Identifying the causes of human-elephant conflict in the Indo-Bhutan foothill region of Assam

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ABSTRACT
Significant changes in land use and land cover (LULC) lead to the shrinking of elephant habitats and regular human-elephant confrontations, triggering human-elephant conflict (HEC). The present study aims to assess the underlying causes of HEC in the Indo-Bhutan Foothill region of Assam, India by using both primary and secondary data. The study area was divided into three buffer zones extending from the forest zone. Landsat 4-5 TM C2L2 and Landsat 8-9 OLI/TIRS C2L2 data were used for supervised image classification for 2011 and 2023, respectively, to detect LULC changes. A Getis-Ord Gi analysis was performed to identify hotspots, and kernel density analyses were used to map HEC density. Further, primary data were collected from 384 households in 2023 using a semi-structured interview schedule. A decrease in agricultural land was observed across all zones in all districts. Dense forest vegetation increased in all zones except zones 1 and 2 of the Udalguri district. An increase in built-up areas/settlements, open forest and man-made vegetation was evident throughout the study area. The density of HEC incidents is highly concentrated in zone 1 across three of the districts, except in Chirang. The hotspot patterns are more pronounced in Udalguri and Baksa at confidence levels of 99%, 95% and 90%, whereas in Kokrajhar, they are significant only at 99%, and no hotspots were observed in Chirang. The main reasons for HEC are changes in LULC, distance from elephant habitats, and the attraction of elephants to available of food sources in the human landscape.

KEYWORDS
land use and land cover; hotspot analysis; buffer zone; human-elephant interaction; human-elephant conflict

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1. Introduction

Humans and elephants have had a long relationship since the history of human civilisation. HEC is a growing issue in many parts of India, as well as in the Bodoland Territorial Region (BTR) of Assam. This study is about the causes of HEC in the buffer zones (5599.04 sq. km) of BTR. Although elephants were used in war, as beasts of burden and worshipped as deities in most of Asia (Sukumar 2003), HEC becomes inevitable when the area for human settlement overlaps with their habitat. People extract resources daily from the forest (Thant et al. 2020), leading to a decline in wildlife habitat quality and a decrease in natural food sources available to animals, aggravating the conflict between humans and wildlife. The shrinking of elephant habitats has progressively forced elephants into closer contact with people, resulting in more frequent conflict (Shaffer et al. 2019). Habitat loss and deforestation are also some of the reasons why elephants are exposed to human life (Rahman 2019). The life expectancy and population of elephants are also some of the reasons for HEC. Elephants are long-lived animals, and their survival depends upon regular migration over large distances to search for food, water and social and reproductive partners (Sukumar 2003; Whyte 2012). This may explain why elephants traverse human habitat regions in search of food to survive, leading to human-elephant close interaction. Study indicates that Loxodonta cyclotis elephants travel up to 7–8 km daily (Mills et al. 2018) and Pygmy elephant moves about 9.5 km per day (Alfred et al. 2006) in search of food.

As per the latest available statistics, the elephant population in Assam was estimated to have increased to 5828 by 2024 (Piraisoodan et al. 2024). In the state, the population of elephants has shown a steady increase from 5246 in 2002 to 5828 in 2024. In this region, elephants and humans live in the same ecological landscape and share the land, leading to HEC. Further, study (Kusena 2009) indicates that HEC hotspots have increased predominantly in areas where cultivation, settlement, and water sources coincide. HEC poses a grave threat to their continued harmonious co-existence. For instance, there are several potential bio-physical reasons, such as water sources in a dry season, known elephant trails, preferred wild fruit trees and feeding ground, etc. that lead to HEC (Compaore et al. 2020). Due to such overlap between agricultural lands and elephant habitats, farmers experience considerable damage to their cultivated crops and gradually lose positive attitudes towards the elephants (Santiapillai et al. 2010).

Several studies (Lenin and Sukumar 2011; Ndlovu et al. 2016; Naha et al. 2020) indicate that human population growth has led to the expansion in agriculture, animal rearing, loss of forest cover, and increased sharing of land between humans and elephants, thereby leading HEC. The probability of crop raiding also increases with the growth of elephant population. Landscape transformation pushes human and elephant populations to live in ever closer proximity, leading to an increase in HEC (Shaffer et al. 2019). The HEC was seen in the North Kalimantan Province of Indonesia due to the rapid transformation of forests to oil palm plantations (Suba et al. 2017). Contrastingly, a study (Gubbi et al. 2014) showed that there is no correlation between conflict incidences per unit area and elephant density, forest cover, forest perimeter of protected areas and presence of physical barriers. During 1995–2006, the refugee crisis in the Democratic Republic of Congo (DRC), had a significant impact on elephant habitat, during which an area of 300 km.sq. was deforested in the Virunga National Park (Beyers et al. 2011).

The HEC rate depends on elephant movement, which is influenced by rainfall, elevation and temperature (Arham et al. 2018). When protected areas are hit by drought, wildlife, including elephants, tend to migrate towards human settlements and plantations in search of water and green vegetation (Mariki et al. 2015). The majority of HEC occurs when elephants traverse human-inhabited areas, and this has intensified due to the approximate 70% increase in elephant numbers in India between 1980 and 2002 (MoEF Govt. of India 2010), despite habitat loss (Lenin and Sukumar 2011). Elephant may also become more aggressive due to the consequences of their lost habitat and food sources (Rahman 2019). A study (Hoare 1999) shows that the sex of elephants also plays a significant role in HEC, as the degree of tolerance to human disturbance is greater in males; therefore, they are found closer to human settlements than females.

One of the most relevant causes of HEC in eastern India is the production of Haaria rice beer and the resulting alcoholism, as intoxicated people harass and chase elephants from the region (Naha et al. 2020). Fruiting and mature crops are more frequently targeted during elephant raids (Compaore et al. 2020). Due to habitat loss and declining food avaliability in forest areas, elephants increasinly move into human dominated landscape in search of food (Arham et al. 2018). Additionally, the percentage of cropland, rubber tree cover and natural forest cover are also potential factors affecting HEC (Chen et al. 2016).

In BTR, the elephants seasonally move out of the forest to the foothill region in search of food. Consequently, incidents of HEC occur mainly in the foothill areas, causing heavy economic losses to the people living in this belt. The growing human populations, demands for cultivable lands, and conversion of elephant habitat to human habitation and cropland have resulted in serious HEC in Assam, North-east India (Talukdar and Barman 2003). The people of the study area are changing their livelihood practices for better economic opportunities; consequently, many have converted arable land into perennial plantations. The conversion of forest areas to built-up areas and agricultural land has forced humans and elephants to share the same landscape, leading to spontaneous HEC. The Elephants of this region, Elephas maximus indicus, often move in large herds. While venturing into human habitat, they usually destroy crops, damage houses, fences and occasionally cause human fatalities. Above all, the HEC affects the social and economic security of farmers and poses significant challenges to elephant conservation within their home range (Nath et al. 2015).

HEC always has a negative impact on both humans and elephants and can potentially harm both species (Ngure 1995; Ekobo 1997). In the Hambantota District of Sri Lanka, elephants have reportedly been killed using mine bombs and poisoning (Liyanage 2012). Resolving HEC remains a major challenge. However, a growing understanding of wildlife behaviour, human activities, and the spatio-temporal patterns of human-wildlife conflict has led to the suggestion, development, and adoption of various prevention and mitigation approaches (Fernando et al. 2005; Gubbi 2012; Baruch-Mordo et al. 2013; Hoare 2015). Therefore, there is a need for a comprehensive study to identify sustainable solutions to HEC, and the present study is a humble attempt in this regard.

2. Materials and methods

2.1 Defining variables

In this study, the frequency of HEC is defined as the number of HEC incidents experienced by the villagers during a given period. For example, if the five households in a village have experienced HEC on date 'x' of that period then the frequency will be considered as '1' and if the same five households along with other households or only other new households have experienced HEC on 'y' date then the frequency of HEC of the village will be considered as '1 + 1' and it will continue up to nth frequency. i.e. 1 + 1 + … + ^{nth}. The intensity of HEC is defined as the number of households affected in a single day. For example, if the elephant entera village and affect one household on day 'a', then the intensity of HEC would be 1 and on the day 'b', elephants affected 4 households (which may include the same household), then the intensity of HEC of that day would be 4. Therefore, the total intensity of the HEC in the village during the study period would be '1 + 4 = 5'.

2.2 Geographical site

The present study is based on both primary and secondary data. The study area includes Udalguri district, Baksa district, Kokrajhar district and Chirang district of the BTR in Assam. These four districts are the only parts of the state that share an international boundary with Bhutan. The study area covers the forest areas of the Lesser Himalayan foothill region and the adjoining human habitats of the BTR. For the present study, three buffer zones were created from the periphery of the dense forest zones. The Dense Forest zone boundary was demarcated using a Landsat 8 satellite image from 2023. The dense forest zone boundary refers to the line beyond which the actual dense forest exists, as identified from the 2023 satellite image. The entire study area covers six forest divisions, namely the Dhansiri Forest Division in Udalguri district, the Baksa Forest Division in Baksa district, the Parbatjhora, Kachugaon, and Haltugaon Forest Divisions in Kokrajhar district, and the Chirang Forest Division in Chirang district. However, since the Parbatjhora Forest Division of Kokrajhar district is isolated from the buffer zones and very few HEC incidents have been reported there, it has been excluded from the study area.

2.3 Data collection and analytical approaches

For the present study, primary data were collected to understand the human perspective on HEC, while secondary data were gathered to assess the association between distance from dense forests and HEC occurrence. According to the available literature, the wild Asiatic Elephant (Elephas maximus indicus) moves approximately 21 km per day (Mobasheri and Buckley 2021), indicating an average movement of about 10.5 km while venturing out from, and returning to, its habitat. Accordingly, a buffer zone of 10.5 km was created by dividing 21 km by two. Furthermore, according to data provided by the Divisional Forest Offices, most HEC incidents are concentrated within 10.5 km of the forest boundary. Only a very insignificant proportion, about 1.59% of villages reporting HEC cases, were recorded beyond 10.5 km during the period 2012–2022. Thus, it can be inferred that the elephants in the study area generally move about 10–11 km away from their habitat. Therefore, the 10.5 km zone was divided into three equal buffer zones (strata). Buffer Zone 1 falls within <3.5 km, Buffer Zone 2 ranges from 3.5–7.0 km, and Buffer Zone 3 ranges from 7.0–10.5 km from the dense forest periphery.

Sample size determination

For the present study, the sample size was determined using Cochran's (1977) method of sample size determination. According to Cochran, when the population size and prevalence are known, the sample size can be determined using the following formula (Uakarn et al. 2021):

$$n = \frac{p(1-p)}{\frac{e^2}{Z^2}+\frac{p(1-p)}{N}},$$

where

n … sample size for finite population,
N … population size, e … acceptable sample error,
p … the population proportions,
Z … Z value at relatability level or significance level,
α … alpha value.

Here confidence level = 95%, α = 0.05, critical value or Z = 1.96, e = 0.05, and N = 92464 households.

Hence, the estimated sample size (n) is 383. To obtain an even number, the sample size was increased from 383 to 384 by adding one sample. Considering the possibility of non-responses from some sampled households, an additional 10% oversampling was included. Therefore, the total sample size for the study became 422.4. However, to obtain a round figure for each selected village, the sample size was further increased to **432, i.e. [{(16 samples from each village + 2 nonresponses from each village) × 2 villages from each zone} × 3 zones in each district] × 4 districts**.

Before the sample selection, a list of villages experiencing HEC during 2012–2022 was obtained from the Divisional Forest Offices of the BTR. The villages within each zone were then arranged in descending order based on the number of HEC incidents. Thereafter, the villages experiencing the highest and second-highest number of HEC incidents within each zone were selected for the study. For each selected village, a list of households that had experienced HEC at least once during the study period was prepared using secondary data collected from the Forest Range Offices and Divisional Forest Offices for the period 2012–2022. From the prepared list, 8 households experiencing HEC were selected by applying a systematic circular sampling technique with a random start. Furthermore, an equal number of households located nearest to the conflicted households that had never experienced HEC were also selected. The intensity, frequency and number of HEC incidents were calculated based on the secondary data.

Land Use and Land Cover (LULC) maps for time periods (2011 & 2023) were generated to observe changes over time. The LULC maps correspond to the years 2011 and 2023, representing the periods just before and after the available secondary data. Furthermore, primary data were also collected in 2023. To prepare the LULC map, data were acquired from two different Landsat images and processed separately for two years. For 2011 and 2023, satellite images from Landsat 4-5 TM C2L2 and Landsat 8-9 OLI/TIRS C2L2, respectively, were downloaded from the USGS Earth Explorer. The downloaded images were processed separately for each year. The images of a specific year were combined into a single file to create a band composite. For both years, a total of 7 bands (1–7) were used for the LULC image band composite. During the creation of the band composite, the RGB colour combinations were adjusted for colour enhancement and correction. Specifically, the natural colour band combinations of Red-5, Green-2, and Blue-1 for Landsat 5, and Red-4, Green-3, and Blue-2 for Landsat 8 were used. The images were then mosaiced to merge them into a single raster file. A total of six satellite images for 2011 and five satellite images for 2023 were combined to cover the entire study area. The combined images were subsequently masked using the desired shapefiles/polygons of the study area. A total area of 9191.3 sq. km was masked from the mosaic image for the study area. Finally, the images were classified using the maximum likelihood image classification method.

A supervised image classification technique was applied for the LULC image classification. For this purpose, six major classes were created: 1) Agricultural land, 2) Built-up areas/settlements, 3) Water bodies, 4) Barren land, 5) Open Forest and man-made vegetation, and 6) Dense Forest vegetation. These six major classes include several sub-classes. However, the major class/feature agricultural land does not contain any additional sub-classes. The sub-classes houses/buildings, factories, industries, temples, roads and railways were included under the major class/feature built-up areas/settlements. Similarly, rivers, canal, pond and lake are under major class/feature water bodies, while sand bars and dry land/soil without vegetation cover were classified under barren land. Shrubs, herbs, trees, plantations, sparse vegetations, and perennial planation such as rubber plantations, banana plantations, tea plantations, and areca nut plantations were classified under open forest and man-made vegetation. For better classification and to identify the vegetation cover used by elephants as habitat, perennial plantations were included under open forest and man-made vegetation, as elephants frequently use these areas for shelter during the daytime. Lastly, dense forest vegetation includes natural forest vegetation.

For the year 2011, a larger number of training samples were used (agricultural land-1000, for built-up areas/settlements 1000, for water bodies-300, for barren land-200, for open forest and man-made vegetation-600, and for dense forest vegetation-200) because the image was comparitively more difficult to identify and classify than the 2023 image (for agricultural land-1000, for built-up areas/settlements 1000, for water bodies-300, for barren land-100, for open forest and man-made vegetation-500, and for dense forest vegetation-200). The training samples were selected randomly for classification. The different classes/features were then stored in a signature file. This signature file was subsequently classified using the maximum likelihood classification method to generate the final LULC map. The generated LULC map was then verified using ground data to assess its accuracy. For ground verification, Google Earth image was used and compared with the LULC map. For the accuracy assessment, Producers Accuracy, Overall Accuracy, the Kappa Coefficient/Kappa Accuracy Assessment method was applied. The following are the data produced for accuracy assessment (Tab. 1).

As per the generated Kappa accuracy assessment data from the confusion matrix (Tab. 1) for the year 2011, the user accuracy for agricultural land is 91.08%, for built-up areas/settlements is 82.19%, for

Tab. 1 Confusion matrix/error matrix for Kappa accuracy assessment.

Class/Features		1	2	3	4	5	6	Total
		Agricultural land	Built-up areas /settlements	Water bodies	Barren land	Open forest and man-made vegetation	Dense vegetation and forest	
Confusion matrix/error matrix for Kappa accuracy assessment for the year 2011								
1	Agricultural land	143	4	0	0	10	0	157
2	Built-up areas/settlements	7	180	0	0	12	20	219
3	Water bodies	4	0	80	4	7	0	95
4	Barren land	0	0	0	60	0	0	60
5	Open forest and man-made vegetation	6	18	0	0	160	10	194
6	Dense vegetation and forest	0	10	0	0	0	170	180
	Total	160	212	80	64	189	200	905
Confusion matrix /error matrix for Kappa accuracy assessment for the year 2023								
1	Agricultural land	93	0	0	0	0	0	93
2	Built-up areas/settlements	2	84	0	0	9	5	100
3	Water bodies	5	1	55	0	1	0	62
4	Barren land	0	0	0	44	0	0	44
5	Open forest and man-made vegetation	0	0	0	3	97	0	100
6	Dense vegetation and forest	0	0	0	0	0	100	100
	Total	100	85	55	47	107	105	499

water bodies is 84.21%, for barren land is 100%, for open forest and man-made vegetation is 82.47% and for dense forest vegetation is 94.44%. The producer accuracy for agricultural land is 89.38%, for built-up areas/settlements is 84.91%, for water bodies are 100%, for barren land is 93.75%, for open forest and man-made vegetation is 84.66%, and for dense forest vegetation is 85%. The overall accuracy is 87.62%,

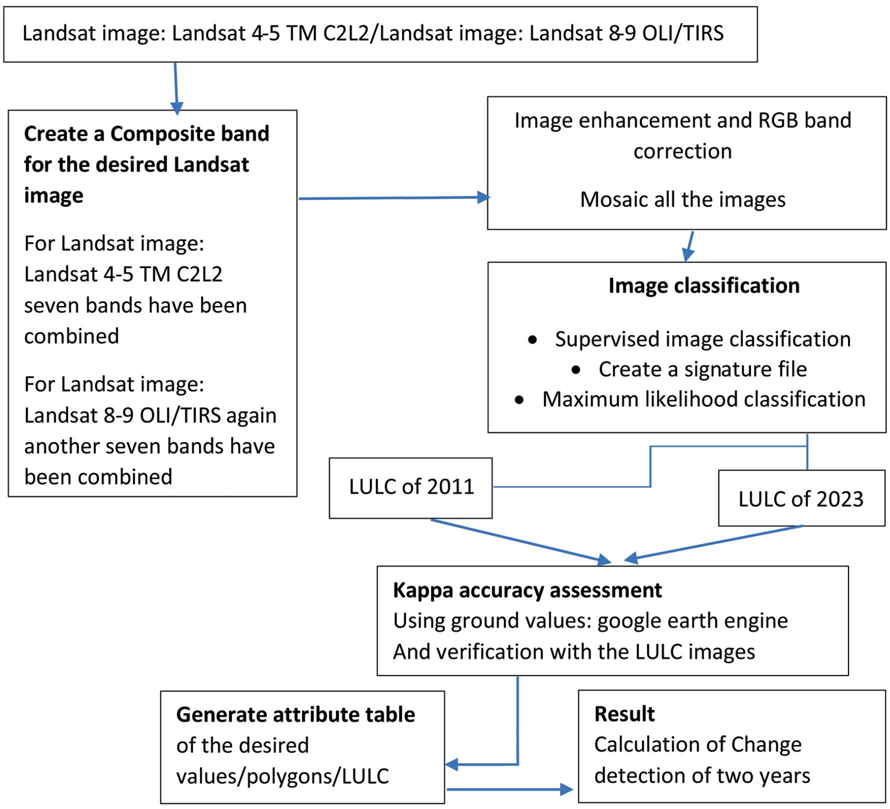


Fig. 1 Image processing of LULC.

the kappa coefficient is 0.85, and the Kappa accuracy is 84.72%. Since the overall accuracy exceeded 80%, and the kappa coefficient satisfies the chance agreement, there is a strong agreement between the classified and referenced data. Therefore, the LULC image can be interpreted, and with the help of the attribute table, the area of the features can be calculated. As per the generated Kappa accuracy assessment data (Tab. 1) for the year 2023, the user accuracy for agricultural land is 100%, for built-up areas/settlements is 84%, for water bodies are 88.71%, for barren land is 100%, for open forest and man-made vegetation is 97%, and for dense forest vegetation is 100%. The producer accuracy for agricultural land is 93%, for built-up areas/settlements is 98.82%, for water bodies are 100%, for barren land is 93.62%, for open forest and man-made vegetation is 90.65%, and for dense forest vegetation is 95.24%. The overall accuracy is 94.79%, the Kappa coefficient is 0.94 and the Kappa accuracy is 93.66%. Since the overall accuracy exceeded 80%, and the kappa coefficient satisfies the chance agreement, there is a strong agreement between the classified and referenced data. Therefore, the LULC image can be interpreted, and using the attribute table, the area of the features can be calculated. Based on these results, the areas under different features have been calculated for the Dense Forest zone, Zone 1, Zone 2 and Zone 3, respectively, for each district for the years 2011 and 2023.

The following steps have been used for image classification (Fig. 1).

Three different types of analyses have been done for hotspot analysis, they are- i) Spatial autocorrelation, ii) Kernel density and iii) Getis-Ord Gi:

i) Spatial autocorrelation
The spatial autocorrelation High/Low clustering report (Getis-Ord General G) tool in ArcGIS software has been used to show how the variables are associated in a given space. The spatial autocorrelation, also known as the Global Moran's I tool, simultaneously measures spatial autocorrelation based on feature locations and feature values (as defined by Esri). This spatial tool in ArcGIS calculates the Moran's I Index value, along with the z-score value and p-value, to evaluate the significance of that index (Esri). In this research work, spatial autocorrelation analysis was used to examine whether the three variables – number of HEC households, frequency of HEC, and intensity of HEC – were spatially associated. Subsequently, spatial autocorrelation was performed individually for those three variables before conducting Kernel Density Analysis and Getis–Ord Gi hotspot analysis for further investigation.

ii) Kernel density analysis
Kernal density is a data analysis tool in ArcGIS software that calculates the density of features/variables and their association within and around neighbourhood features. For this study, point features were used to examine the density. The point features in the study reperesent the intensity, frequency and number of HEC households over a period. For this analysis, secondary data collected were used. The data gathered were summed to get the total number of HEC affected households, frequency, and intensity of HEC. This tool showed how the density of HEC is concentrated within particular zone of the study area.

iii) Getis-Ord Gi hotspot analysis
The Getis-Ord Gi hotspot analysis is used to identify the hotspots and cold spots of the features. The feature values were calculated using data collected from 2012–2022. The data include different kinds of HEC experienced by several households in BTR. The analysis was done for the three variables. The variables include – number of HEC households, frequency of HEC, and intensity of HEC.

3. Results

3.1 LULC changes from 2011–2023

Fig. 2 and Fig. 3 show the overall scenario of changes in LULC between 2011 and 2023. In the dense forest zone, the results show a significant change in the dense forest vegetation in all the districts. It is also observed that some parts of the dense forest vegetation have been converted into open forest and man-made vegetation. Moreover, water bodies have increased in all the districts, whereas barren land has decreased in all the districts except one.

In zone 1, during the study period, open forest and man-made vegetation increased in all the districts. In Udalguri, it increased by 4.84 per cent points, in Baksa by 8.96 per cent points, in Kokrajhar by 6.16 per cent points, and in Chirang by 9.88 per cent points. In contrast, dense forest vegetation has slightly increased in the Udalguri district by 5.74 per cent points, while it decreased in the other three districts, namely Kokrajhar by 15.87 per cent points, Chirang by 5.57 per cent points, and Baksa by 3.38 per cent points. A nominal increase in built-up areas/settlements was also observed in zone 1 of Udalguri (6.72 per cent points), Baksa (6.75 per cent points), Kokrajhar (3.30 per cent points) and Chirang (4.06 per cent points). Agricultural land, however, decreased in Udalguri by 12.50 per cent points, in Baksa by12.09 per cent points, in Kokrajhar by1.81 per cent points, and in Chirang by12.58 per cent points. The increase in water bodies is apparent in three districts, whereas the opposite trend is the observed in Udalguri district. On the other hand, an increase in barren land is observed only in Kokrajhar district.

In zone 2, a significant decrease in agricultural land is observed across all the districts. Built-up areas/settlements have increased in all the districts, namely in Udalguri by 3.42 per cent points, in Baksa by 3.54

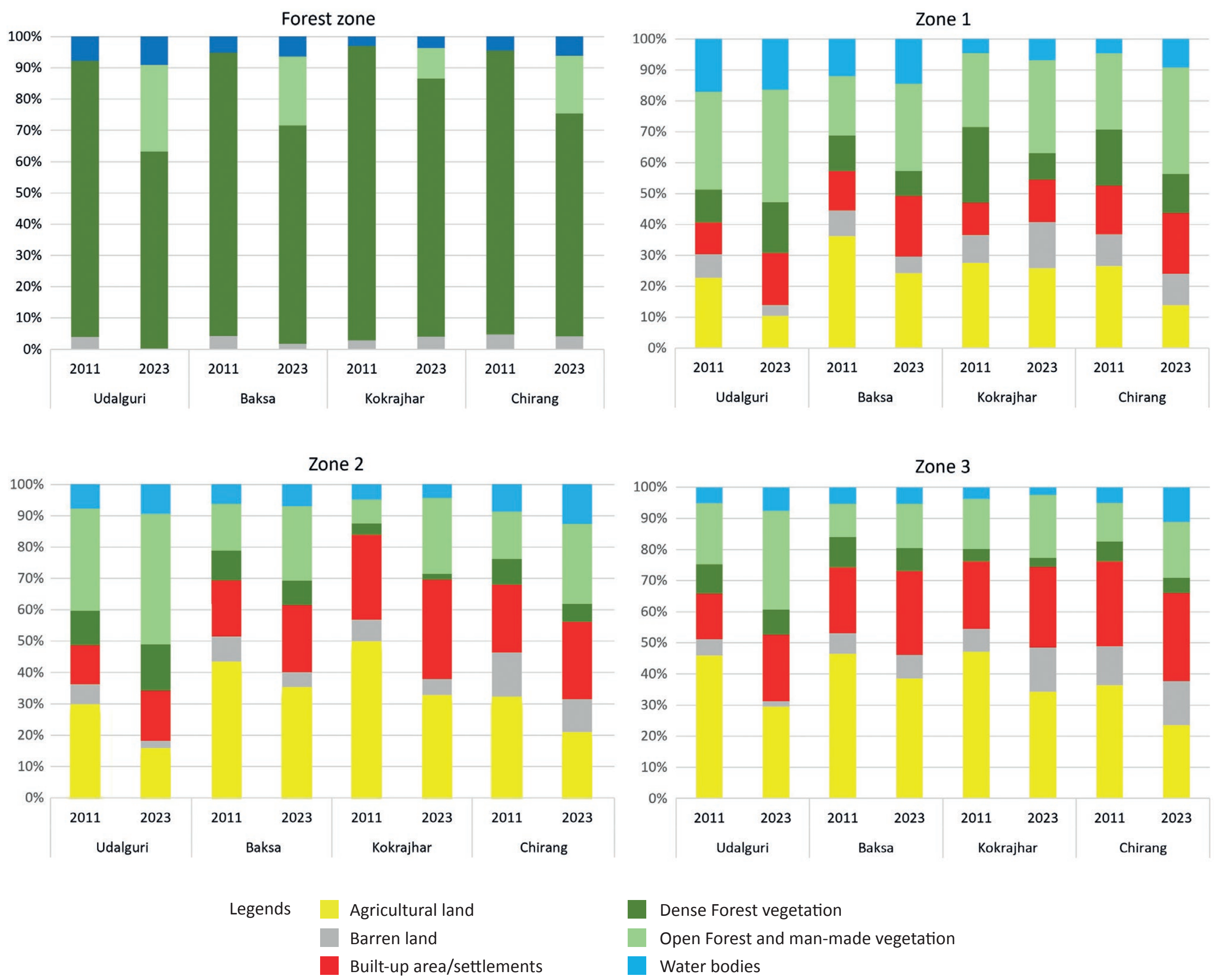


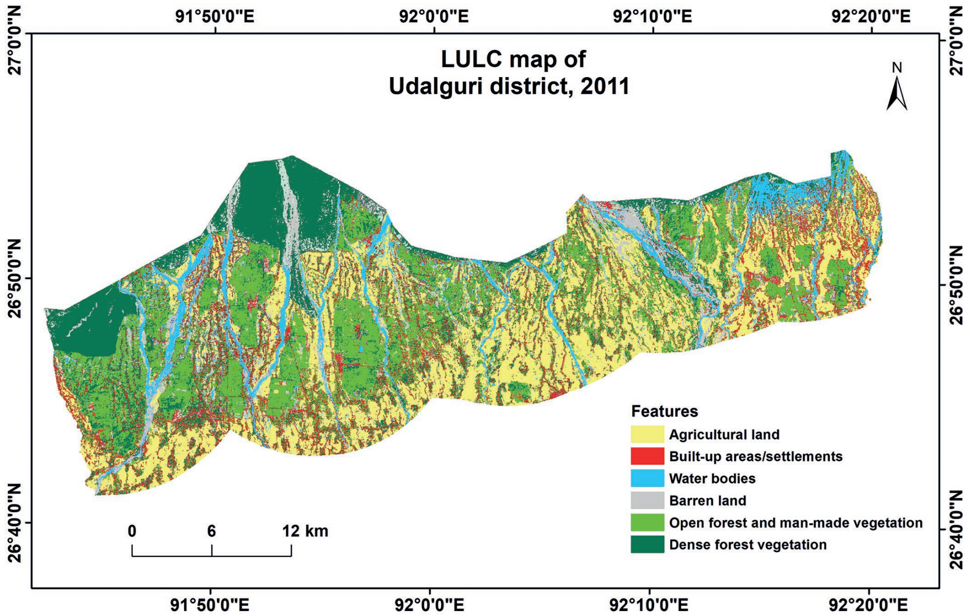
Fig. 2 LULC changes from 2011–2023 in percentage.

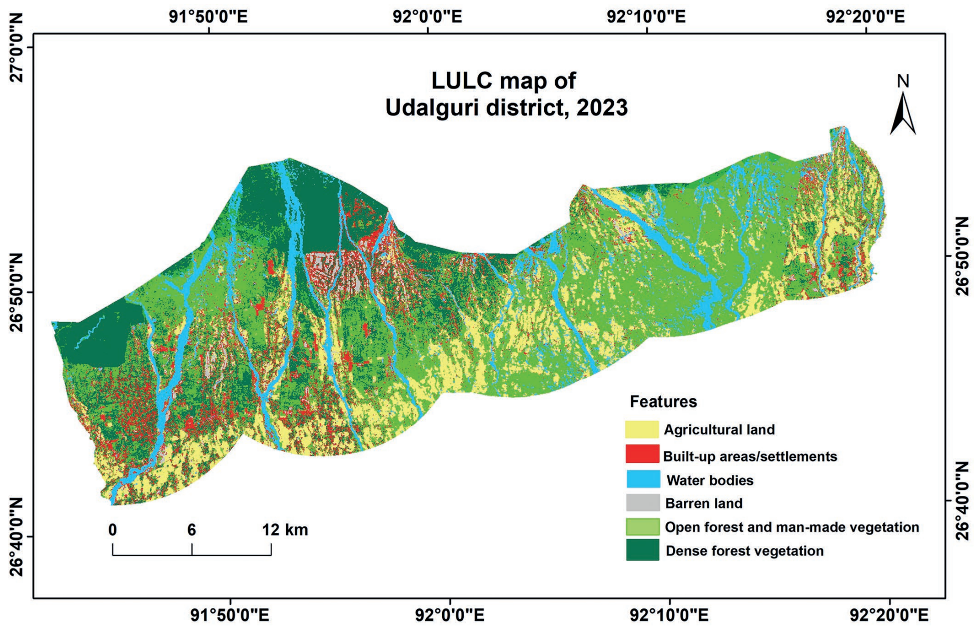
per cent points, in Kokrajhar by 4.52 per cent points, and in Chirang by 3.11 per cent points. Dense forest vegetation has slightly decreased in three districts, except in Udalguri district. Barren land has decreased in all the districts, although to varying degrees. Water bodies have increased in three districts, whereas the opposite trend is observed in Kokrajhar district.

In zone 3, a significant decrease in agricultural land and a nominal decrease in dense forest vegetation are observed across all four districts. In contrast, built-up areas/settlements, and open forest and man-made vegetation have increased throughout the districts. Water bodies, however, have declined only in Kokrajhar district, while barren land has declined only in Udalguri district.

3.2 Density analysis of HEC villages

Spatial autocorelation analysis based on Moran's Index revealed significant clustering in the number of HEC households, frequency of HEC, and intensity of HEC (results not shown). Further, the Moran's Index (0.123) indicates significant clustering in the number of HEC households, implying that the number of HEC households are spatially associated with one another. The values of variance (0.000137), z-value (10.77) and p-value (0.000) also indicate significant clustering. Therefore, clustering map analyses, such as Kernel density analysis, could be performed for the number of HEC households. The spatial autocorrelation result indicates that there is only a 1% likelihood that the clustering pattern is random. Furthermore, Moran's Index (0.106) indicates significant clustering in the frequency of HEC, suggesting that the frequency of HEC events is spatially associated. The variance value (0.000134) also indicates a close spatial association among the observations, while the z-value (9.42) and p-value (0.000) conform significant clustering. Therefore, clustering map analyses, such as Kernel density analysis, could also be performed for the frequency of HEC. The spatial autocorrelation result indicates that there is only a 1% likelihood that the clustering pattern is random. Similarly, the Moran's Index (0.128) indicates significant clustering in the


LULC map of
Udalguri district, 2011
N
Features
Agricultural land
Built-up areas/settlements
Water bodies
Barren land
Open forest and man-made vegetation
Dense forest vegetation
0 6 12 km
91°50'0"E
92°0'0"E
92°10'0"E
92°20'0"E
27°0'0"N
26°50'0"N
26°40'0"N


LULC map of
Udalguri district, 2023
N
Features
Agricultural land
Built-up areas/settlements
Water bodies
Barren land
Open forest and man-made vegetation
Dense forest vegetation
0 6 12 km
91°50'0"E
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92°20'0"E
27°0'0"N
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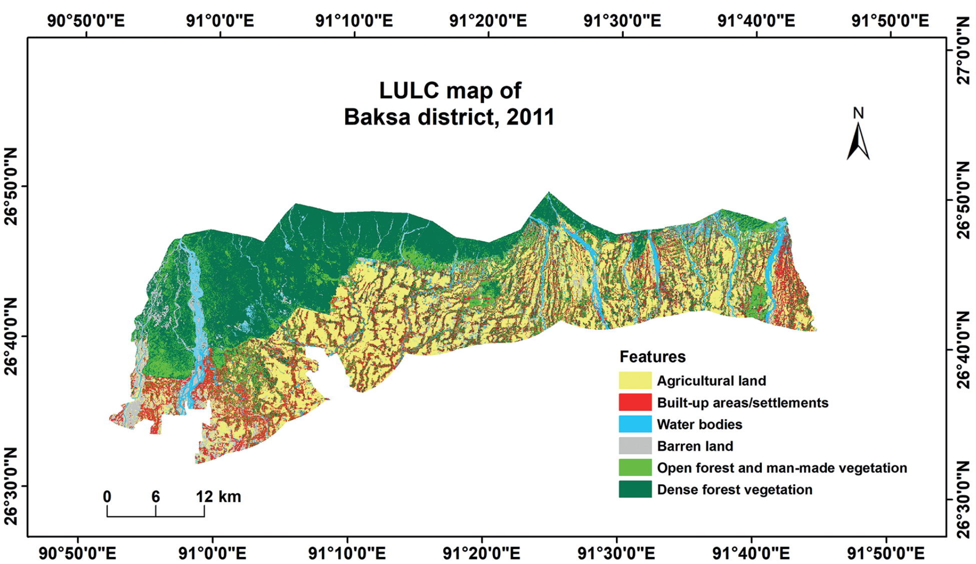
LULC map of
Baksa district, 2011
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Features
Agricultural land
Built-up areas/settlements
Water bodies
Barren land
Open forest and man-made vegetation
Dense forest vegetation
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90°50'0"E
91°0'0"E
91°10'0"E
91°20'0"E
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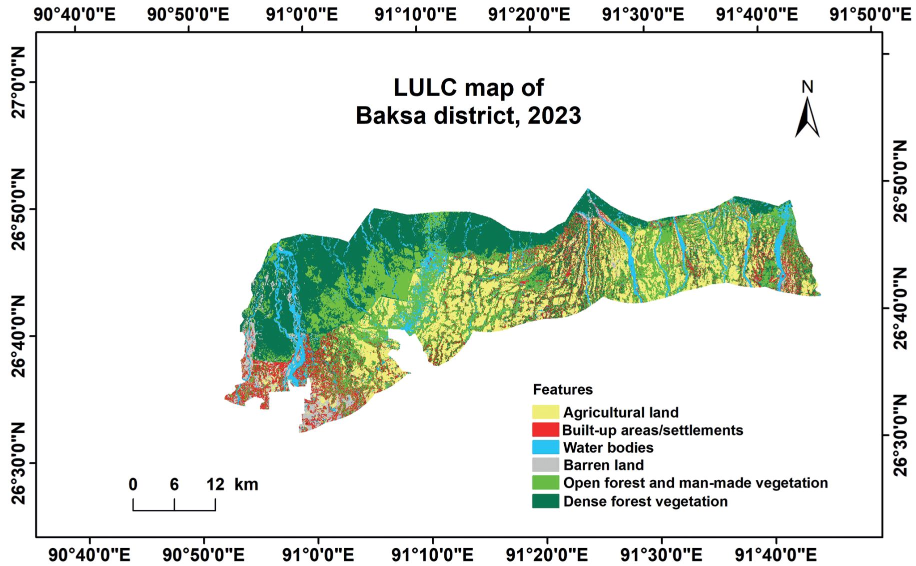
26°30'0"N


LULC map of
Baksa district, 2023
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Features
Agricultural land
Built-up areas/settlements
Water bodies
Barren land
Open forest and man-made vegetation
Dense forest vegetation
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91°0'0"E
91°10'0"E
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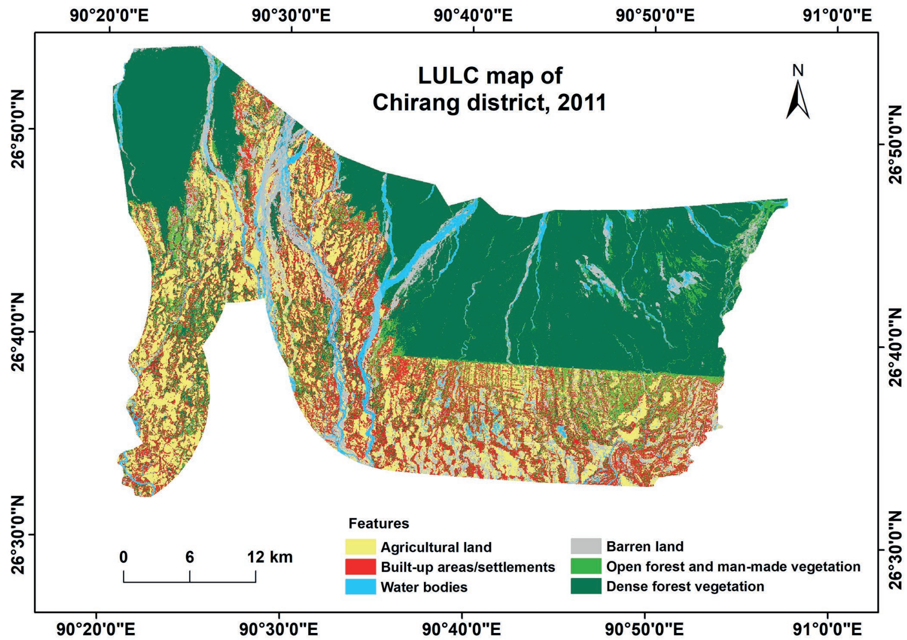
26°30'0"N


LULC map of
Chirang district, 2011
N
Features
Agricultural land
Built-up areas/settlements
Water bodies
Barren land
Open forest and man-made vegetation
Dense forest vegetation
0 6 12 km
90°20'0"E
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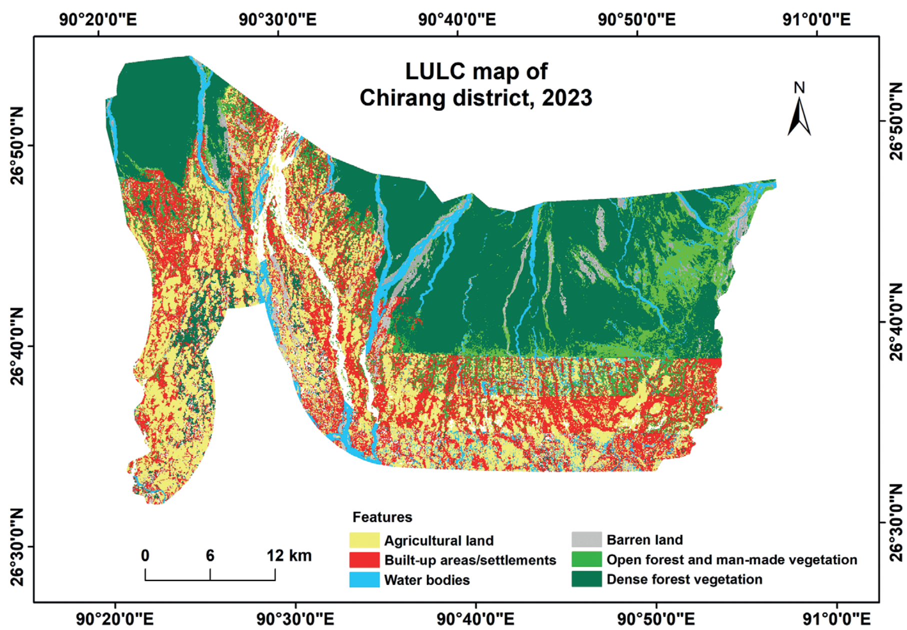
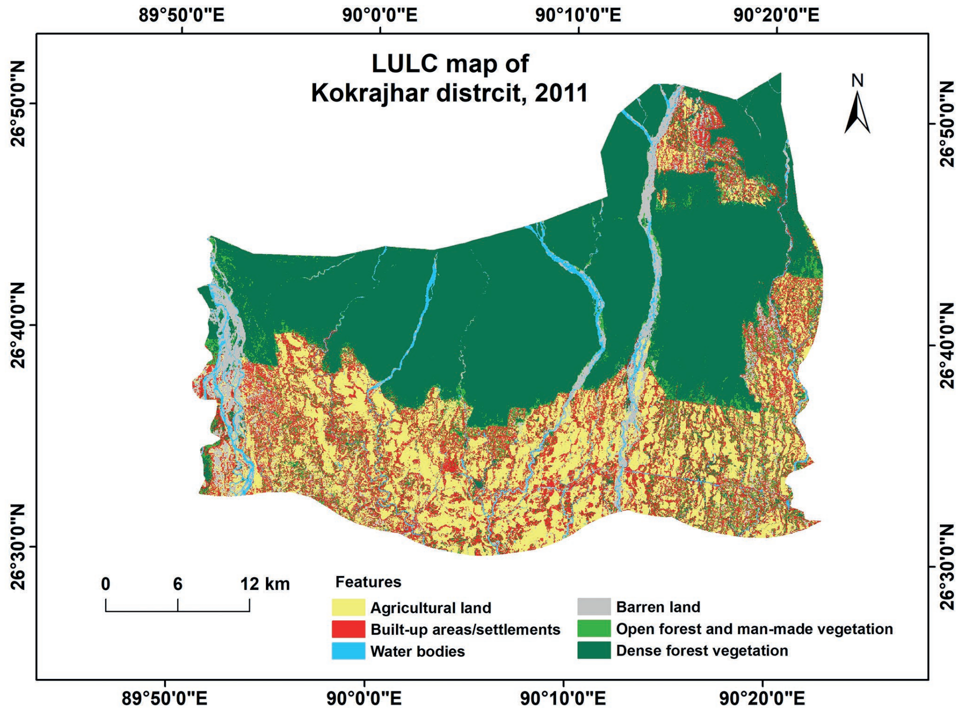
90°50'0"E
91°0'0"E
26°50'0"N
26°40'0"N
26°30'0"N


LULC map of
Chirang district, 2023
N
Features
Agricultural land
Built-up areas/settlements
Water bodies
Barren land
Open forest and man-made vegetation
Dense forest vegetation
0 6 12 km
90°20'0"E
90°30'0"E
90°40'0"E
90°50'0"E
91°0'0"E
26°50'0"N
26°40'0"N
26°30'0"N



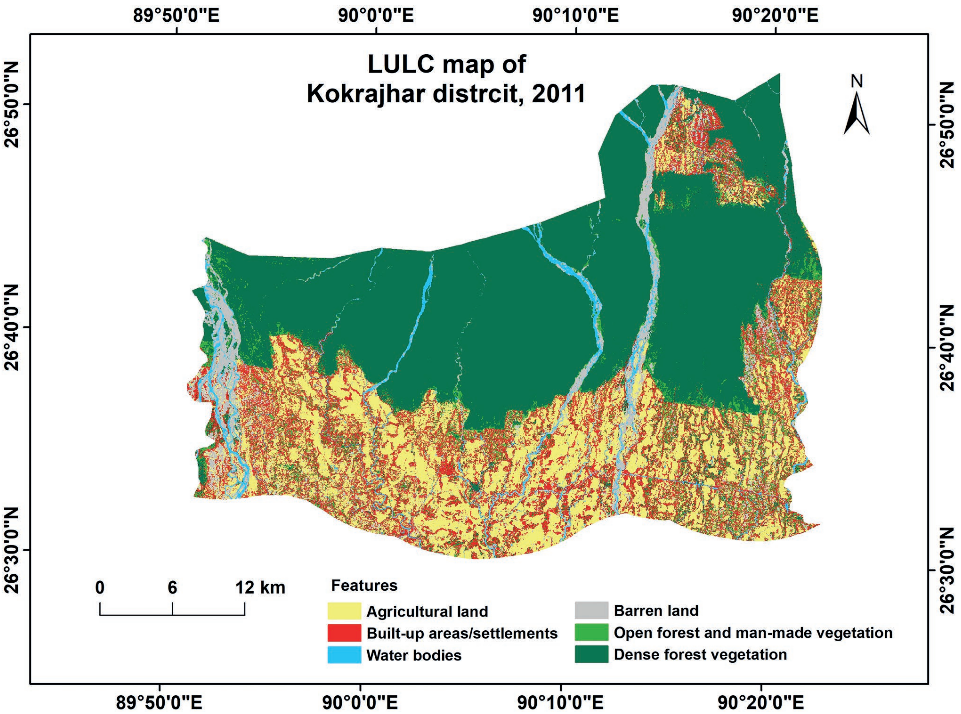


Fig. 3 LULC changes over two periods 2011 and 2023.

intensity of HEC, implying that the intensity of HEC is spatially associated across the study area. The values of variance (0.000137), z-value (11.14), and p-value (0.000) further confirm significant clustering. Therefore, clustering map analyses, such as Kernel density analysis, could also be carried out for the intensity of HEC. The spatial autocorrelation result indicates that there is only a 1% likelihood that the clustering pattern is random.

3.3 Density analysis of the study area

The Kernel density analysis (Fig. 4Aa) reveals that the number of HEC households is highly concentrated in the Udalguri district. In this district, zone 1 exhibits densities ranging from very low to very high, with high density forming the dominant category. Zone 2 exhibits densities ranging from very low to high, with medium density forming the dominant category.

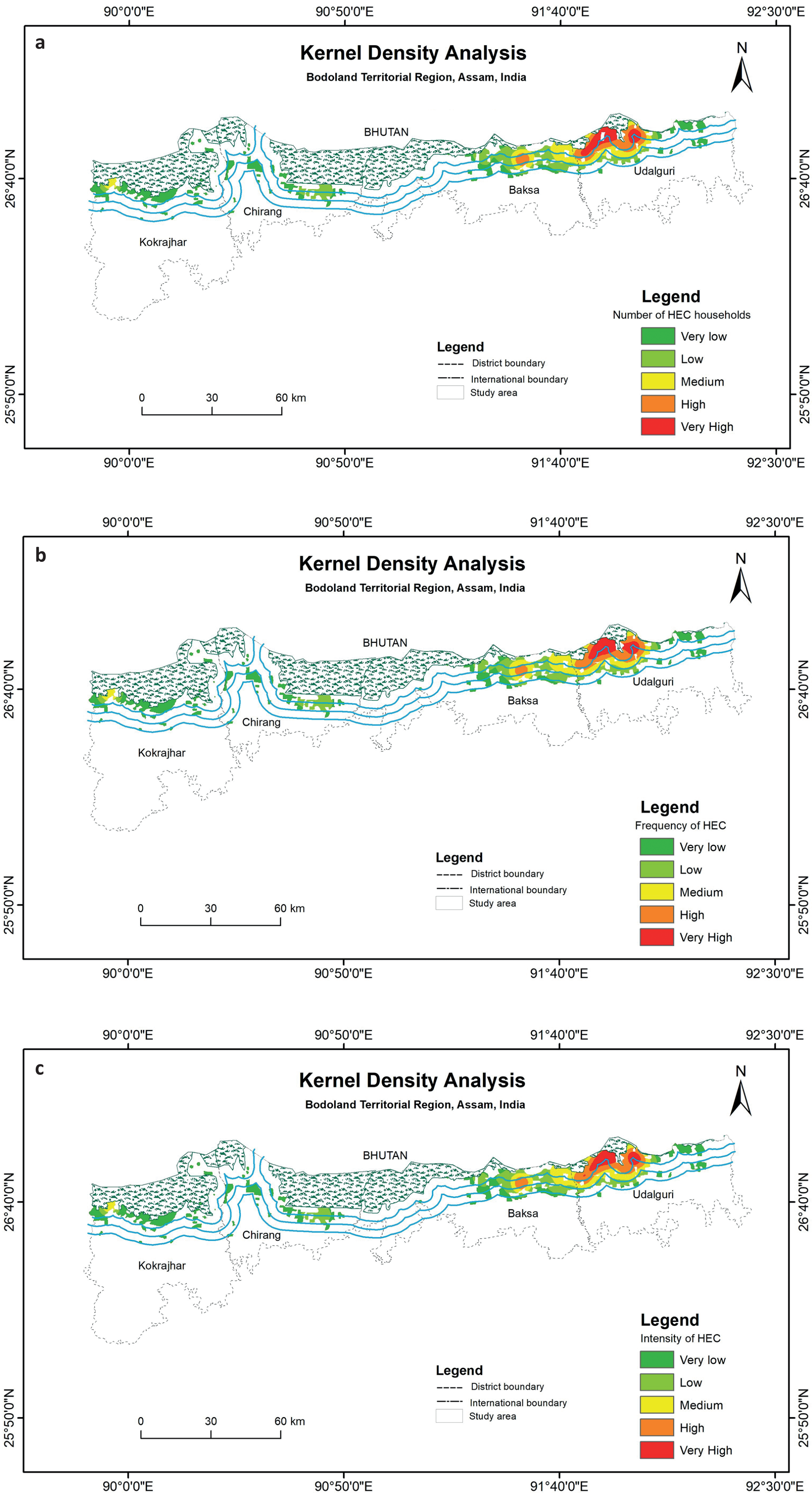


Fig. 4A Kernel density analysis Hot spot analysis.

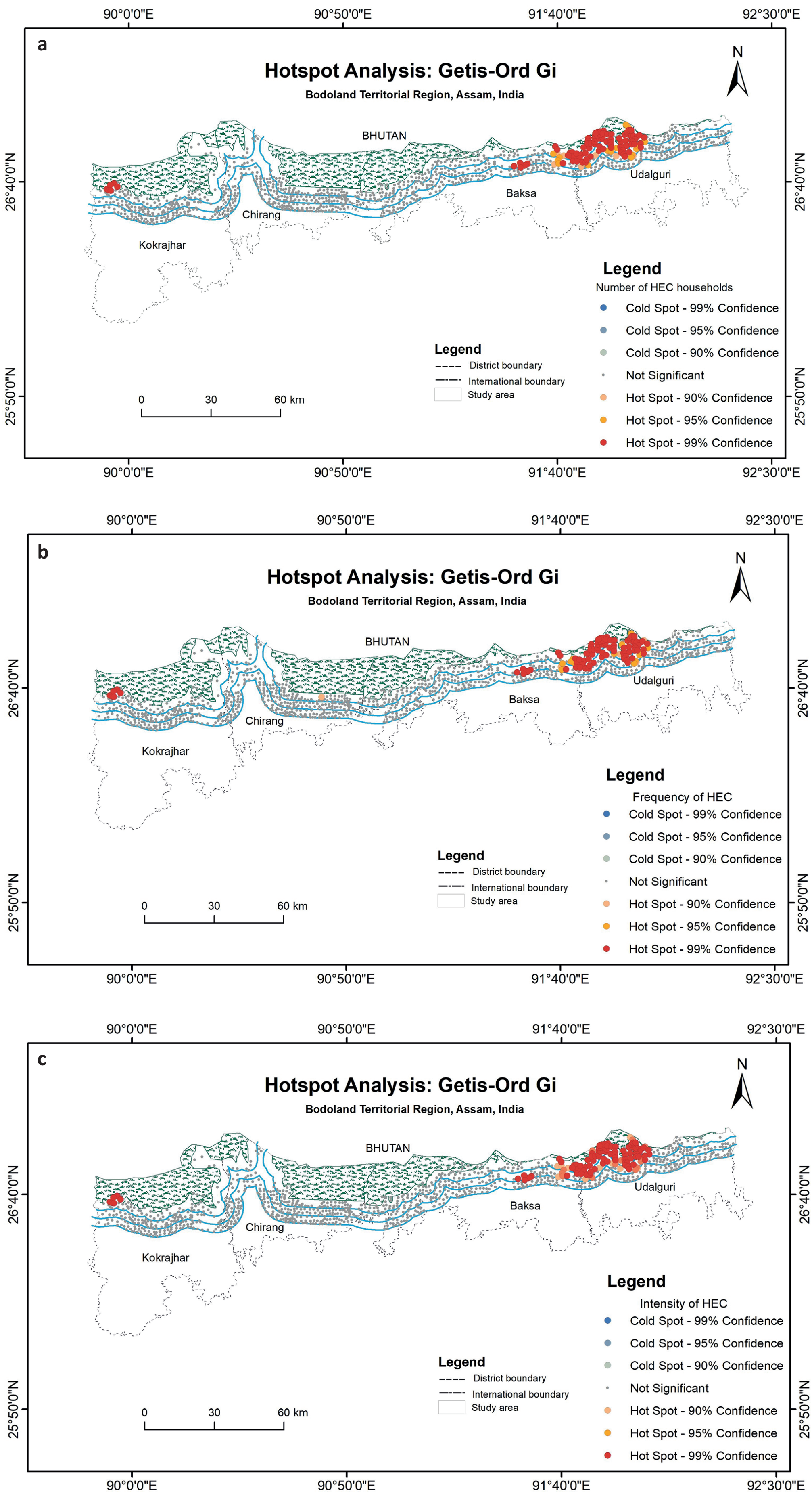


Fig. 4B Getis-Ord Gi density analysis Hot spot analysis.

Zone 3 exhibits two types of densities, namely very low and low. In the Baksa district, the density of the number of HEC households ranges from very low to medium density. Zone 1 of this district exhibits densities ranging from very low to medium, with very low forming the dominant category. Zone 2 exhibits density ranging from very low to high, with very low density forming the dominant category. Zone 3 exhibits its density ranging from very low to medium, with very low density forming the dominant density. In the Chirang district density of number of HEC households ranges from very low to low. In both zone 1 and zone 2 of this district, very low-density villages dominate, whereas only a limited number of villages fall under the low-density category. In the Kokrajhar district, the density of HEC households ranges from very low to medium. The majority of villages are concentrated within the very low-density category in all the three zones.

The Kernel density analysis (Fig. 4Ab) reveals that the frequency of HEC is highly concentrated in the Udalguri district. In this district, the density of HEC frequency ranges from very low to very high. Zone 1 of this district exhibits densities ranging from very low to very high and is predominantly characterised by high density. Zone 2 exhibits densities ranging from very low to high, and is mainly characterised by the medium density category. In contrast, zone 3 exhibits only two density categories, namely low and very low, and is mainly characterised by the dominance of the very low density category. In the Baksa district, the density of HEC frequency ranges from low to high. Zone 1 of this district exhibits only two density categories, ranging from low to very low, with the very low density category concentrated across most villages. Zone 2 exhibits densities ranging from low to high, with the low density category concentrated across many villages. Similarly, zone 3 exhibits densities ranging from low to medium, with the very low density category dominating most villages. In the Chirang district, the density of HEC frequency ranges from very low to low, and the majority of villages across all three zones fall within the very low density category. In the Kokrajhar district, HEC frequency is largely confined to the very low and low density categories. In this district, zone 1 is predominantly characterised by very low density, while zone 2 is mainly characterised by low density. In contrast, zone 3 is again dominated by the very low density category.

The Kernel density analysis (Fig. 4Ac) of HEC intensity reveals that HEC intensity is highly concentrated in the Udalguri district. In this district, zone 1 exhibits densities ranging from very low to very high and is predominantly characterised by the high density category, along with a substantial concentration of the medium density category. Zone 2 ranges from very low to high density and is mainly dominated by low- and medium-density categories. In contrast, zone 3 exhibits only low and very low density categories, with very low density dominating most villages. In the Baksa district, the density of HEC intensity ranges from very low to high. Zone 1 of this district is largely characterised by the very low density category. Zone 2 exhibits densities ranging from very low to high, although low and very low density categories are more concentrated. Similarly, Zone 3 ranges from very low to medium density, with the very low density category dominating most villages. In the Chirang district, HEC intensity is confined mainly to very low and low density categories. Across all three zones, the majority of villages fall within the very low density category, while only a few villages exhibit low density. Similarly, in the Kokrajhar district, HEC intensity is largely characterised by densities ranging from very low to medium. Zone 1 and zone 2 of this district are predominantly dominated by the very low density category, whereas villages in zone 3 are concentrated mainly within the low density category.

3.4. Getis-Ord Gi analysis for Cold-spot and Hot-spot

The spatial autocorrelation for Getis-Ord Gi statistics for coldspots and hotspots analysis indicates the significant value are more likely to be random. In the present analysis, the z values and p-values indicate being closer to the random value meaning that sufficient clustering could not be found in the study area. The Moran's Index (0.178) shows a significant clustering of the number of HEC households, indicating that the distribution of the number of HEC households is spatially associated. The variance (0.067), z-value (0.69), and p-value (0.049) also indicate significant clustering. Therefore, hotspot analysis could be performed for the number of HEC households. Similarly, the Moran's Index, variance, z-value and p-value of frequency of HEC are the same as those for the number of HEC households, which also indicates significant clustering. Therefore, hotspot analysis could also be performed for the frequency of HEC. The Moran's Index (0.193) further indicates significant clustering in the intensity of HEC, suggesting that the intensity of HEC is spatially associated within the study area. The variance (0.069), z-value (0.74), and p-value (0.046) also indicate significant clustering. Therefore, hotspot analysis could also be performed for the intensity of HEC. However, only hotspot areas (90%–99% confidence level) were identified within the study area, whereas no cold-spot were observed.

The hotspot analysis of the number of HEC households using Getis-Ord Gi is presented in Fig. 4Ba. The analysis indicates that in the Udalguri district, there are significant hotspots in the number of households affected by HEC. While considering a 99% confidence level, 59 hotspots could be seen in zone 1 of the district, along with 4 hotspots at a 95% confidence level, while the rest of the number of HEC households are insignificant. In zone 2, 18 hotspots could be seen at

99% confidence level, 7 hotspots at 95 %, and 4 hotspots at the 90% confidence, while the rest are insignificant. In zone 1 of Baksa while considering a 99% confidence level, 3 hotspots could be seen, along with only 1 hotspot at the 95% confidence level and only 2 hotspots at 90% confidence level. In zone 2, while considering a 99 % confidence level, 6 hotspots could be seen, along with 3 hotspots at the 95% confidence level and 1 hotspot at the 90% confidence level. In zone 3 of the district, only 1 hotspot at the 99 % confidence level is found, while the rest are insignificant. The number of HEC households is insignificant in the Chirang district. In Kokrajhar district only 6 hotspots at 99% confidence level are noted. As such no coldspots have been observed for the number of HEC households in the study area.

The hotspot analysis of the frequency of HEC households using Getis-Ord Gi is presented in Fig. 4Bb. In zone 1 of Udalguri district, while considering the 99% confidence level, 55 hotspots could be seen, along with 6 hotspots at 95% confidence level, and 2 hotspots at the 90% confidence level, while the remaining areas are insignificant. In zone 2, 18 hotspots could be seen at the 99% confidence level, 4 hotspots at the 95% confidence level, and 1 hotspot at 90% confidence level, while the remaining areas are insignificant. The frequency of HEC is insignificant in zone 3 of Udalguri district. In zone 1 of Baksa district, while considering 99% confidence level, 2 hotspots and only 1 hotspot at the 95% confidence level could be observed. In zone 2, 6 hotspots could be seen at the 99% confidence level, 2 hotspots at the 95% confidence level, and only 1 hotspot at the 90% confidence level. In zone 3, only 1 hotspot at the 99% confidence level is identified as a hotspot, while the remaining are insignificant. In the Kokrajhar district 6 hotspots at the 99% confidence level could be seen in zone 1, while the remaining values are insignificant. No coldspots could be observed in the entire study area for the frequency of HEC. Similarly, in the Chirang district, neither significant hotspots nor coldspots were been detected.

The hotspot analysis of the intensity of HEC households using Getis-Ord Gi is presented in Fig. 4Bc. While considering the intensity of HEC in zone 1 of the Udalguri district, 59 hotspots could be seen at the 90% confidence level, 4 hotspots at the 95% confidence level, and 1 hotspot at the 90% confidence level, while the remaining areas are insignificant. In zone 2, 18 hotspots at the 99% confidence level, 6 hotspots at the 95% confidence level, and 5 hotspots at the 90% confidence level are observed, while the remaining areas are insignificant. In zone 3, the intensity of HEC is insignificant.

In zone 1 of Baksa district, 3 hotspots at the 99% confidence level and 3 hotspots at the 90% confidence level are observed, while the remaining areas are insignificant. In zone 2, 6 hotspots at the 99% confidence level, 3 hotspots at the 95% confidence level, and 1 hotspot at the 90% confidence level are observed, while the remaining areas are insignificant. In zone 3, only 1 hotspot at the 99% confidence level has been noted, and the remaining areas are insignificant. In the Chirang district, the intensity of HEC is

Tab. 2 Observed and expected value of number of HEC villages. Chi-square test.

District	Value		Zone 1	Zone 2	Zone 3	Total
Udalguri	Observed value (O)		72.0	39.0	26.0	137
	Expected value(E)		69.5	39.1	28.4	137.0
Baksa	Observed value (O)		35.0	32.0	30.0	97.0
	Expected value(E)		49.2	27.7	20.1	97.0
Kokrajhar	Observed value (O)		36.0	8.0	5.0	49.0
	Expected value(E)		24.9	14.0	10.1	49.0
Chirang	Observed value (O)		31.0	19.0	10.0	60.0
	Expected value(E)		30.4	17.1	12.4	60.0
Total	Total observed value		174.0	98.0	71.0	343.0
	Total expected value		174.0	98.0	71.0	343.0
Chi-square test	**Value**	**df**	**Asymp. sig. (2-sided)**	**Exact sig. (2-sided)**	**Exact sig. (1-sided)**	**Point probability**
Pearson chi-square	20.811[a]	6	.002	.002		
Likelihood ratio	21.088	6	.002	.002		
Fisher's exact test	20.350			.002		
Linear-by-linear association	7.367[b]	1	.007	.007	.004	.001
N of valid cases	343					

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 10.14.
b. The standardized statistic is −2.714.

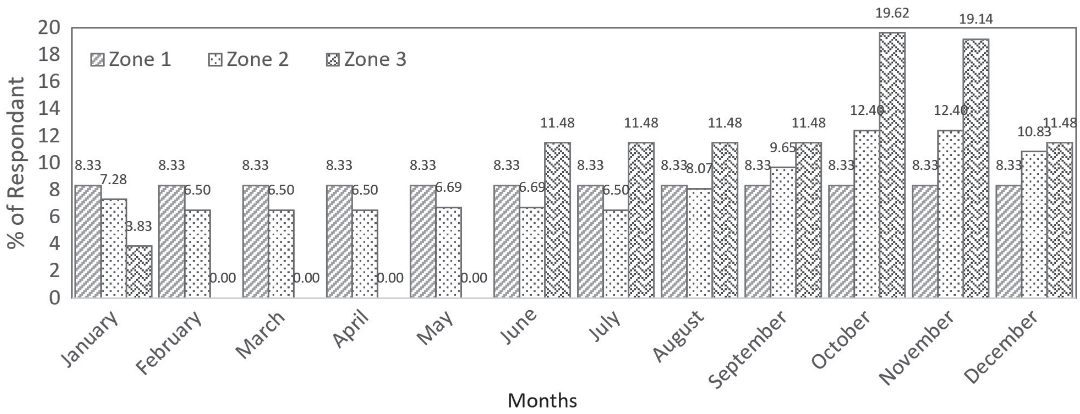


Fig. 5 Distribution of HEC by month and zone.

insignificant; therefore, no hotspots or cold spots are present. In the Kokrajhar district, only 6 hotspots at the 99% confidence level could be observed. No cold spots could be seen in the entire study region.

3.5 Chi-square analysis

The chi-square analysis (Tab. 2) shows a statistically significant result, indicating a spatial relationship between the zones and HEC villages. In other words, there are significant spatial variations in the occurrence of HEC across different buffer zones.

To support the findings derived from the secondary data, primary data were also collected from the field. According to the respondents, HEC occurs for several reasons in the study area. Information regarding the causes of HEC was collected from households that had experienced HEC at least once. Based on the responses seasonality is one of the major factors influencing HEC. To understand this temporal distribution of HEC, respondents were asked: "Usually during which month do you face damages/conflict by/with the elephant?" The result (Fig. 5) show that the occurrence of HEC varies across different months of the year. As per the results (Fig. 5), HEC occurs throughout the year in zone 1. In zone 2 and 3, the HEC is relatively higher during the months of October, November, and December. In zone 3, no respondents reported HEC during February, March, April, and May, whereas the occurrence is higher during June, July, August, and September. Similarly, in zone 2, HEC is reported to be high during July, August, and September, while in the remaining months the occurrence of HEC remains relatively constant.

3.6 Role of physiography in HEC

To understand the role of physiography in HEC, a minute observation on the landscape of the study area was carried out during the field survey. It was observed (Fig. 6) that elephants find it difficult to cross the steep slopes filled with rocks and pebbles. Instead, they preferred to move through tea garden, where human settlements are absent and thereby no one to chase them away. While following this route, elephants tend to select specific places or forest patches where they

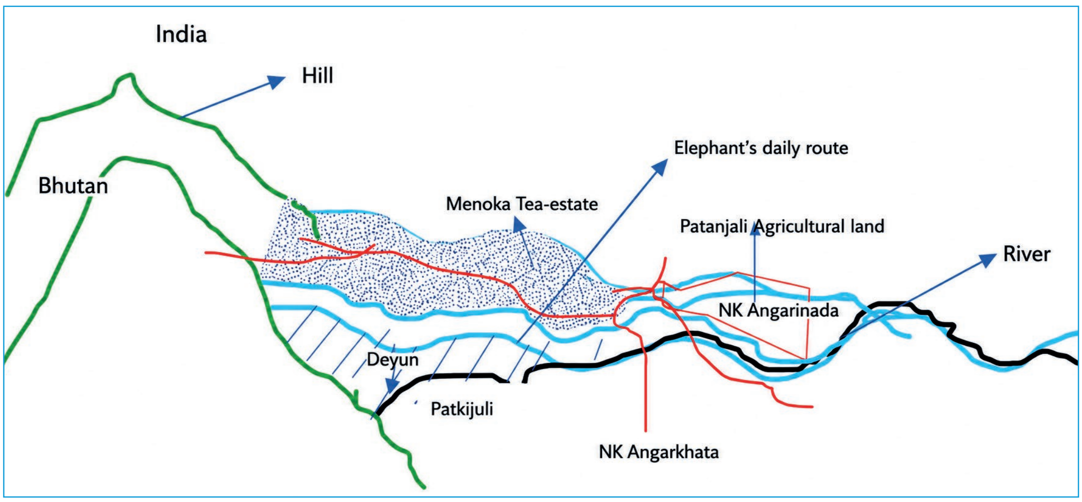


Fig. 6 Physical features as protecting barriers against HEC (An outline map of elephant movement routes in elephant in NK Angarkhata).

can remain for several days and access sufficient food resources. Consequently, elephants move from the tea garden directly towards the Pantjali agricultural land and forest patch in NK Angarkhata village. From there, they further traverse towards nearby human settlements, agricultural land, and plantation areas.

4. Discussion

The LULC analysis reveals that the areas under agricultural land and dense forest vegetation have decreased in all three zones across all districts during the study period. This prominent change can be mainly attributed to the increase in open forest and man-made vegetation, along with the expansion of built-up areas/settlements. During the field survey, it was observed that the increase in open forest and man-made vegetation resulted from conversion of agricultural land into plantation areas such as tea plantation, rubber plantation, banana plantation and areca nut plantation. Built-up areas/settlements are also expanding due to human population growth. The expansion of human settlements has led to a decline in dense forest vegetation in Zone 1 of the Kokrajhar district, which is one of the main reasons for HEC. Due to habitat loss and the decreases in food availability within forest areas, elephants increasingly move into the human landscape in search of food (Arham et al. 2018). People are also planting rubber trees and bananas for their higher economic value compared to traditional paddy cultivation, despite the fact that banana plantation attract elephants. Such plantations contribute significantly to the increase in open forest and man-made vegetation. However, large-scale banana plantations are mainly undertaken by businessmen who are willing to take the risk of damages caused by elephants, while common people continue to largely depend on rice cultivation. Previous studies have also shown that agricultural land, rubber tree cover, and natural forest cover are important factors potentially facilitating HEC (Chen et al. 2016). The local communities in some parts of Zone 1 have transformed rice fields into areca nut and rubber plantations to avoid regular crop raiding by elephants. The agricultural land in Zone 1 of Chirang district is decreasing due to a high percentage of land conversion to open forest, the expansion of settlement areas, and the increase in water bodies. Due to the growing size of water bodies and unprotected riverbanks, agricultural land frequently becomes uncultivable, leading to a loss of agricultural land and an increase in the width of the riverbanks. Similarly, in the Baksa and Udalguri district, open forest and man-made vegetation, and built-up/settlement areas are increasing, whereas barren land and agricultural land are decreasing. In Baksa, water bodies have expanded, while barren land has declined due to the conversion of land into tea and areca nut plantations. Such barren land was once uncultivated due to the fear of crops being raided by elephants. In Udalguri, dense forest vegetation cover appears to have increased in the satellite imagery; however, this may be attributed to pixel formation in satellite images of plantations of large trees in and around tea gardens. However, in reality, the areas of tea plantations, categorised as open forests, are increasing significantly.

In zone 2 of Kokrajhar district, open forest and man-made vegetation have increased significantly due to the introduction of perennial plantations such as banana, rubber tree, and areca nut plantations. In this zone, settlements have also increased due to the increased due to human population growth. Over the years, large scale deforestation has occurred in the area for construction activities and the expansion of settlements. Similarly, in Chirang, Baksa and Udalguri, agricultural land has decreased due to the increase in open forest and man-made vegetation. Open forest and man-made vegetation have increased mainly due to plantations such as, banana, rubber tree, and areca nut plantations as well as tea plantations in Baksa and Udalguri. Water bodies in Chirang, Baksa, and Udalguri have also increased due to the changes in river courses, river bank erosion, and the creation of man-made water bodies such as ponds.

In zone 3, the decrease in agricultural land is more pronounced in the Udalguri district due to the conversion of agricultural land into tea gardens as a source of income and as a measure to avoid crop raiding by elephants. In the Baksa district, the conversion of agricultural land into plantations such as areca nut and rubber trees was observed during the field study. Meanwhile, built-up areas/settlements are increasing across this zone in all the districts. This increase in built-up areas/settlements is also the result of population growth, deforestation, and the nucleation of families, thereby contributing to decrease in agricultural land. Dense forest vegetation, particularly reserve areas, have been converted into revenue villages. Consequently, dense forest vegetation is gradually changing into open forest and man-made vegetation. However, water bodies and barren land show a fluctuating pattern across all the districts within the zone.

It is also observed that within the dense forest zone, dense forest vegetation has been transformed into open forest and man-made vegetation. This change is mainly due to deforestation and tree smuggling, and may also partly result from the satellite image being captured during the dry winter season. The density of HEC is highly concentrated in zone 1 of the Udalguri district due to the availability of dense forest vegetation, open forest and man-made vegetation, agricultural land and built-up areas/settlements within the zone. Dense forest vegetation is relatively high in this zone because of the presence of large trees in and around the tea gardens where elephants are often found residing, as observed during the field survey.

This close co-existence of humans and elephants has contributed to the high density of the HEC in zone 1 of the district. The district also contains some small forest patches in zone 1 and 2 where elephants prefer to stay. Whenever they get hungry, they move out of the forest and traverse towards human settlements in search of food, thereby resulting in HEC. As evident from the satellite images, these areas of the district earlier were covered with dense forest, which used to be purely the elephant habitats. Over time, however, these dense forest vegetations were converted into built-up areas/settlements and tea gardens, leading to increased human-elephant co-existence. In zone 2, density and hotspots of HEC are comparatively lower because of the larger concentration of human settlements, where people frequently chase elephants away before they can cause significant damages to property. For the same reason, HEC is even lower in zone 3 of the district.

The frequency and intensity of elephant depredation appear to be closely related to the geographical arrangement of the farming areas (Santiapillai et al. 2010). The conflict rate also depends on the frequency with which elephants raid villages, as well as their need for food and water. In addition, the frequency of conflict is also dependent on the distance of settlements from the elephant habitat zone (Reddy and Workneh 2014). The density of HEC is high only on the eastern side of the Baksa district because the other parts of the district are safeguarded with fencing. On the western side, the district is bordered by Manas National Park, a protected area equipped with high-voltage electric fencing. As a result, elephants are generally unable to cross into nearby settlements. However, occasional instances of other wild animals attacking humans on the western side are reported. Such instances occur when animals cross the fences during power outages or when smaller animals are able to pass through the fencing. On the eastern side, the density of HEC is higher in zone 2 rather than zone 1 due to its physiographic characteristics of the area. Zone 2 contains forest patches and rubber plantations where elephants prefer to stay. Whenever they get hungry, they come out of the forest and traverse towards nearby human settlements in search of food, often resulting in HEC. In contrast, zone 3 exhibits lower HEC density and no significant hotspots, mainly due to the higher concentration of human settlements in the area.

In the Chirang district, low to very low density of HEC is observed because tea plantations and small patches of forest are largely absent in and around human settlements, limiting the opportunities for elephants to co-exist with human, and damage properties. In this district, HEC mainly occurs when elephants move out of the dense forest zone and traverse into nearby human settlements.

In the Kokrajhar district, the density of HEC is higher than Chirang in zone 1 due to the legalisation of villages within forest areas under the Forest Right Act (FRA) 2006. This reflects an increase in human settlements within protected areas. In addition to these legalized villages, there are some more encroached villages, some of which are also undergoing the process of recognition under FRA 2006, in Kokrajhar district. This situation clearly indicates the coexistence of humans and elephants, leading to medium to very low density of HEC.

The distance analysis (zonation) also shows that HEC is closely associated with the distance between human settlements and elephant habitats. Zone 1 exhibits a significantly higher occurrence of HECs because the area was once part of the elephant habitat, and still elephants prefer to stay there periodically. Moreover, zone 1 is located very close to the dense forest zone, which serves as a primary elephant habitat. Zone 2 experiences comparatively lower HEC because it is located farther from the elephant habitat. Similarly, HEC in zone 3 is much lower than in the other zones, mainly due to its greater distance from elephant habitats.

Elephants are likely attracted to yam farms, grain stores, and fruiting trees in the villages near Nazinga Game Ranch in Burkina Faso (Hema et al. 2010), which often leads to crop raiding. Similarly, the types of crops cultivated and the available of fruits in the study area also play a significant role in causing HEC. In the study area elephants are highly attracted to rice cultivation, as well as other crops, and plants/fruits/vegetables such as, jackfruit, elephant apple, wood apple, gourd, cabbage, tomato, banana, tapioca, pumpkin, sweet potato, coconut, tender leaves of coconut tree, areca nut, bamboo, salt, alcohol, etc. It appears that once elephants become accustomed to feeding on rice, they do not forget it, and whenever the cultivation season of rice comes, they come to eat again in the same place. From the informal group discussion, it was known that in zone 1 of all the districts, elephants start to eat the rice crops right from the initial stage of paddy cultivation, through the milky stage, till it is ready to harvest. In addition, elephants also consume rabi and zaid crops. Sometimes they slowly traverse towards zone 2 and zone 3 either intentionally or while they are chased away by the people from zone 1. Then they eat the rice of different stages in those zones, as well as rabi and zaid crops. As elephants are seen to be more attracted towards rice, cropping seasons/months also have a significant role in causing HEC. Furthermore, some other seasonal crops, fruits, trees, and plantation also attract elephants, leading to HEC.

5. Conclusion

The LULC changes resulting from the growing human activities in the Indo-Bhutan foothill region of Assam were well observed between 2011 and

2023. Significant changes in 1) Agricultural land, 2) Built-up areas/settlements, 3) Water bodies, 4) Barren land, 5) Open Forest and man-made vegetation, and 6) Dense Forest vegetation are quite apparent. The expansion of commercial tree plantations, deforestation, and human settlements are some of the major causes of HEC. Human activities either attract or disturb elephants. The variation in HEC with the distance between human settlement and elephant habitats is well observed in the study area. Elephants tend to traverse towards human settlements more frequently during the months of paddy cultivation, indicating that rice is also one of the major causes of HEC. Frequent HEC incidents have been causing lots of difficulties to both humans and elephants in the study area. Thus, there is a need to adopt mitigation measures for reducing HEC. Based on field observations and respondents' reports, some of the most effective measures for preventing HEC in the study area include well-regulated electric fencing, bio-fencing, plastic wire fencing with polythene bags acting as scarecrows, and the use of firecrackers. However, the effectiveness of these measures largely depends on elephant behaviour and proper implementation. Furthermore, attempts have been made to identify area-specific effective measures for mitigating HEC. Conserving forest areas would be an important step toward reducing habitat loss for elephants and mitigating human elephant conflict.

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