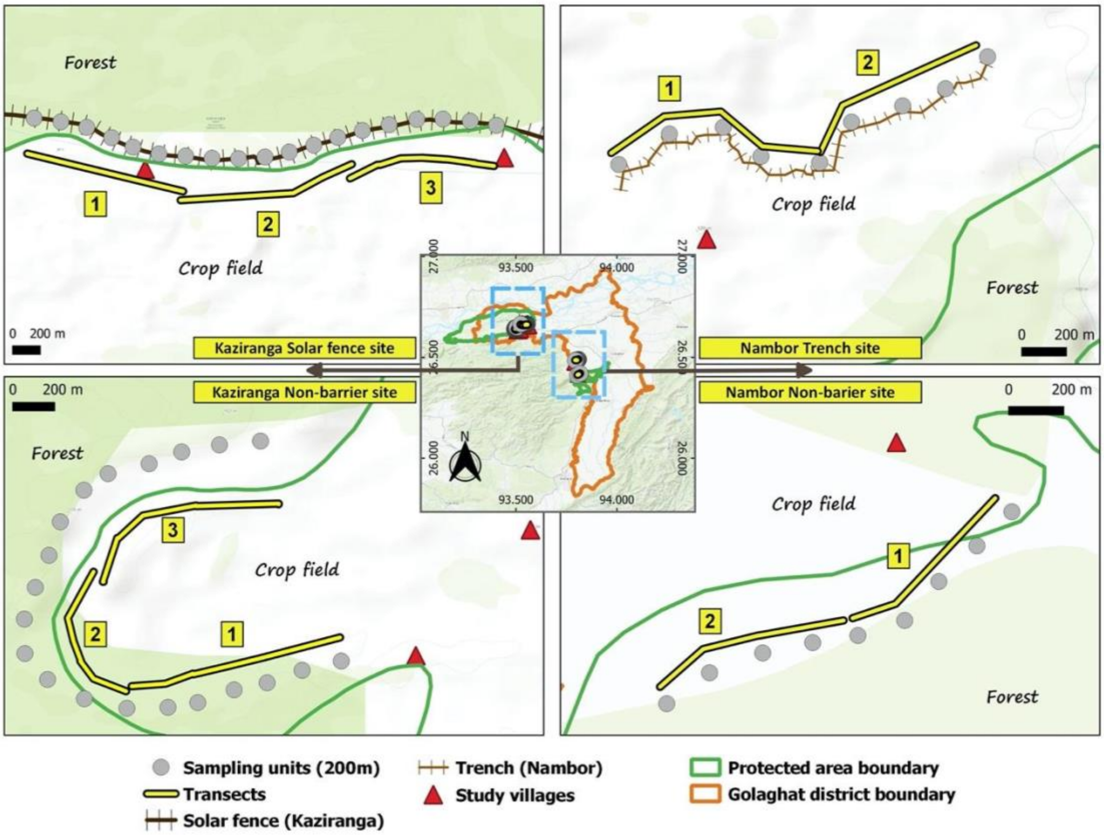
7.2. Data collection:

1. *To assess spatio-temporal shift in the extent of Human-Elephant conflict*:

Historical conflict data of Golaghat district for the last decade, i.e., 2010-2019, involving, i) crop/property damages, ii) loss of human and iii) loss of elephant lives, from the Assam Forest Department of the respective study sites were collected. The data had limitation of unavailability of exact geographical coordinates conflict location. However, the names of villages along with their respective number of conflict incidents were considered for further spatial modeling. The crop/property damages data include details on the type of damage, the quantity of damage, monetary estimation of loss, whether or not compensated, amount of money compensated, and year of compensation allotment. The data for loss of human lives includes the number of deaths, type of surrounding of the incident, whether or not compensated, amount of money compensated, and year of compensation allotment. Similarly, data about the loss of elephant lives includes the number of deaths, reason of death, type of surroundings, gender of elephant, age of elephant. Location of villages was marked manually and verified with village polygon files acquired from NASA-SEDAC open-source platform (Meiyappan et al., 2018), which were later on merged with conflict dataset from the forest department (FD). Village locations (polygons) were verified on the ground during the field exercise.

2. *To evaluate the effectiveness of physical barriers*:

Two types of physical barriers were identified in the two study sites *viz.* solar fences and elephant-proof trench near KNP and NDWLS, respectively. Agoratoli range of KNP has a 6 km long solar fence on the National Park boundary. However, the two study villages adjacent to KNP and the barrier could only cover 4.2 km as the rest lies out of the extent of the chosen villages. As for the village chosen near NDWLS, the entire length of the 2 km long elephant-proof trench could be monitored. Subsequently, both types of barriers were divided into equal parts with a distance of 1.4 km and 1 km between each for KNP and NDWLS, respectively. In these parts, a total of three and two parallel transects were done along the barriers in KNP and NDWLS barrier sites. Similarly, the same method was repeated along the reserve boundary for non-barrier sites. The length of these parallel transects equals 1.4 km each for KNP and 1 km each for NDWLS. The sampling was done in units of 200m×7 and 200m×5 in each transects in KNP and NDWLS, respectively. Each transect had four temporal replicates. Each temporal replicate had an interval of a maximum of five days from the previous replicate at both sites separately. Therefore, In KNP, a total effort of 16800m (200m×7 units×3 transects×4 replicates) in both the barrier and non-barrier sites were made. In NDWLS, an effort of 8000m (200m×5 units×2 transects×4 replicates) in both the barrier and non-barrier sites were made. Monitoring of the physical barriers throughout the sampling period ensured, *viz*., recording breaches in the barriers, direct or indirect signs of elephants, or crossing to human settlement areas using sign surveys (Appendix 1) (Kioko et al., 2008) (Map 2).



Map 2: Transect layouts for elephant sign survey along the barrier and non-barrier sites of Kaziranga National Park and Nambor-Doigurung Wildlife Sanctuary

3. *To assess people's perception on the HEC and mitigation measures*:

Semi-structured questionnaire surveys of the chosen villages were conducted in both sites. The number of households to be interviewed in each village were figured out, that if a village had households <100, then 30% were covered, if they had ≥100, then 20% were covered, to be able to cover maximum respondents within the given time (pers. comm. with Dr. Upma Manral). Before the commencement of the interviews, written consent from the respective village head was signed; verbal approvals from the interviewee were also taken. Questions were designed to know people's views on HEC, about their losses, compensation scheme, change in instances of HEC before and after the installation of the barriers, and their willingness to be active for maintenance of the barriers, total times for power cut per day in the area (for looking at the scope of low-volt electric barrier fence), and other related socio-economic information. Since a few people have deployed low-voltage electric fences in the area to avoid elephant incursion in their crop fields (Appendix 2), hence power cut time per day was also questioned to the interviewee for looking at the further scope on the low-volt electric fence. Here, the willingness to pay for the maintenance of barriers was chosen as a proxy to assess people's perceptions on the barriers. Willingness to pay was questioned in terms of hypothetical monetary inputs from the interviewee. The financial amount was confirmed with a double bidding method, in which a precise range of minimum and maximum financial inputs was collected (Hadker et al., 1997). The bidding was initiated from Indian rupees 10 and then increased in two steps. In the second bid, the "no" answer from the respondent decreases the bid to find a precise estimate. A total of n=249 interviews were taken. All the respondents are aged between 18-72 years, ensuring fair representation of all communities, genders, and professions. One respondent from each family of the household was interviewed and lasted for not more than 20 minutes. Apart from these, open discussions and interviews with the Village Defence Parties (VDP), NGOs of the area, and forest officials of both sites are documented to understand the perspective of every stakeholder involved with HEC and its mitigation.

7.3. Analyses:

1. *To assess spatio-temporal shift in the extent of Human-Elephant conflict:*

For visualization of historical spatio-temporal pattern and dispersion of HEC in the study area, an optimized hotspot analysis was carried out using the "Hotspot Analysis (Getis-Ord Gi*)" tool in ArcMap version 10.6 by making input village features consisting of conflict incidents for all data types occurring between each year starting from 2010 to 2019 (Getis & Ord, 1992).

To reduce data interpretation complexity, the conflict data were divided into five groups having an interval of one year, i.e., 2010-11, 2012-13, 2014-15, 2016-17, 2018-19. This hotspot analysis tool helps in detecting clusters of high values often indicative of a hotspot. The *p* and *z* values of each village input feature are either 90%, 95%, or 99% confident to determine the statistical significance of the potential conflict clusters (Kalinic & Crisp, 2018). Optimized hotspot analysis requires a feature such as polygon data in the dataset. In case, if two or more features (village polygons) have similar data (number of conflict incidents) then it aggregates them as one value after implementing a correction method. A feature has a neighbourhood composed of a group of different features around it. A feature having a high (positive) *z*-value is considered to be statistically significant conflict hotspot and will be surrounded by other features of a high *z*-value. Larger the *z*-score, an intense clustering of high values (hotspot) is observed. A *z*-score is calculated by comparing the conflict incidence value of a particular feature class with respect to the overall mean conflict incidence of all the features, if the comparison of the particular feature is larger than the overall mean conflict incidence calculated by the tool then it results in a statistically significant *z*-score (Getis & Ord, 1992; Ord & Getis, 1995; Kalinic & Crisp, 2018). A *z*-score ≥ 1.96 (≥ 95% CI) are considered as highest potential conflict hotspot. This tool interrogated the input data and determined settings that produced optimal hotspots of HEC for each year in the district.

2. *To evaluate the effectiveness of physical barriers*:

For assessing the effectiveness of the two types of barrier with respect to the non-barrier sites, the difference in means of encounter rates of elephant signs of the three sites, i.e., solar fence, trench, and non-barrier areas was determined by a Welch Analysis of Variance (ANOVA) using package “stats” in Rstudio *version* 1.4.1717 software. For that, the categorical independent variable, i.e., ‘type of barrier’ (divided into 'solar fence’, ‘trench’ and ‘no barrier’), was modelled with the continuous dependent variable, i.e., 'encounter rate of elephant signs'. To determine statistically significant difference between mean encounter rates of the types of barriers, a multiple pairwise comparison post-hoc test, i.e., the Games-Howell multiple comparison test was done using the package "rstatix" in Rstudio (Kassambara, 2021).

Further, for determining the relationships of predictor variables in driving the encounter rates of elephant signs, a generalized linear model (glm) with family "Poisson" was executed. The response variables, i.e., the encounter rates (signs/km) were calculated by dividing the numbers of signs at each sampling unit by 0.2 km. The predictor variables such as distance from the nearest forest, distance from the nearest water stream, and distance from the nearest human settlement were calculated by using the "Euclidean distance" tool after projecting the vectors in WGS1984 UTM 46N projection (30m spatial resolution) in ArcMap version 10.6 (Table 1). In total, eight glm models were run with various combinations of predictor variables, including null model (encounter rate~1) and global model (encounter rate~). Afterward, the better fit model was chosen based on the least AICc value (Secondary Akaike's Information Criterion corrected for smaller sample sizes) of all the model AICc (s) (Burnham & Anderson, 2004).

Table 1: List and description of different predictor variables used for assessing their relationship between encounter rates of elephant signs

Variable names	**Variable type**	**Categories**	**Mean ± SE**
Barrier occurrence	Factor	Solar fence (n=21)	-
		Trench (n=10)	-
		No barrier (n= 31)	-
Distance from settlement	Continuous	-	190.46±15.64m
Distance from forest	Continuous	-	226.04±53.33m
Distance from stream	Continuous	-	951.76±83.9m

3. *To assess people's perception on the HEC and mitigation measures*:

People's perception on the barriers is assessed by their willingness to pay for the maintenance of the barriers used as a proxy. This will in turn determine people's view on the deployed barriers; otherwise, if they would want to have a barrier in their area to reduce elephant incursion in their villages. The continuous data of willingness to pay was further categorized into three classes, i.e., '1' indicates protest zero (where the amount was zero, and the respondent is unwilling to pay as the government should pay or not interested in paying), '2' for true zero (where the amount was zero, and the respondent was reluctant to pay due to low income), and '3' representing positive willingness to pay (where the amount was higher than zero). The third category, i.e., the willingness to pay category, was not categorized further to reduce complexity. A multinomial logistic regression in R Studio v.1.4.1717 software was run using the package 'nnet' (Ripley & Venables, 2021) for barrier and non-barrier sites separately, keeping category '2' as reference. The independent variables are all the socio-economic and conflict-related information that affects people's willingness to pay for maintenance of the barriers. Out of the seven predictor variables, variables such as overall power cut were calculated by multiplying frequency and duration of power cut, change in elephant incursion frequency, and change in crop-raiding frequency by subtracting their present estimates of elephant activities with the past as asked by the interviewer (Table 2 & 3). Various combinations of socio-economic and conflict-related variables were modeled, including null model (wtp~1) and global model (wtp~), and in total, 11 logistic regression models for barrier sites and 13 models for non-barrier sites were executed. The parsimonious model was selected based on the least AICc value amongst all the models, separately for both the sites (Burnham & Anderson, 2004).

Table 2: List and description of different predictor variables used for determining people's perception on barriers based on their willingness to pay (WTP) for the maintenance of the barriers at barrier sites.

Variable names	***Variable type***	***Categories***	***Mean±SE***
Zone	*Factor*	*KNP (n=50)*	-
		NDWLS (n=72)	-
Age	*Continuous*	-	*41.55±1.4*
Gender	*Factor*	*Male (n= 75)*	-
		Female (n= 47)	-
Ethnicity	*Factor*	*Assamese (n= 49)*	-
		Nepali (n= 3)	-
		Adivasi (n= 61)	-
		Mishing (n= 11)	-
		Bihari (n= 1)	-
No .of family members	*Continuous*	-	*5.35±0.17*
Qualification	*Ordinal*	*None (n= 61)*	-
		Primary (n= 19)	-
		Secondary (n= 13)	-
		Senior Secondary (n= 24)	-
		Higher Secondary (n= 2)	-
		Graduate (n= 3)	-
Annual income	*Continuous*		*61500±3802.43*
House type	*Ordinal*	*Kaccha (n= 100)*	-
		Semi-Kaccha (n= 6)	-
		Pacca (n= 8)	-
		Bamboo Shed (n= 8)	-
Overall power cut	*Continuous*	-	*84.27±3.83*
HEC cases	*Factor*	*Yes (n=110)*	-
		No (n=12)	-

Net loss	*Continuous*	*-*	*16404±1032.3*
Compensation	*Factor*	*Yes (n=13)*	*-*
		No (n=109)	*-*
Time taken for compensation	*Continuous*	*-*	*1.88±0.56*
WTP category	*Factor*	*Protest zero (n=53)*	*-*
		True zero (n= 4)	*-*
		Positive (n= 65)	*-*
Change in elephant incursion frequency	*Continuous*	*-*	*-0.9±0.05*
Change in crop-raiding frequency	*Continuous*	*-*	*1.24±0.17*

Table 3: List and description of different predictor variables used for determining people's perception on barriers based on their willingness to pay (WTP) for the maintenance of the barriers after barrier installation at non-barrier sites.

Variable names	***Variable type***	***Categories***	***Mean±SE***
Zone	*Factor*	*KNP (n=55)*	*-*
		NDWLS (n=72)	*-*
Age	*Continuous*	*-*	*44.14±1.2*
Gender	*Factor*	*Male (n= 72)*	*-*
		Female (n= 55)	*-*
Ethnicity	*Factor*	*Assamese (n= 108)*	*-*
		Nepali (n= 5)	*-*
		Adivasi (n= 13)	*-*
		Sonowal (n=1)	*-*
		-	*-*
No .of family members	*Continuous*	*-*	*5.28±0.23*
Qualification	*Ordinal*	*None (n= 46)*	*-*
		Primary (n= 16)	*-*

		Secondary (n= 18)	-
		Senior Secondary (n= 40)	-
		Higher Secondary (n= 6)	-
		Graduate (n= 1)	-
Annual income	*Continuous*	-	*66795.3±3309.6*
House type	*Ordinal*	*Kaccha (n= 98)*	-
		Semi-Kaccha (n= 25)	-
		Pacca (n= 4)	-
		-	-
Overall power cut	*Continuous*	-	*77.6±3.94*
HEC cases	*Factor*	*Yes (n=125)*	-
		No (n=2)	-
Net loss	*Continuous*	-	*22941.27±1304.31*
Compensation	*Factor*	*Yes (n=21)*	-
		No (n=106)	-
Time taken for compensation	*Continuous*	-	*2.75±0.65*
WTP category	*Factor*	*Protest zero (n=36)*	-
		True zero (n=10)	-
		Positive (n= 81)	-
Change in elephant incursion frequency	*Continuous*	-	*-1.24±0.13*
Change in crop-raiding frequency	*Continuous*	-	*-1.22±0.13*

8. Results:

8.1. Conflict hotspots and dispersion of extent of HEC:

In the Golaghat district, HEC cases, i.e., elephant deaths, human deaths, crop/property depredation found fluctuated along with the number of villages reporting the conflict incidents over time without showing any particular trend. A total of 4193 cases were reported between 2010 and 2019. Out of the five villages reporting highest numbers of overall HEC cases in the last decade (Figure 3), Diffloo Pathar, located between Agoratoli and Kohora ranges of KNP, had a total of 270 cases, with 113 cases recorded alone in 2016. However, it is essential to note that in recent years, viz., 2017-2019, the number of total conflict incidents and their reporting has decreased significantly (Figure 4). Thus, both the frequency of HEC instances and their spatial configuration fluctuated simultaneously.

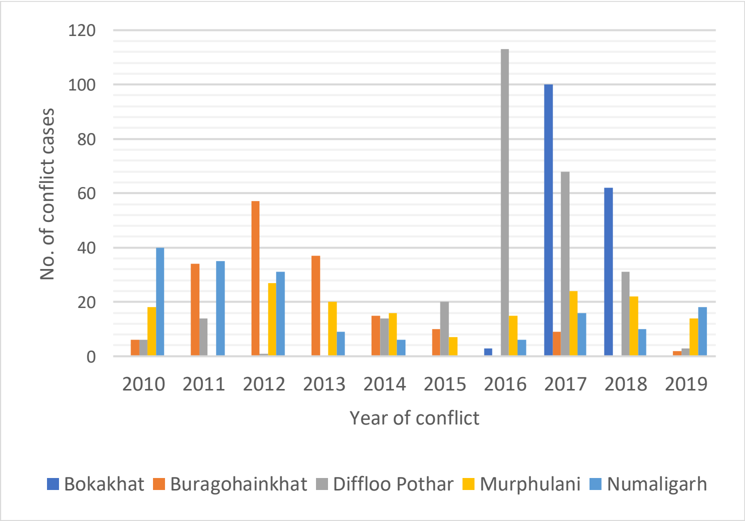


Figure 3: Number of HEC cases in top five conflict encountered villages in Golaghat district between 2010-2019.

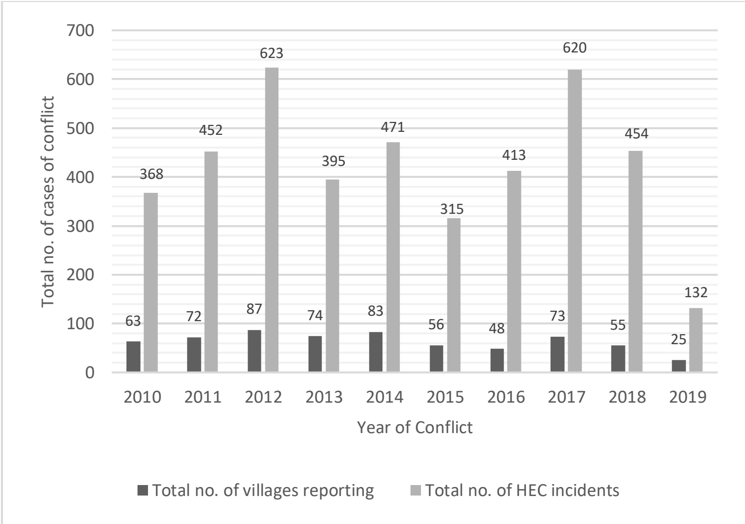


Figure 4: Number of villages and their respective number of HEC cases in Golaghat districts within the time frame of 2010-2019

The estimation of overall HEC cases over the decade portrayed that the highest percentage of HEC occurred between the years 2016-2017 with 25% (n=1033) of the conflict and the least was 14% (n=586) occurring between 2018-2019 (Figure 5). Crop/property damage was reported highest in 2017 with 14.9% (n=612) reported cases (Figure 6).

Out of 72 human deaths, 89% (n=64) were male and 11% (n=8) were females, and the highest cases occurred in 2013 with 20.8% (n=15) total deaths (Figure 7).

From a total of 14 elephant deaths, 65% (n=11) females and 34% (n=6) males with the highest reported deaths occurring in 2011 and 2015, claiming lives of 4 elephants in both the years, caused either from electrocution or injuries by falling into drains (Figure 8).

Figure 5: Plot representing percentage and number of HEC cases in Golaghat district between 2010-2019

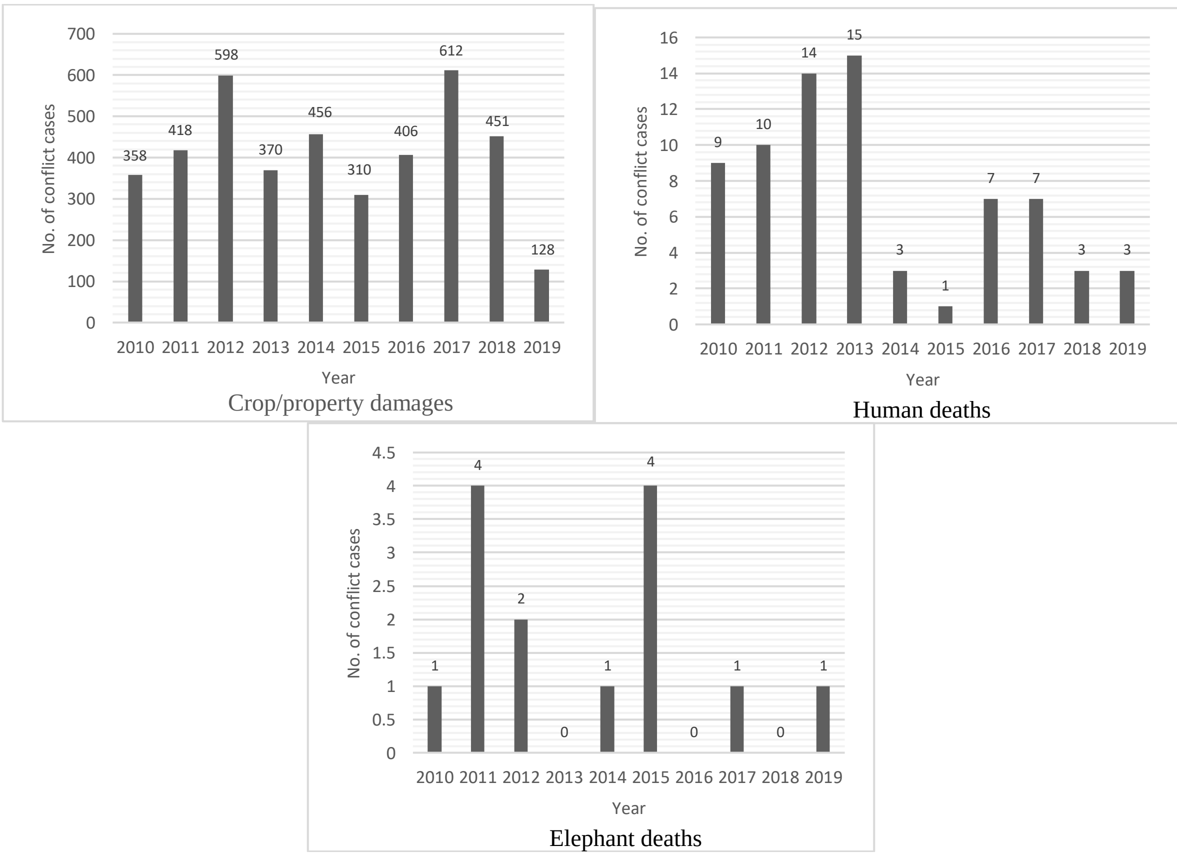
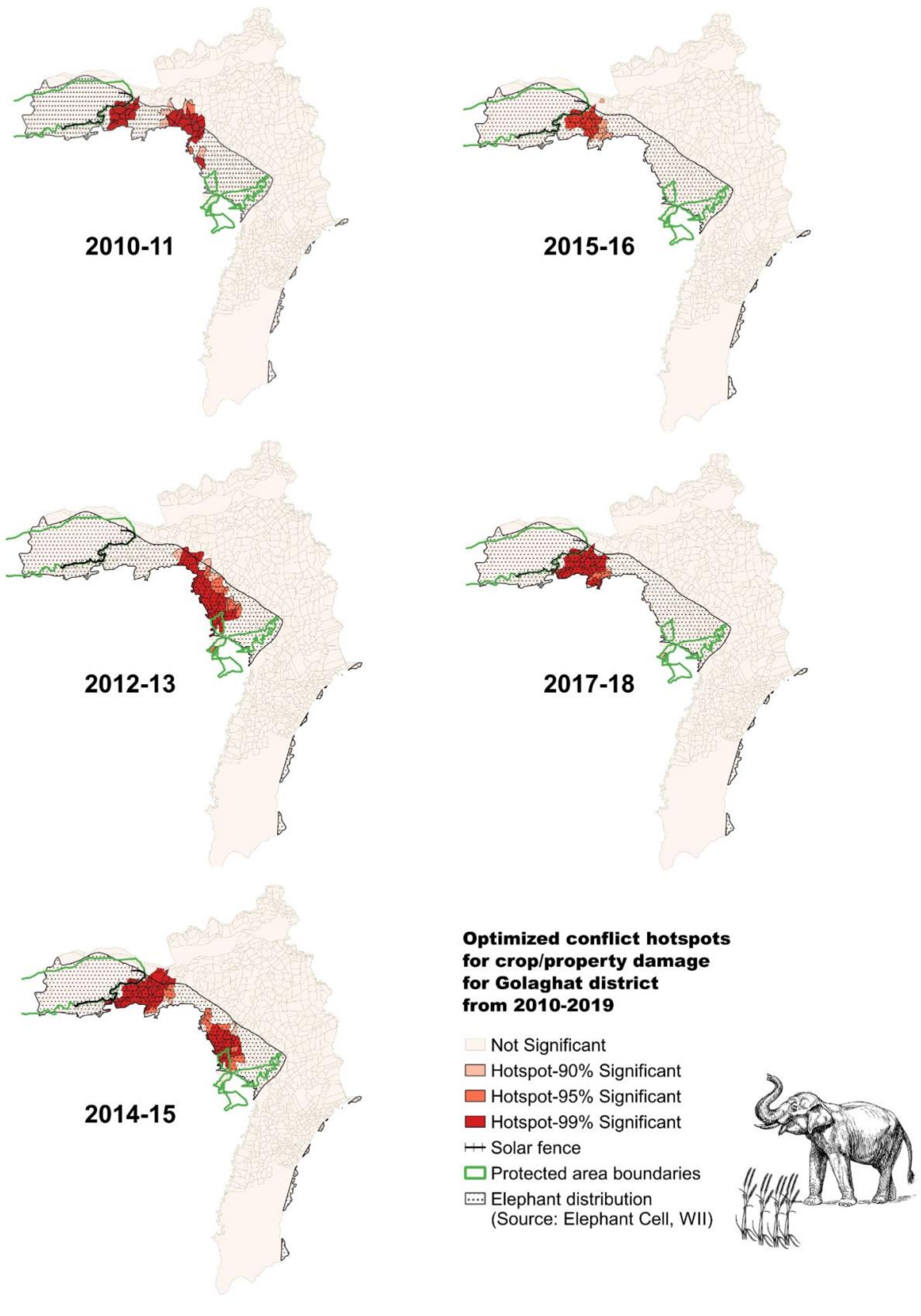
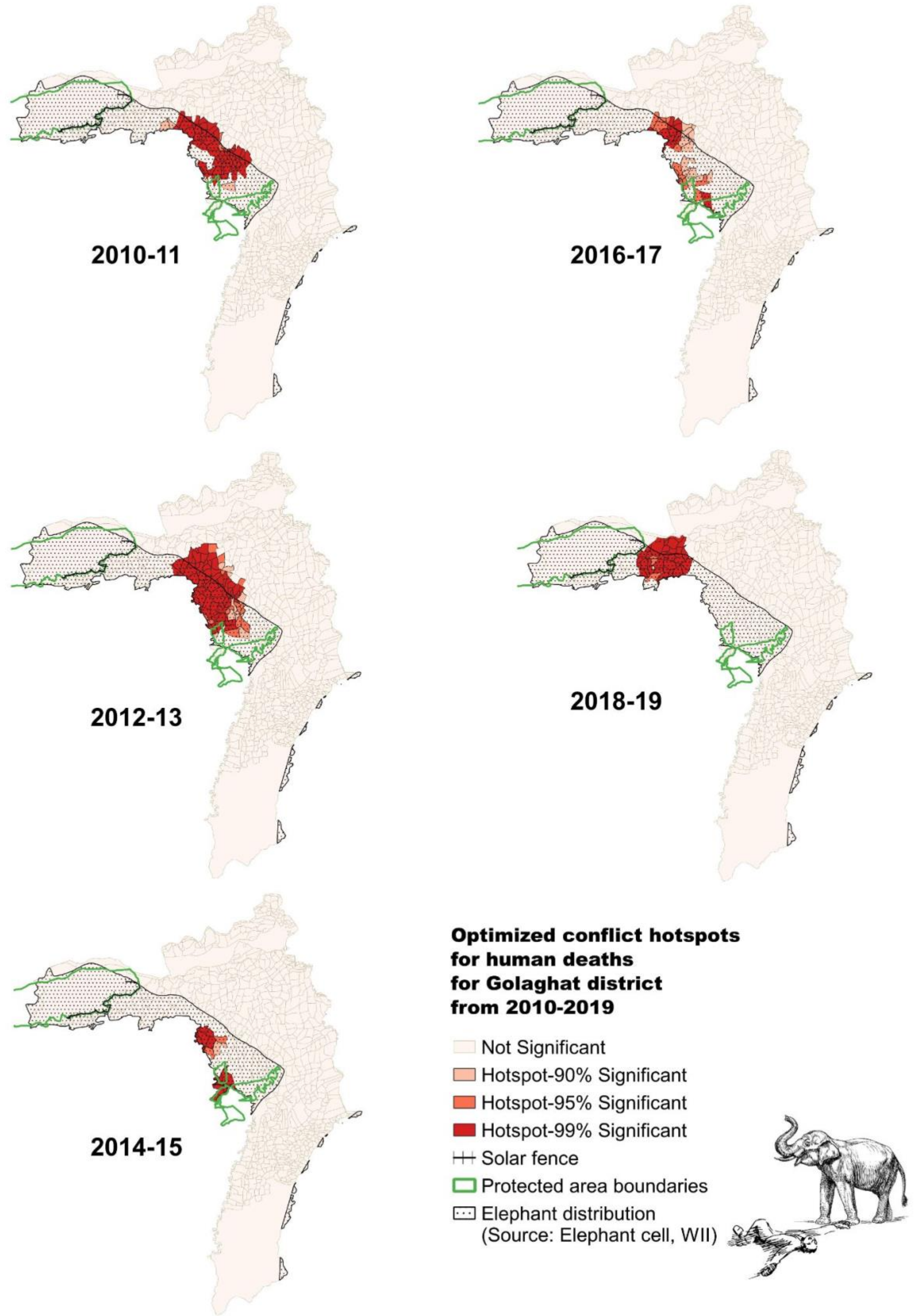


Figure 6: Number of crop / property damage by elephants in Golaghat district between 2010-19; Figure 7: Number of human mortality by elephants in Golaghat district between 2010-19; Figure 8: Number of elephant mortality in Golaghat district between 2010-19

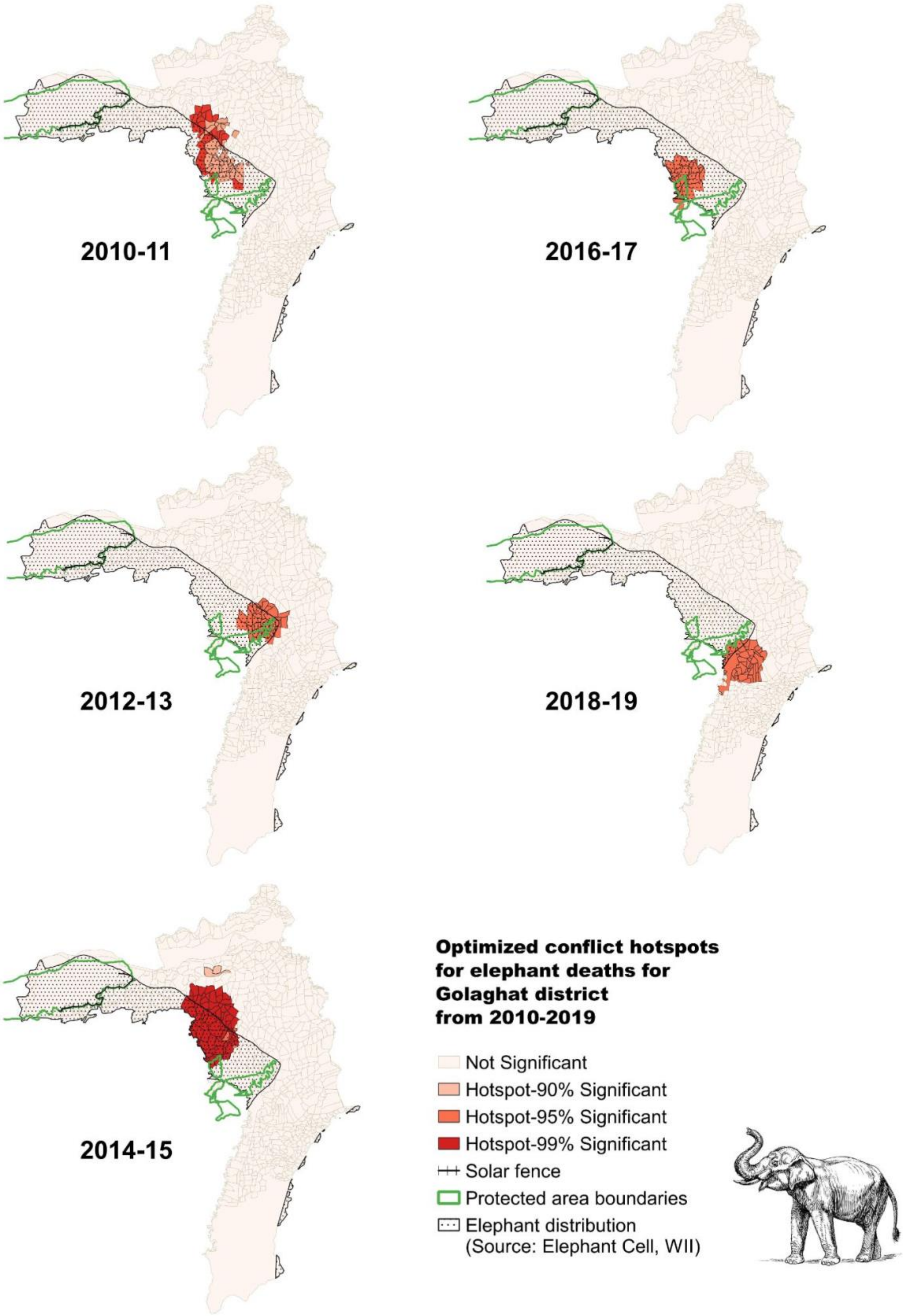
The spatial configuration of HEC at the village level was patchy over the decade. High HEC hotspots are exhibited by two clusters composed of different villages with significant (z-score≥1.96) spatial patterning throughout the decade (Maps 3,4,5). These hotspots are concentrated in the western (near KNP) and south-western (near NDWLS) portions of the Golaghat district. The optimized hotspot analysis indicated around a 16% increase in the conflict hotspot emerging villages, shown by a significant z score ≥ 1.96 (≥ 95% CI) from 2016-2017 to 2018-2019 including all types of conflict in Golaghat. 64 villages between 2010-2011, 83 villages between 2012-2013, 195 in 2014-2015, 30 between 2016-2017, and 57 villages between 2018-2019 are identified as conflict hotspots (with 95% confidence interval) facing crop/property damages by elephants (Map 3). Likewise, 87 villages between 2010-2011, 123 villages between 2012-2013, 31 between 2014-2015, 53 between 2016-2017, and 61 villages between 2018-2019, became hotspots (with 95% confidence interval) of high human death caused by HEC in that period (Map 4). However, relatively fewer, i.e., 84 villages between 2010-2011, 65 between 2012-2013, 121 between 2014-2015, 34 between 2016-2017, and 46 villages between 2018-2019 are identified as hotspots (with 95% CI), reporting elephant mortalities caused by HEC (Maps 5).



Map 3: Conflict distribution and dispersion over the time period between 2010-2019 in the form of optimized crop/property damage hotspots for Golaghat district



Map 4: Conflict distribution and dispersion over the time period between 2010-2019 in the form of optimized human death hotspots for Golaghat district



Map 5: Conflict distribution and dispersion over the time period between 2010-2019 in the form of optimized elephant death hotspots for Golaghat district

8.2. Effectiveness of physical barriers:

The highest mean encounter rate was observed for the non-barrier sites (3.31±0.67SE signs/ km), followed by trench near NDWLS (2.5±0.96 signs/km), and solar fence in KNP (0.77±0.27 signs/km) (Figure 2).

A significant difference among the encounter rates of sites with solar fence, trench, and without barriers was estimated ($F=13.74$, $df=2$, $p<<0.01$). Simultaneously, the post-hoc analysis suggests that only the means of encounter rates of the solar fence and no barrier sites are significantly different ($\beta=1.09$ (0.571-1.61, CI=0.95, adj $p<<0.01$)) (Table 4). The difference between the means of encounter rates of elephant signs of solar fence-trench and trench-no barrier sites are not found significantly different ($p>0.05$) (Table 4). It means that solar fence may be relatively more effective than trench in reducing elephant incursion into the human-settlement areas respective to the non-barrier sites since fewer elephant signs were encountered. However, inference from the results indicates that trench does not perform well as compared to solar fence as it is seen to have more encounter rate and higher mean than the solar fence sites (Figure 9). Overall, encounter rates at barrier sites are found relatively lower than non-barrier sites (Figure 10).

Table 4: Table representing the output of post-hoc Games-Howell multiple comparison test to look at the difference between mean encounter rates of all sites

y	Groups	Estimate	95% CI (lower	95% CI (lower)	Adj p-value	Significance
Encounter rate	Solar fence-Trench	0.745	-0.112	1.6	0.09	ns
Encounter rate	Solar fence-No barrier	1.09	0.571	1.61	<<0.01	****
Encounter rate	Trench-No barrier	0.348	-0.566	1.26	0.6	ns

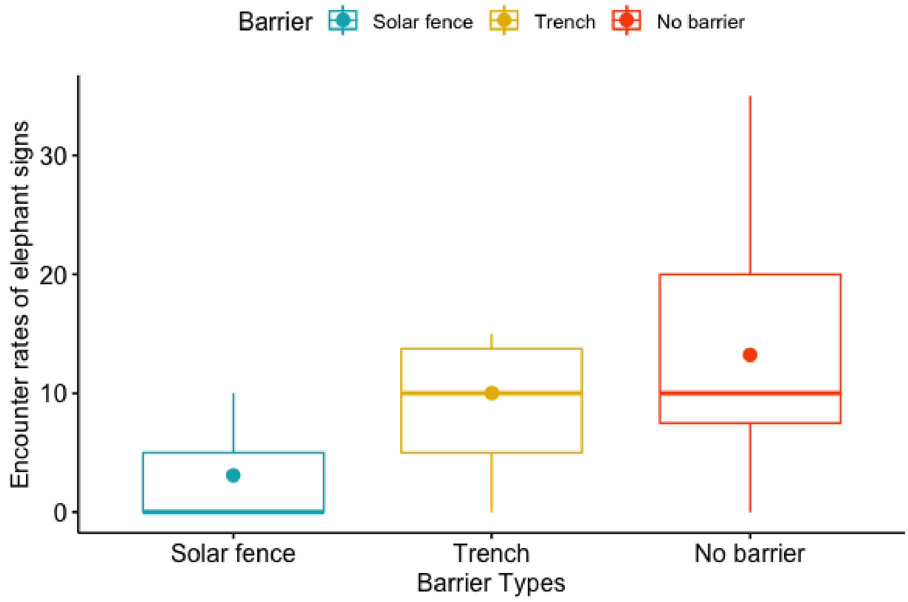


Figure 9: Box plot indicating quantiles and mean encounter rates for different categories of barriers and non-barrier sites

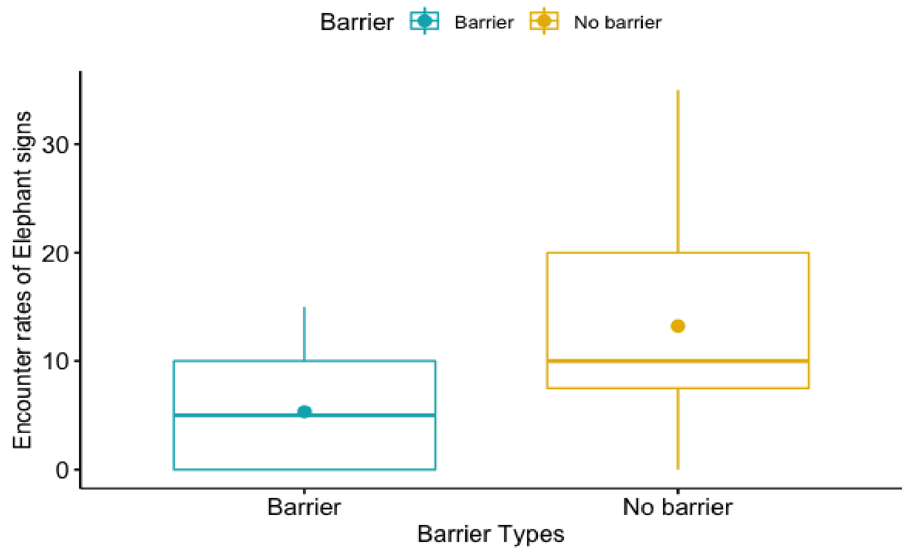


Figure 10: Box plot indicating quantiles and mean encounter rates of barrier and non-barrier sites

From the results of glm, it is observed that the global model (encounter rate~) consisting of all predictor variables has the lowest AICc value of 658.82 (AICc weight=0.76). Therefore, 'mod6' (global model) was considered the best fit model with the highest predictive power (Table 5). The best-fit model suggests that only three out of the five predictor variables significantly affect encounter rates. In the presence of a solar fence, the encounter rates of elephant signs are found to decrease significantly (β=-1.74±0.2SE, $p<<0.05$) (Figure 2).

Likewise, in the presence of a trench, the encounter rates also decrease significantly (β=-1.42±0.46SE, p<0.01), but of lower relative significance to the solar fence (Figure 7). However, the encounter rates also increase significantly with the increase in distance from the forest (β=0.001±0.0003, p<0.05). The other variables, such as distance from the nearest stream and human settlement do not significantly affect the encounter rates (p>0.05) (Table 6).

Table 5: Estimates of predictor variables towards the elephant encounter rate as per the least AICc based best fit model ("mod6" global model)

Coefficients	Estimate	SE	z-value	Pr(>|z|)	Significance
Intercept	2.8	0.2	13.9	< 2e-16	***
solar fence	-1.74	0.2	-8.83	< 2e-16	***
trench	-1.43	0.47	-3.06	0.002	**
distance from settlement	0.0002	0.0003	0.653	0.51	
distance from forest	0.0009	0.0004	2.39	0.02	*
distance from stream	-0.0002	0.0001	-1.77	0.07	.

Table 6: Performed eight generalized linear models to check the effect of predictor variables on the encounter rates of elephant signs with their model estimates and AICc

Model names	Model description	df	AICc	ΔAICc	AICc Weight	Log likelihood
mod6	encounter_rate~ barrier_occ+dist_settlement +dist_forest+dist_stream	56	658.82	0	0.76	-322.65
mod5	encounter_rate ~ barrier_occ+dist_settlement +dist_stream	57	662.3	3.48	0.13	-325.61
mod1	encounter_rate~barrier_occ	59	663.47	4.65	0.07	-328.53
mod7	encounter_rate~barrier_occ+ dist_settlement	58	664.81	5.99	0.04	-328.05
mod4	encounter_rate ~ dist_stream	60	744.38	85.57	0	-370.09
mod2	encounter_rate~dist_settlem ent	60	821.88	163.06	0	-408.84
m1	encounter_rate~1	61	822.58	163.76	0	-410.26
mod3	encounter_rate ~ dist_forest	60	823.62	164.8	0	-409.71

Abbreviations used: barr_occ= occurrence of barrier, dist_settlement= distance from settlement, dist_forest= distance from forest, dist_stream= distance from stream.

8.3. People's perception on physical barriers as a mitigation measure:

In the areas installed with barriers, either a solar fence or a trench, out of a total of 122 respondents, 44% belonged to the unwilling category due to a lack of interest ("1", protest zero), 3% people were unwilling due to low income ("2", true zero), and 53% were willing to pay ("3", positive). Eleven logistic regression models were run using multiple meaningful possible combinations of socio-economic and conflict-related predictor variables (Appendix 3). Out of them, the model consisting of all the conflict-information-related predictor variables has shown the least AICc value (test_m2; AICc=209.84). This model suggests that as the human-elephant conflict instances in the village persist, people who are uninterested to pay are convinced to pay (β=-6.24±0.0003SE, p<<0.05), but the willingness of people to pay decreases with increasing HEC (β=-4.4±0.0003SE, p<<0.05). It is estimated that if people get compensated, the unwillingness of people decreases (β=-19.7±0.0006, p<<0.05) and people are more willing to pay (β=20.7±0.0006SE, p<<0.05). However, if the payment of compensation takes more time, then the unwillingness increases (β=1.63±0.02SE, p<<0.05) and vice-versa also holds (β=-0.06±0.02SE, p<<0.05). It observed that with change in elephant incursion frequency, both unwillingness (β=-1.32±0.0003SE, p<<0.05) and willingness (β=-1.11±0.0003SE, p<<0.05) of people reduces significantly. Further, with change in the crop-raiding frequency of elephants, the unwillingness of people was found negatively associated (β= 0.13±0.001SE, p<<0.05) and people become even more willing to pay (β=0.62±0.001, p<<0.05). Also, an increasing overall power cut in the area found a close to a significant positive relationship with the unwilling category (β=0.02±0.01SE, p=0.06). In the model, it is evident that the variables such as the overall power cut issue do not represent the willingness of people. Also, net loss caused by the elephants does not have significant effects on the willingness or unwillingness to pay (Table 7) (Figures 11 & 12).

Table 7: Table representing estimates and level of significance of best fit multinomial logistic regression for describing the relationship with predictor variables and categorical variable of Willingness to pay ("2"= true zero, as the reference category) on the barrier sites

Category	Coefficients	Estimate	SE	z-value	Pr(>|z|)
1 (Unwilling)	Intercept	6.47	0.0003	17448.51	<<0.05
	Overall power cut	0.02	0.01	1.85	0.06
	HEC instances	-6.23	0.003	-17887.55	<<0.05
	Net loss	-4.72^{E-05}	4.05^{E-05}	-1.16	0.24
	Compensation	-19.77	0.0006	-31343	<<0.05
	Time taken for compensation	1.63	0.015	108.01	<<0.05
	Elephant incursion change	-1.31	0.00035	-3742.54	<<0.05
	Crop-raid frequency change	0.13	0.0009	138.02	<<0.05
3 (Willing)	Intercept	6.13	0.0003	16707.61	<<0.05
	Overall power cut	0.001	0.01	0.12	0.9
	HEC instances	-4.4	0.0003	-12658.06	<<0.05
	Net loss	-3.03^{E-05}	3.96^{E-05}	-0.76	0.44
	Compensation	20.75	0.0006	32880.03	<<0.05
	Time taken for compensation	-0.06	0.02	-4.17	<<0.05
	Elephant incursion change	-1.11	0.0003	-3132.91	<<0.05
	Crop-raid frequency change	0.62	0.0009	649.44	<<0.05

In the non-barrier sites, out of 127 respondents, 29% belonged to the unwilling category due to a lack of interest ("1", protest zero), 7% people were unwilling due to low income ("2", true zero), and 64% were willing to pay ("3", positive). A total of 13 multinomial logistic regression models were applied (Appendix 4). Out of them, the model consisting of all the conflict-information-related predictor variables has the least AICc value (test_m2, AICc=126.68). This best fit model offers a similar variable combination as that for the barrier sites. This model suggests that as the human-elephant conflict instances in the village persist, uninterested people are convinced to pay (β=-6.02±0.0003SE, p<<0.05), and willing people found negative in relationship with increasing human-elephant conflicts (β=-4.81±0.0003, p<<0.05). It is seen that if people get compensated, then both unwillingness (β=-18.1±0.0006SE, p<<0.05) and willingness of people decreases (β=-12.27±0.0006SE, p<<0.05). However, if the compensation payment takes more time, then the unwillingness (β=1.26±0.02, p<<0.05) and willingness of people increases (β=1.01±0.02SE, p<<0.05). It observed that with change in elephant incursion frequency, both unwillingness (β=0.13±0.001SE, p<<0.05) and willingness (β=0.9±0.001SE, p<<0.05) of people increase significantly. Further, with the change in the crop-raiding frequency of elephants, the unwillingness of people hikes up (β=5.48±0.002SE, p<<0.05) and people become even more willing to pay (β=7.44±0.002SE, p<<0.05). In the model, it is evident that the variables such as the overall power cut issue in the area and net loss caused by the elephants do not have significant effects on the willingness or unwillingness to pay (Table 8) (Figures 11 & 12). The mean willingness to pay the amount for people belonging to all three WTP categories on the barrier sites was found 18.44±2.13 INR (SE; 0-160 INR), whereas it was observed 27.99±2.95 INR (SE; 0-275 INR) in non-barrier sites.

Table 8: Table representing estimates and level of significance of best fit multinomial logistic regression for describing the relationship with predictor variables and categorical variable of Willingness to pay ("2" = true zero, as the reference category) on the non-barrier sites

Category	**Coefficients**	**Estimate**	**SE**	**z-value**	**Pr(>|z|)**
1 (Unwilling)	Intercept	21.77	0.0003	67709.22	<<0.05
	Overall power cut	0.007	0.009	0.81	0.41
	HEC instances	-6.02	0.003	-18509	<<0.05
	Net loss	6.67^{E-05}	4.16^{E-05}	1.6	0.1
	Compensation	-18.1	0.0006	-26998.28	<<0.05
	Time taken for compensation	1.26	0.02	70.82	<<0.05
	Elephant incursion change	0.13	0.001	87.63	<<0.05
	Crop-raid frequency change	5.48272	0.0002	20263.52	<<0.05
3 (Willing)	Intercept	27.57	0.0003	87265.55	<<0.05
	Overall power cut	-0.02	0.01	-1.54	0.12
	HEC instances	-4.81	0.0003	-15083.37	<<0.05
	Net loss	5.30^{E-05}	4.31^{E-05}	1.22	0.21
	Compensation	-12.27	0.0006	-18226.73	<<0.05
	Time taken for compensation	1.01	0.02	56.59	<<0.05
	Elephant incursion change	0.9	0.002	598.31	<<0.05
	Crop-raid frequency change	7.44	0.0002	35766.03	<<0.05

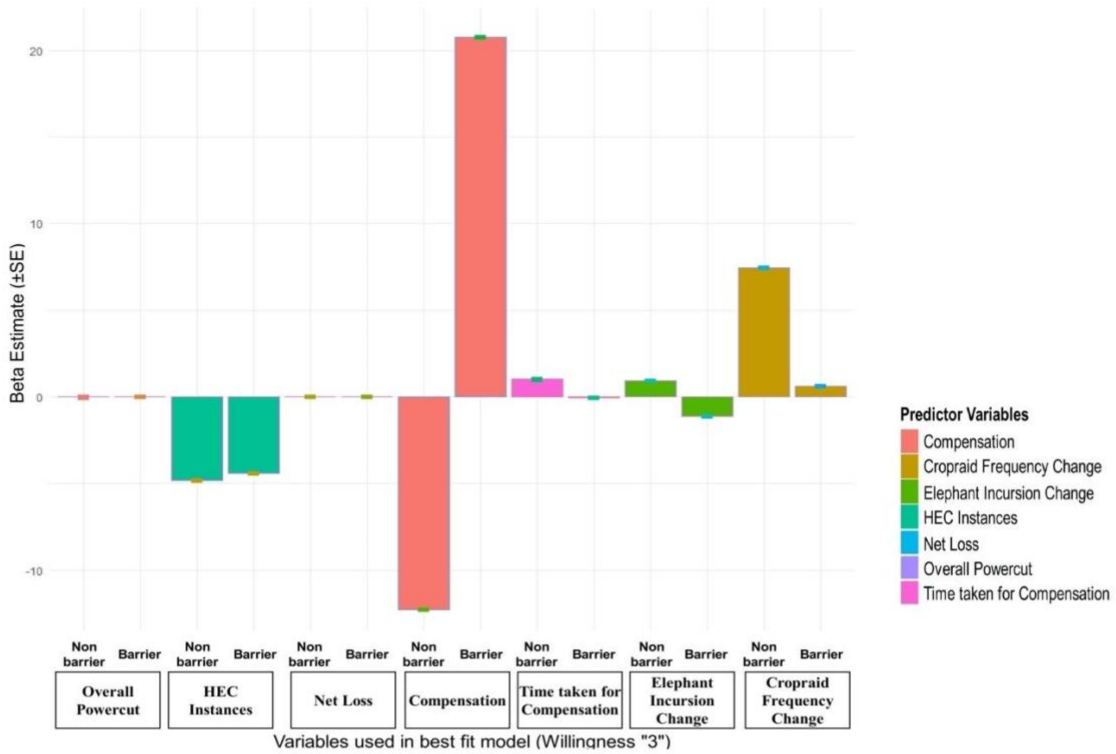


Figure 11: Comparisons of the relationship between beta estimates and different variables from least AICc model for category "3" (willing to pay for maintenance of barriers) for both barrier and non-barrier sites

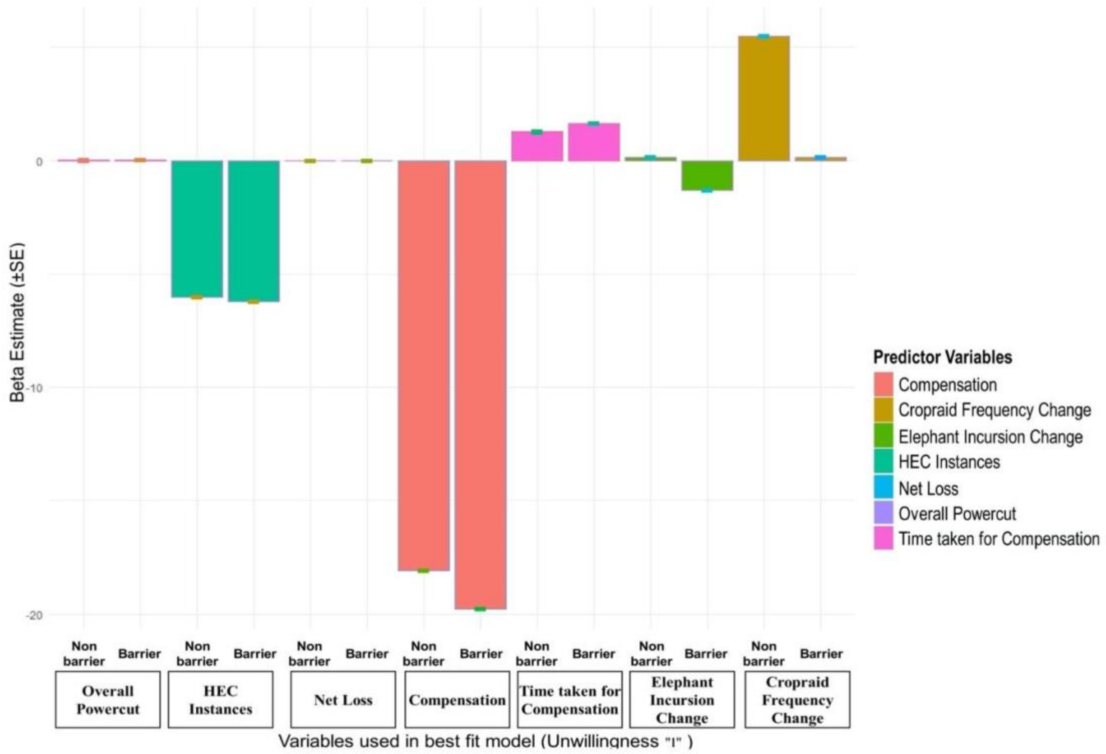


Figure 12: Comparisons of the relationship between beta estimates and different variables from least AICc model for category "1" (unwilling to pay for maintenance of barriers) for both barrier and non-barrier sites

9. Discussion:

The optimized hotspot analysis showed an average 16% increase in the emergence of high conflict hotspot villages, having $z \geq 1.96$ (≥ 95% CI) from 2016-2017 to 2018-2019 including all forms of conflict for the district of Golaghat. However, the number of conflict cases recorded from 2017 to 2019 has seen a sharp decline. These results can be possible either due to lack of conflict reporting, or otherwise an actual decline in HEC cases due to enhancement or increase in the practice of traditional and personal methods of mitigation, support from the FD and NGOs, or installation of physical barriers. It is evident that the number of villages reporting conflict after 2017 reduced by 23% in 2018 and 66% in 2019 (Figure 1). People in these fringe areas are habituated to live along the reserves. Still, there is a lack of support from the FD as only 13% out of 249 total families interviewed are compensated a meager average amount of ₹520 (±101SE) for an average net loss of ₹21,000 (±825SE) of crop/property damages and payment of only ₹21,000 per human death. This makes people lose hope to get protection measures from the authorities. Hence people in the area are seen to be involved in personally invested mitigation measures, such as net fences, lower wattage solar fences, make-shift watchtowers, group night guarding, and personal trenches around tea gardens, houses, and crop fields (*pers. obs.*). People also get provisions from NGOs such as Aaranyak, The Corbett Foundation (TCF), and World Wide Fund (WWF) such as high range torch lights with, raincoats, gumboots, forming village task forces, building firm quality watchtowers, promoting and providing training for increasing market outreach of alternative livelihood options such as vermicomposting, mushroom cultivation, fishery, handloom products, bamboo products to divert their complete reliance on agriculture. The presence of a wall built in 2011 and simultaneous felling of forested land in the No Development Zone (NDZ) for expansion of township and flattening of hilly terrain to develop golf course by Numaligarh Refinery Limited

(NRL) blocked traditional migratory pathway of elephant (National Green Tribunal, 2016). The presence of trenches in and around tea estates of Golaghat district and, likewise, the coming up of a 2 km elephant-proof trench in the Bokial range of LDRF might be responsible for reducing conflict cases.

Notably, the high HEC hotspots are concentrated in clusters around the two reserved forest areas of Kaziranga National Park on the western and Nambor-Doigurung WLS on the southwestern side, indicating less dispersion or shift in the extent of conflict (Maps 3,4,5). These results are supported by the report titled, "Status and Distribution of Elephants in India", released in 2020 by Sukumar et al. (2020), stating that the bordering districts of Karbi Anglong and Nagaon including the Nambor-Doigurung WLS on the eastern side of Karbi-Anglong district has an elephant density of 0.29 elephants per km^2 while KNP has 1.52 elephants per km^2, which is relatively higher densities than other parts of Golaghat district. The report also shows records of the Golaghat district having elephant presence outside these above-mentioned forested areas but not beyond the high hotspot villages, as seen in the results. The low elephant presence and restricted conflict beyond these HEC hotspots can be due to the limited availability of forest cover and increasing density of urbanized areas with increasing distance from the protected areas, which are reported to be avoided by elephants (Sukumar et al., 2020; Evans et al., 2020).

As expected, this study is evident that although barriers, no matter whether solar fence or trench, did not entirely reduce HEC cases. However, a significant decline in encounter rates at barrier sites relative to no barrier sites suggests that barriers can do help in reducing conflict, although not entirely (Neupane *et al.*, 2018). The solar fence was relatively better than the trench as evident and reduces the severity of the HEC instances. Previous studies suggest that the mitigation measures including physical barriers should be implemented based on planned and scientifically based pilot surveys on the barrier's performance (Rangarajan et al., 2010; Desai & Riddle, 2015). In their study on the effectiveness of fences in Kenya, Kioko et al. (2008) suggest that the success of electric fences, or any physical barriers, should be based on-site or region-specificity, maintenance intervals, and proximity measures to highly dense elephant presence areas.

The state of Assam lies in the floodplains of the mighty Brahmaputra, where siltation is a common issue. Therefore, the functioning of elephant-proof trenches is bound to fail if not maintained timely (Borah et al., 2005). Trenches, although they are not an effective tool for regions with high rainfall, yet a combination of trenches with a vegetative barrier, such as the cultivation of lemon or chilies, might prove to be effective if maintained well (Government of India, 2017). Similarly, due to overcast weather in the monsoon season, an increase in water level during flooding may also limit the functioning of solar fences, which is often cumbersome to restore, as stated by the forest staff and locals. However, the material and construction quality of the barriers do make a difference, but this study did not take these features into account as no records were available on their maintenance (Natrajan et al., 2021).

A similar study of Davies et al. (2011) in Asian elephants concludes that different physical barriers such as chili and electric fences effectively decrease HEC, including crop raiding. In contrast to the result of this study, few studies found fences to be ineffective as elephants are quick learners, and they use their tusks as insulators to break down fences (Mutinda et al., 2014). Other studies recommend the involvement of local communities in planning, construction, and better maintenance for a successful intervention (Gunaratne & Premarathne, 2005). In addition to solar fences, change of crops to less preferred cash crops such as lemon, chili, turmeric along the forest-village edge is supported by various studies (Fernando et al., 2008; Hedges & Gunaryadi, 2010; Mmbaga et al., 2017; Neupane et al., 2017). Changing the crop type and less reliance on paddy for cultivation help minimize HEC and contribute to generating alternate livelihoods to local communities (Neupane et al., 2018).

This study concludes that with increased distance from the forest, detection of elephant signs increases; this may indicate that the reserved areas and other areas with forest cover in the district may be unsuitable habitats for the elephants as they are moving out from the protected areas. The KNP (Nagaon and Golaghat district), Karbi-Anglong, and Nagaland make up the Kaziranga-Karbi Anglong Elephant Reserve holding a population of 2318 elephants, the highest in the state of Assam (Sukumar et al., 2020). Contradictory to this is the fact that these protected areas are infested with invasive species of plants, such as *Mimosa invisia inermis, Rosa multiflora, Lantana camara,* etc, degrading grassland quality and leading to a decline in palatable forage for elephants (Sukumar et al., 2020; WII et al., 2007). The rise in intraspecific competition might be another reason but cannot be concluded without any robust study. Meanwhile, forest degradation due to human encroachment, illegal felling, and land-use conversion in Assam is a proven fact, leading to a decline in habitat availability and forcing elephants out of protected areas (Choudhary, 2004; Rangarajan et al., 2010). Golaghat district offers diffuse boundaries between tea estates, crop fields, and forests which often act as a refuge during elephant's movement from smaller forest patches to more extensive and more habitable disjunct forest patches. Therefore, these agroforestry mosaics can serve as an opportunity for initiating and escalating conservation efforts beyond protected areas (Kshettry, 2020).

The multinomial logistic regression evaluated the relationship between the three categories of willing or unwillingness influenced by different predictor variables and how and which of the predictors affect people's willingness or unwillingness to pay for the maintenance of the barriers. In the sites, people were either unwilling to pay as they think maintenance and enhancement of the barrier is the role of authorities and themselves do not want to get involved or otherwise were unable to pay due to low income. In contrast, only those people were willing to pay who care about peaceful co-existence and hence support the idea of modern mitigation techniques and want to involve themselves in such interventions to limit their losses due to elephants (Whitehead, 1992, Hadker et al., 1997, Pate & Loomis, 1997).

In the sites installed with barriers, it can be inferred from the results that if the conflict frequency increases in the area unwilling people can actually be convinced to pay, thinking that proper maintenance of barriers might be able to reduce the occurrence of HEC instances (Arrow et al., 1993). In contrast, willing people might be unwilling to pay as barriers fail to function to decrease conflict. If people are getting compensated, all people are convinced to pay when they are satisfied with the compensation system. However, if the payment process gets delayed, all people become unwilling as they distrust the authorities and their efforts to solve HEC. But as there is an increase in elephant incursion frequency, the hesitant people might become willing to enhance the barrier, whereas, willing people distrust the functioning of the barrier. However vice-versa is true in the case of an increase in crop-raiding frequency (Reb & Connolly, 2007).

It is important to note that not much difference is seen in the non-barrier sites because as HEC instances increase, unwilling people feel the need for a barrier (also suggested by Tversky & Kahneman, 1981), but on the other hand, people who were initially willing lose their hope on the ability of the authorities and their interventions to reduce the issue (also suggested by Neupane et al., 2017). But it is seen that in the case where people get better compensation, then unwilling people would want to have a barrier. Still, willing people would not want to invest in a barrier if they are already getting compensated. However, if authorities take more time to compensate, then unwilling people remain unconvinced, but otherwise, people's willingness increases in need of a barrier to reduce HEC. It is interesting to see that with an increase in elephant incursion and crop-raiding frequency, unwilling people do not want to pay as they believe they distrust any intervention methods of the authorities anymore. But, people who are willing to pay are optimistic that the barrier can solve the issue.

Therefore, the perception of people on barriers in both the sites, i.e., with and without barriers, was influenced by various conflict-related variables, the performance of barriers, and the competency of authorities to deal with HEC. This goes in parallel to significant works done on assessing the social perception of conflict, where people's attitudes and views are seen to be influenced by different socio-economic variables (Karanth & Kudalkar, 2017; Dickman, 2010).

Developing a proper understanding of conservation issues is crucial in prospering positive attitudes among people towards elephant conservation and the success of any management program. This successively augments the willingness to pay of stakeholders and the effectiveness of conflict mitigation. Education imparts sensitivity and alertness in people; hence awareness of elephant conservation is essential. Kaziranga is an active hub of ecotourism in the district, bringing livelihood options for local people and diverting them from dependence on agriculture. Therefore, advancement and relaxation in ecotourism protocol will stimulate the participation of more other local people.

Most of the locals expressed dissatisfaction on different types physical barriers, often shaping their decision regarding willingness to pay for the maintenance of the barriers or installation of barriers. Moreover, it is advocated that the involvement and consent of local communities is a must prior to installation of physical barriers. An agreement of consent on active involvement in maintenance along with financial support for maintenance should be provided to them to evoke interest in the maintenance work (Government of India, 2017; Neupane et al., 2017).

It is documented in the study that local communities often demand equal involvement on policy-level HEC management plans, which is repeatedly ignored. The increased stake of local people in the decision-making process is said to enhance people's perception and impart a sense of belongingness in species conservation (Neupane et al., 2017). Otherwise, improvement of the compensation payment system by ensuring transparency decreased complicacy in application filling, and timely payment mechanism. This enhances trust in authorities and helps build a positive attitude towards the species, their conservation, and support and participation in mitigation interventions. The authorities should develop provisions such as providing livelihood opportunities, incentives, crop insurances as a part of HEC mitigation initiatives. Improvement of early warning systems, such as quick SMS alerts, announcements, and improvised night guarding, can effectively manage human-elephant conflict. The government should engage and collaborate with VDP groups, NGO(s), and youth clubs to organize awareness drives, field trips, and competitions to attract local people's attraction towards conservation. Strengthening and aid communication gaps between locals and authorities and within officials can smoothen the management process. Training forest staff on quick response techniques, communication with locals, and barrier maintenance can improve the mitigation processes (Government of India, 2017).

10. Management implications:

In Assam, significant works on HEC mitigation have been carried out, including installing community-managed power fences, driving away crop-raiding elephants into forests using *kumkis* (trained captive elephants), forming community-based anti-depredation squads (ADS), and using bio-repellents like chili smoke (WWF-India, 2020). The forest department has been trained to manage human-elephant conflict. The Sonitpur model of human-elephant conflict management successfully reduced conflict in the Sonitpur and Udalguri districts in the northern bank of river Brahmaputra (WWF-India, 2020).

In the southern bank, such as the Golaghat district, protected areas like Kaziranga National Park have solar fences, trenches, surveillance cameras, and watchtowers installed as mitigation measures. The forest staff is well trained and does night patrolling in and around the reserve. Recently, the Kaziranga National Park authorities have initiated similar work in the Agoratoli range of Kaziranga National Park, where a 6 km long and 12-13ft high hanging solar fence is under progress of installation (pers. comm. Range Officer Bidyut). This has been replicated from a successful model (hanging solar fences) tried and tested as an effective mitigation measure along the boundary of Manas National Park (WTI, 2020). In areas near the NDWLS only elephant-proof trenches were installed apart from all traditional mitigation measures.

For successful management of human-elephant conflict, it is often suggested that proper planning, experimentation, and a suitable scientific approach should be programmed pre and post-implementation of any mitigation measures. In Golaghat, solar fence was found to be relatively more effective than the trench. Therefore a combination of both along with their proper maintenance can be an effective solution. Furthermore, the government should be involved in using and installing modern barriers with support from local people. Improvisation of the compensation system by the FD of Golaghat forest divisions is essential for conflict management success and gaining the trust of local people.

Moreover, local people should be encouraged to continue cost-effective traditional preventive methods such as night guarding, makeshift cost-effective community fencing, noise repellents, and fire to drive away the elephants. These will ensure a successful, sustainable, reliable, cost-effective, and long-term prevention of conflict (Distefano, 2005). Authorities and the local people of Golaghat can use other available alternatives such as electric low-cost infrasonic audio detectors, which can act as early warning systems (Sayakkara et al., 2017), lemon cultivation at the forest-village interface (pers. comm. Dr. Naveen Pandey).

11. A way forward:

This study emphasizes the importance of an appropriate mitigation system, as the mitigation structures are resource intensive to construct and maintenance. Elephants are highly intelligent animals and are found to defeat most of the physical barriers. Any physical barrier deployed in a combination of other relevant barriers is relatively better than a single physical barrier in most elephant habitats. Apart from this, it is necessary to conserve elephants beyond protected areas, especially in the agro-forestry mosaics. General research on habitat quality, habitat utilization, and habitat suitability for the resident wildlife population must be advanced in the areas with high human-wildlife conflict. This is necessary to find a landscape-appropriate robust solution to retain a high density of animals inside the protected areas that can sustain a good population of all species. Elevation in the nursery plantation rates in areas of heavily degraded elephant habitats by the forest department with the active involvement of the local communities is one among the peaceful solutions of conflict management. In addition, eradication of invasive species and their further control will ensure the availability of palatable forage for multiple species dependent on them and add to conservation. Moreover, equal representation of all stakeholders and revision of the compensation/relief provision schemes will positively affect the conservation of species and the trust-building of local people with the FD.

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Appendices:

Appendix 1: *Datasheet of sign survey of barrier and non-barrier sites in Golaghat district showing encounter rates per site along with other site covariates.*

trails	encounter_rate	barrier_occ	dist_settlement	crop	dist_forest	dist_stream
KZB01_200	10	solar_fence	186	Brassica_juncea	70	197.7576447
KZB01_400	0	solar_fence	200	Brassica_juncea	100	387.3698425
KZB01_600	5	solar_fence	235	Brassica_juncea	70	252.0167084
KZB01_800	10	solar_fence	210	Brassica_juncea	70	285.0687561
KZB01_1000	10	solar_fence	230	Brassica_juncea	70	20.28123665
KZB01_1200	10	solar_fence	210	Brassica_juncea	80	43.89001465
KZB01_1400	0	solar_fence	130	Brassica_juncea	100	69.58666992
KZB02_200	0	solar_fence	125	Brassica_juncea	140	91.94778442
KZB02_400	0	solar_fence	160	Brassica_juncea	70	12.32355976
KZB02_600	0	solar_fence	180	Brassica_juncea	70	0.168360814
KZB02_800	0	solar_fence	80	Brassica_juncea	100	104.0112839
KZB02_1000	0	solar_fence	120	Brassica_juncea	80	221.7434235
KZB02_1200	0	solar_fence	200	Brassica_juncea	80	360.4259033
KZB02_1400	0	solar_fence	220	Brassica_juncea	80	402.4043884
KZB03_200	0	solar_fence	370	Brassica_juncea	20	296.4936523
KZB03_400	0	solar_fence	200	Brassica_juncea	20	198.1425781
KZB03_600	0	solar_fence	250	Brassica_juncea	20	89.02897644
KZB03_800	5	solar_fence	260	Brassica_juncea	50	77.63943481
KZB03_1000	10	solar_fence	240	Brassica_juncea	30	155.7459106
KZB03_1200	5	solar_fence	200	Brassica_juncea	100	351.6409607
KZB03_1400	0	solar_fence	100	Brassica_juncea	110	536.6567993
KZNB01_200	30	no_barrier	30	Brassica_juncea	20	1633.928223
KZNB01_400	35	no_barrier	30	Brassica_juncea	20	1715.244751
KZNB01_600	0	no_barrier	55	Brassica_juncea	20	1768.807861
KZNB01_800	20	no_barrier	40	Brassica_juncea	20	1841.315674
KZNB01_1000	10	no_barrier	65	Brassica_juncea	20	1890.171387
KZNB01_1200	10	no_barrier	150	Brassica_juncea	20	2005.078125
KZNB01_1400	15	no_barrier	200	Brassica_juncea	25	2134.318848
KZNB02_200	20	no_barrier	315	Brassica_juncea	40	2021.530029
KZNB02_400	25	no_barrier	400	Brassica_juncea	50	1843.101807
KZNB02_600	10	no_barrier	400	Brassica_juncea	40	1761.632446
KZNB02_800	0	no_barrier	250	Brassica_juncea	70	1803.742432
KZNB02_1000	0	no_barrier	130	Brassica_juncea	50	1887.230835
KZNB02_1200	15	no_barrier	175	Brassica_juncea	30	1890.471558
KZNB02_1400	20	no_barrier	160	Brassica_juncea	50	1720.134888
KZNB03_200	10	no_barrier	170	Oryza_sativa	30	1531.441895

KZNB03_400	**0**	no_barrier	200	Oryza_sativa	30	1391.465942
KZNB03_600	**10**	no_barrier	220	Oryza_sativa	30	1329.557861
KZNB03_800	**5**	no_barrier	145	Oryza_sativa	20	1235.921143
KZNB03_1000	**15**	no_barrier	120	Oryza_sativa	20	1170.833618
KZNB03_1200	**10**	no_barrier	120	Oryza_sativa	20	1145.571411
KZNB03_1400	**10**	no_barrier	100	Oryza_sativa	20	1002.383911
NMB_B01_200	**15**	trench	115	Camellia_chinensis	850	498.3179626
NMB_B01_400	**30**	trench	85	Camellia_chinensis	1500	602.0219727
NMB_B01_600	**10**	trench	120	Camellia_chinensis	1500	771.980835
NMB_B01_800	**0**	trench	70	Oryza_sativa	1300	873.5440674
NMB_B01_1000	**5**	trench	100	Oryza_sativa	1300	750.6911011
NMB_B02_200	**10**	trench	70	Camellia_chinensis	1280	874.3742065
NMB_B02_400	**15**	trench	112	Camellia_chinensis	1220	1022.640076
NMB_B02_600	**5**	trench	50	Camellia_chinensis	870	1185.759277
NMB_B02_800	**10**	trench	70	Oryza_sativa	790	1306.799683
NMB_B02_1000	**0**	trench	180	Oryza_sativa	800	1412.593384
NMB_NB01_200	**25**	no_barrier	286	Oryza_sativa	30	523.6791992
NMB_NB01_400	**20**	no_barrier	240	Oryza_sativa	30	686.1242065
NMB_NB01_600	**10**	no_barrier	290	Oryza_sativa	30	851.1289063
NMB_NB01_800	**20**	no_barrier	315	Oryza_sativa	30	1003.716858
NMB_NB01_1000	**10**	no_barrier	460	Oryza_sativa	30	1149.600342
NMB_NB02_200	**0**	no_barrier	570	Oryza_sativa	30	1336.789551
NMB_NB02_400	**30**	no_barrier	660	Oryza_sativa	50	1359.44165
NMB_NB02_600	**5**	no_barrier	260	Oryza_sativa	50	1257.039673
NMB_NB02_800	**0**	no_barrier	100	Oryza_sativa	70	1382.801514
NMB_NB02_1000	**20**	no_barrier	75	Oryza_sativa	80	1282.389771

Abbreviations used: barr_occ= barrier occurrence, solar_fence=Solar fence, no_barrier= no barrier, dist_forest= distance from forest, dist_settlement=distance from settlement, dist_stream=distance from stream, KZB=Kaziranga Barrier, KZNB=Kaziranga Non-Barrier, NMB_B=Nambor barrier, NMB_NB= Nambor Non-Barrier

Appendix 2: *Questionnaire to evaluate human-elephant conflict and mitigation strategies in Golaghat District, Assam, India*

<table>
<tr><td colspan="10">General Information
Name of Interviewee: Date & Time:</td></tr>
<tr><td colspan="10">Part 1: Respondent Details</td></tr>
<tr><td>1a. Name:</td><td></td><td>1b. Age</td><td></td><td>1c. Sex</td><td>M</td><td>F</td><td>T</td><td>F</td><td>T</td></tr>
<tr><td colspan="2">2. Name of village:</td><td colspan="8"></td></tr>
<tr><td colspan="2">3. GPS Location:</td><td colspan="8"></td></tr>
<tr><td colspan="2">4. Education qualification:</td><td colspan="8"></td></tr>
<tr><td colspan="2">5. Ethnicity:</td><td colspan="8"></td></tr>
<tr><td colspan="2">6. Occupation/ Source of income:</td><td colspan="8"></td></tr>
<tr><td colspan="2">7. Number of Family Members</td><td colspan="8"></td></tr>
</table>

<table>
<tr><th rowspan="2">Relation with respondent</th><th rowspan="2">Age</th><th rowspan="2">Sex</th><th rowspan="2">Education qualification</th><th rowspan="2">Occupation</th><th colspan="2">Nature of Work</th><th rowspan="2">Annual Income</th></tr>
<tr><th>Continuous-(1)/Seasonal-(2)</th><th>Duration of work</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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8.Living here since:

9. Housing and other amenities

Amenities Name	Types
House	1-Pucca 2-Semi-Pucca 3-Kutcha 4-Hut 5-Temporary
Sanitation	1-Yes 2-No
Grain Storage Shed	1-Yes 2-No | Quantity _________ qntl | Storage duration _________ months
Main Cooking Fuel	1-Wood 2-Charcoal 3-Kerosene 4-Cow Dung 5-LPG
Electricity	1-Yes 2-No | Power cut frequency per day ______ | Power cut duration per day ______ hrs
Source of Water	1- River, 2- Govt supply, 3- Hand pump/tube well, 4-Natural stream, 5- other (specify)

Part 2: Land Ownership

1. Do you own any agricultural land?	Yes How much land do you own (Type/Quantity/Local Unit):	No
2. What crops do you grow and how much area does it cover?		
3. How many times farming is done each year and when?		
4. Have you changed the type of crop grown in your field in the last five years?	Yes What are the reasons for the change in crops grown:	No
5a. Main Income Crop		
5b. Investment and Yield (Unit/Rupees)		
6. Crop raiding by wildlife or fear of animal attack	Yes Estimated loss (Unit/Rupees):	No
7. Crops no longer grown/ Reasons(list in rank order)/New crops/Reasons(list in rank order)		
8. Distance of land from forest and a physical barrier		

9. Any mitigation strategy is followed by you or your nearby farm holders	Yes What are they:	No

Part 3: Conflict details

1. Is there any HEC instances in your village?	Yes What type of HEC have you suffered? 1-Agriculture / Stored grain Related, 2-Life Related, 3-Both	No

2. Agriculture / stored grain-related HEC

S.no.	Crop/grain destroyed	Net Loss out of Total Income/year	Compensation 1-Yes, 2-No If yes, Amount compensated (Rs.)	Time taken to receive the compensation

3. Has there been any loss/injury of Human life due to HEC in your family?	Yes	No

4. If yes

Queries	Human	Elephant	Year of Conflict
Numbers killed/injured per encounter			
Compensation 1-Yes, 2-No		**NA**	
Amount compensated (Rs.)		**NA**	

5. Is the compensation program satisfactory? YES NO If no state the reasons why:

Meagre amount paid as compensation	Time delay in compensation	Complicated procedure	The attitude of forest department staff	Others

6. In your view, has the conflict increased/decreased/stable? State the reason

7. What should be done to prevent conflict?

8. What measures do you take to prevent conflict?

Part 4: Efficacy of Physical Barriers

Queries	Pre barrier deployment		Post barrier deployment	
Sighting of conflict animal	Yes	No	Yes	No
Sighting type: 1- Direct, 2- Indirect	Direct	Indirect	Direct	Indirect
Sighting distance from the barrier	**NA**			
Herd size				
Sighting/Encounter season				
Sighting/Encounter frequency per week				
Crop raiding frequency per week				
Damage to property/life: 1- Yes, 2- No				
Compensation: 1- Yes, 2- No				
Relative change in sightings: 1- Increased, 2- Decreased, 3- Not changed, 4- Do not know				
Frequency of barrier maintenance	**NA**			

Part 5: Attitude & Perception

1. What is your perception of the conservation of elephants?

Positive	Negative	Neutral	Not Interested

2.Your views on human coexistence with elephants

Intolerable	Moderately tolerable	Tolerable	Tolerable provided proper measures are taken

3. Should Elephants be restricted from moving out of their habitats?

3.1 If no, what reasons do you think is behind their movement?	Deforestation	Developmental activities	Migration behaviour	Others (Specify)	Unsure
4. Do you think elephants should be conserved?	Agree	Disagree	Unsure	-	-

5. What is your view towards the physical barriers deployed for reducing HEC?

Satisfied	Not Satisfied	Neutral	Not Interested

6. Which barrier do you think is relatively effective? Name _________________ and reason____________________________

Part 6: Willingness to Pay

<u>Scenario </u>– Golaghat has a high frequency of human-elephant conflicts, and you are well aware of this. In the region, government and private agencies have deployed various physical barriers (i.e., solar fences, Elephant proof trenches, and walls) in the district's conflict zones, including this village. These barriers can be helpful for the following reasons:

a) Reducing Human-Elephant conflicts, related casualties and monetary losses
b) Setting up of recreational facilities for tourists due to reduced conflict
c) Livelihood options from tourism

<u>Contingent Valuation Question</u>
To attain the Scenario, maintenance of the physical barriers are necessary for this area.
My set of questions requires you to consider the upcoming years. Please bear the following points in mind when you answer.

1. These physical barriers deployed as discussed here are only one among many other efforts for mitigation of HEC,
2. Golaghat holds essential elephant habitats,
3. Livelihood options are scarce, and your income is limited,
4. Your family and land are at constant risk of elephant attacks,
5. The following set of questions asks you to focus only on the areas where barriers are deployed,

1. Would you be willing to pay any monetary inputs to maintain the barriers at regular intervals?	Yes	No

2. If your answer is 'no,' why are you unwilling to pay at regular intervals?

Government should pay	Private agencies should pay	Inability to pay due to my low income	Other reasons

3. If yes, would you be willing to pay Rs 100 off your household's monthly income, or Rs 1200 per year, starting from June 1st, 2021, towards maintaining the barriers at regular intervals?	Yes	No
4. If your answer is 'no,' are you willing to pay Rs 50 of your household's monthly income, that is Rs 600 per year, for the maintenance of the barriers at regular intervals?	Yes	No

5. What is your minimum willingness to pay to maintain the barriers per month for the upcoming years? Rs ____/month

6. What is your maximum willingness-to-pay per month for the formation, maintenance of the physical barriers? Rs ____/month.

Appendix 3: *Eleven multinomial logistic regression model with their respective AICc, ΔAICc, AICc weight and Log likelihood for barrier sites.*

Model names	Model description	AICc	ΔAICc	AICc Weight	Log likelihood
test_m2	wtp_cat ~ ov_pw + hec+ net_loss + comp+ time_taken_comp +change_ele_freq + change_cropraid_freq	209.84	0	0.64	-86.33
test_m7	wtp_cat ~ quali +ann_income+net_loss+time_taken_comp	211.03	1.18	0.35	-84.19
test_m5	wtp_cat ~ age + ethnicity + no._family+ hec + change_ele_freq + change_cropraid_freq	220.51	10.67	0	-86.1
test_m3	wtp_cat ~ zone + age + ann_income + ht + hec + comp+ net_loss	221.03	11.18	0	-86.36
test_m11	wtp_cat~quali +ann_income+ net_loss+ ov_pw+ hec+ comp + time_taken_comp+ change_ele_freq + change_cropraid_freq	222.69	12.84	0	-74.61
test_m6	wtp_cat ~ quali+ ann_income+ net_loss+ comp+ time_taken_comp+ethnicity +change_ele_freq +change_cropraid_freq	239.09	29.25	0	-75.68
test_m4	wtp_cat ~ gender + ethnicity + quali + ov_pw+ comp+ time_taken_comp+ change_cropraid_freq + change_ele_freq	245.41	35.57	0	-78.84
test_m1	wtp_cat ~ zone + age + gender + ethnicity + no._family+ quali +ann_income + ht	262.71	52.87	0	-79.68
test_m9	wtp_cat~zone+age+gender+quali+no._family+ethnicity+ann_income+h t	262.71	52.87	0	-79.68
test_m10	wtp_cat~zone+ age+ gender+ quali+ no._family+ ethnicity+ ann_income+ ht+ net_loss	264.03	54.19	0	-76.16
test_m8	wtp_cat~zone+ age+ gender+ ethnicity+ no._family+ quali+ ann_income+ ht+ ov_pw+ hec+ net_loss+ comp+ time_taken_comp+ change_cropraid_freq+ change_ele_freq+ perception	309.09	99.24	0	-62.6

Abbreviations used: wtp_cat= WTP category (1,2 and 3), ov_pw=overall power cut, hec= human-elephant conflict (1,0),comp=compensated (1,0), time_taken_comp= time taken for compensation, change_ele_fr=change in elephant incursion frequency, change_crop_raid_fr, no._family=no. of family members, quali=qualification, ann_income= annual income, ht=house type

Appendix 4*: Thirteen multinomial logistic regression model with their respective AICc, ΔAICc, AICc weight and Log likelihood for non-barrier sites.*

Model names	Model description	AICc	ΔAICc	AICc Weight	Log likelihood
test_m2	wtp_cat ~ ov_pw+hec + net_loss + comp + time_taken_comp+ change_ele_freq + change_cropraid_freq	126.86	0	1	-44.96
test_m5	wtp_cat ~ age + ethnicity + no._family+ hec + change_ele_freq + change_cropraid_freq	142.21	15.35	0	-49.94
test_m6	wtp_cat ~ quali+ ann_income+ net_loss+ comp +time_taken_comp+ ethnicity+ change_cropraid_freq +change_ele_freq +	142.91	16.05	0	-31.77
test_m4	wtp_cat ~ gender + ethnicity + quali+ ov_pw + comp+ change_cropraid_freq + change_ele_fre +time_taken_comp	145	18.14	0	-32.81
test_m10	wtp_cat~zone+age+gender+ethnicity+no._family+quali+ ann_income+ ht+ov_pw+ hec+ net_loss+comp+time_taken_comp+ change_cropraid_freq+change_ele_freq+perception	193.12	66.26	0	-18.41
test_m9	wtp_cat~1	218.55	91.69	0	-107.23
test_m8	wtp_cat~change_ele_freq	219.03	92.17	0	-105.35
test_m11	wtp_cat~ov_pw+ hec+comp	224.96	98.09	0	-103.87
test_m3	wtp_cat ~ zone + age + ann_income + ht + hec + comp + net_loss	232.95	106.09	0	-95.31
test_m7	wtp_cat ~ quali +ann_income +net_loss+time_taken_comp	240.77	113.91	0	-99.22
test_m1	wtp_cat ~ zone + age + gender + ethnicity + no._family + quali + ann_income + ht	258.27	131.41	0	-85.9
test_m12	wtp_cat~zone+age+gender+quali+no._family+ethnicity+ann_income+ ht	258.27	131.41	0	-85.9
test_m13	wtp_cat~ zone+ age+ gender+ quali+ no._family+ ethnicity+ ann_income+ ht + net_loss	259.96	133.1	0	-83.04

Abbreviations used: wtp_cat= WTP category (1,2 and 3), ov_pw=overall power cut, hec= human-elephant conflict (1,0),comp=compensated (1,0), time_taken_comp= time taken for compensation, change_ele_fr=change in elephant incursion frequency, change_crop_raid_fr, no._family=no. of family members, quali=qualification, ann_income= annual income, ht=house type