Habitat Suitability Analysis of Asiatic Elephants (*Elephas maximus*) in the Tropical Moist Deciduous Forest of Assam Using Analytic Hierarchy Process (AHP)

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Abstract

Asiatic elephant (*Elephas maximus*) listed as Endangered in the IUCN Red List is the only living species of genus *Elephas*, distributed in the Indian sub-continent and Southeast Asia. The decreasing number of Asiatic elephant is attributed to habitat destruction and human-elephant conflict (HEC) due to human encroachment in the forest areas. Therefore there is a need to understand the habitat suitability of Asiatic elephants and conserve them in situ. The objective of the study is to analyse the habitat suitability and map the corridor of Asiatic elephants in two reserve forests, namely, Barduar and Mayang Hill, situated on both sides of Chandubi Lake in Kamrup District. Remote sensing (RS) and geographic information system (GIS) have been playing an important role in decision-making and conservation of natural resources. Utilization of analytic hierarchy process (AHP) using spatial information and habitat suitability inputs, i.e. landcover, proximity to water, slope, aspect and elevation in GIS platform through weighted overlay, results in habitat suitability map of the species. The output raster is the resultant of untamed life mapping by providing weightage to the combination of factors contributing to their habitat suitability in the AHP model. The map generated will be useful for the conservation of Asiatic elephants in their natural habitat as well as synchronizing human activities to reduce HEC.

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14.1 Introduction

Deforestation, forest degradation and rapid conversion of forests to agricultural land, human settlement and various other developmental activities have resulted in fragmentation and loss of wildlife habitat. During the past few decades, wildlife habitats and wilderness areas have shrunk due to unprecedented human growth and developmental activities (Sanare et al. 2015), especially in Northeast (NE) India. There is a growing need to conserve wildlife habitats and wild species in situ, for which a detailed understanding of the change of their habitat condition both in time and space is required. Although these fragmentation and habitat loss have affected all wildlife species like rhinoceros (*Rhinoceros unicornis*), tiger (*Panthera tigris*), leopard (*Panthera pardus*), etc., elephants (*Elephas maximus*) have become the focal point for conflict and conservation issues. Human-elephant conflicts (HEC) have an untoward impact on local communities like damage to crops and property and loss of human lives which incite fear, anger and hostility among the local communities resulting in retaliatory killings of elephants and undermining of conservation efforts. Forests of the Himalayan foothills and Northeast India accommodate one of the last remaining adequate elephant populations but are severely threatened at the same time (Choudhury 1999; Sukumar 2006). Hence, these areas are high-priority areas for elephant conservation with a distinct call for mitigation of HEC (Gureja et al. 2002). The wild elephant population in the country is estimated to be 29,964, with Karnataka reporting the highest population at 6049, followed by Assam at 5719 (MoEFCC 2017). Therefore, Assam is one of the important strongholds for the survival of Asian elephants.

Remote sensing (RS) and geographic information system (GIS) help understand the wildlife habitat in time and space, its past and present landuse/landcover characteristics, the rate at which the landuse is changing and the factors associated with the changes. Understanding the spatial characteristics of wildlife habitats and the requirements such as food availability, proximity to water, topography, etc. serves as the basis of habitat suitability analysis of the species or a specific species living in that area (Parihar et al. 1986; Davis and Goetz 1990; Roy et al. 1995; Kushwaha and Hazarika 2004; Imam and Kushwaha 2013). Analytic hierarchy process (AHP) is a decision-supporting tool which runs on the principle of pairwise comparisons of priorities and relies on the judgement of decision-makers to derive a priority scale (Saaty 1977). AHP helps decompose the factors on which a species relies for its survival into priorities, and pairwise comparison of priorities helps evaluate the combination of factors on a mathematical basis. Weightage obtained from AHP can serve as inputs in GIS platform for weightage overlay analysis to work out a habitat suitability map of wildlife for its conservation (Ying et al. 2007;

Imam and Tesfamichael 2013). Habitat suitability analysis will stand as a very important tool for study and conservation of wildlife in its natural domain and the reduction of man-animal conflict or specifically human-elephant conflict (HEC) in the areas where humans dwell in close proximity to wildlife habitats.

At present, there are only two living species of the biggest terrestrial animal belonging to two different genera, *Loxodonta africana* (African elephant) and *Elephas maximus* (Asian elephant). *L. africana* has two distinct sub-species found in the Savannas of Central and Western African, and *E. maximus* has at least three sub-species distributed in Sri Lanka (*E. maximus maximus*), Asia and Indian sub-continent (*E. maximus indica*) and Sumatran island (*E. maximus sumatranus*) (Hildebrandt et al. 2006). Attributed as the 'heritage animal of India', the species has found its place in the IUCN Red List as Endangered animal. There are ten (10) known elephant landscapes in India: East-Central landscape (South-West Bengal-Jharkhand-Orissa), Kameng-Sonitpur landscape (Arunachal-Assam), Eastern-South Bank landscape (Assam-Arunachal), Kaziranga-Karbi Anglong-Intaki landscape (Assam-Nagaland), North Bengal-Greater Manas landscape (Assam-West Bengal), Meghalaya landscape (Meghalaya), Brahmagiri-Nilgiri-Eastern Ghats landscape (Karnataka-Kerala-Tamil Nadu-Andhra), Anamalai-Nelliyampathy-High Range landscape (Tamil Nadu-Kerala), Periyar-Agasthyamalai landscape (Kerala-Tamil Nadu) and North-Western landscape (Uttarakhand-Uttar Pradesh). Of the ten elephant landscapes, four are in Northeast India of which three are in Assam itself. There is a growing need to conserve this gigantic terrestrial species. In order to conserve this species in situ, a habitat suitability analysis has been carried out in the tropical deciduous forest of Barduar and Mayang Hill Reserve Forests of Loharghat Range, Kamrup West Forest Division, Assam, India.

14.1.1 Human-Elephant Conflict in Assam and Northeast India

The gigantic mammals are listed under Schedule I of the Wild Life (Protection) Act, 1972 (GOI 2003), which is the highest level of protection granted to any species in India. In Northeast India only 25% of the elephant habitat is located within protected areas which accounts for the high likelihood of HEC in the region. The prime cause of HEC is the loss of habitat and shortage of food owing to a decrease in forest cover. Since 1950 more than half of the elephant habitat has been lost due to the conversion of forest-covered lands to cropland, human settlement areas and other developmental activities (Choudhury 2004). In NE India crops are cultivated on the hill slopes (shifting cultivation), in areas interspersed at the forest edges and the river plains. HEC occurs over crop raiding when elephants travel to the plains of Assam from the Himalayan foothills of Arunachal Pradesh and the hilly areas of Assam as well. Human settlement in the forest areas and at the forest fringes is another major cause of HEC, and most of these conflicts occur in the elephant movement routes, human-encroached elephant habitat areas and small forest patches.

The contiguous habitat in Kameng (Arunachal Pradesh)-Sonitpur (Assam) supports a large elephant population that witnessed HEC since the 1990s due to

crop raiding and damage to property resulting in human deaths which in retaliation caused unexpected harming, and as many as 30 elephants were killed by poisoning during 2001–2002 (Choudhury 2002). Due to human encroachment in the area for various reasons including ethnic clashes in 2002, not less than 50% of the elephant habitat has lost in Sonitpur and nearby areas (Bist 2002; Choudhury 2002). The foothills of Barail range in Assam and Jaintia Hills in Meghalaya harbour as many as 100 elephants around the 1950s, and by the 1980s, the elephant population started declining due to habitat fragmentation in the adjoining hill ranges. The elephants wandered aimlessly in the region due to the loss of habitat in their range and killed 41 people from 1991 to 1997. Later the government sponsored the shooting of 'rogue' elephants, and by the end of the decade, the mammals extirpated from the area (Choudhury 2001a, 2004). Elephant habitats in Garo Hills of Meghalaya have been fragmented and destroyed over the increased practice of shifting (*jhum*) cultivation, logging, coal mining and poaching for ivory (Williams and Johnsingh 1996; Gurung and Lahiri Choudhury 2000; Datta-Roy et al. 2009). On the other hand, HEC has a different context in the hilly areas of Manipur, Nagaland and Mizoram wherein elephants are killed for their flesh, which is a native delicacy (Choudhury 2001b).

14.2 Materials and Methods

14.2.1 Study Area

The study was carried out in Mayang Hill (from 91°29′27.831″E and 25°50′34.412″ N to 91°29′24.993″E and 25°51′48.923″N) and Barduar Reserve Forest (RF) (from 91°26′19.40″E and 26°0′30.856″N to 91°25′32.258″E and 25°52′30.95″N) lying adjacent to the outer hilly ranges of Khasi Hills with an area of 9239.35 ha located in Kamrup District, Assam, India (Fig. 14.1). A tropical climate prevails in the forests, and distinct seasons can be recognized; May to mid-October is the rainy season, when maximum monsoon rainfall occurs and average rainfall is about 1300 mm. The winter experiences only occasional showers. Both the reserve forests are drained by numerous streams. The Chandubi Lake lies in between the two reserve forests. The forests may be classified as tropical moist deciduous forest sub-categorized into Kamrup Sal forest and mixed moist deciduous forest (Champion and Seth 1968).

14.2.2 Data

In this study, Landsat-8 (OLI and TIRS) satellite imagery and ASTER Digital Elevation Model (DEM) were downloaded from the EarthExplorer user interface of the US Geological Survey (USGS) and Survey of India digital toposheets obtained from the Geological Survey of India (GSI), Government of India (Table 14.1).
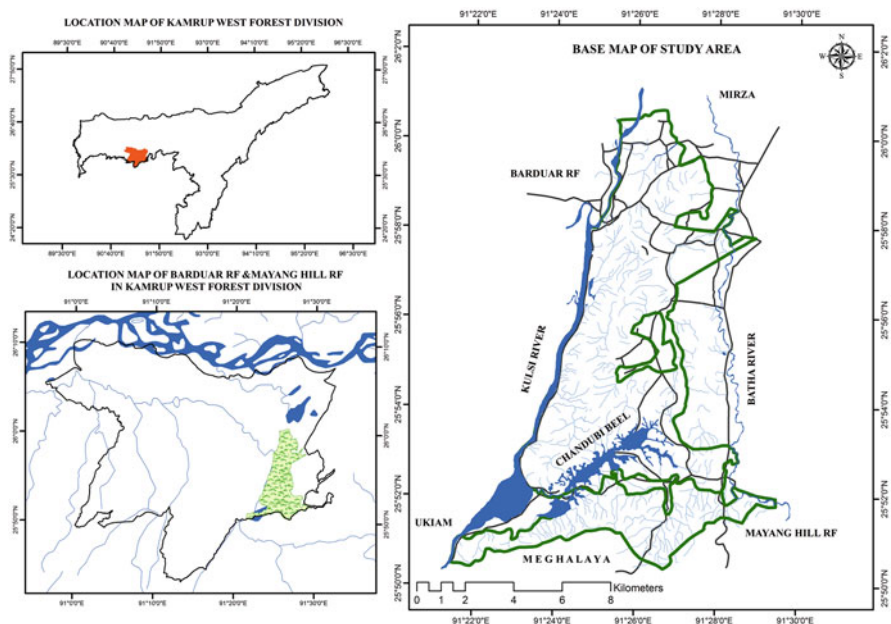
Fig. 14.1 Locational map of the study area

Table 14.1 Details of the data used for spatial mapping

Data	Path and row	Bands	Spatial resolution (in meter)	Period of acquisition
Landsat-8 OLI and TIRS[a] satellite imagery	137/42	11	30 (bands 1, 2, 3, 4, 5, 6, 7 and 9) 15 (band 8) 100 (bands 10 and 11)	March 2016 November 2017
ASTER[b] DEM	–	14	30	November 2011
SOI Toposheet[c]	78O/5	–		2005

[a]Landsat-8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)
[b]Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
[c]Survey of India (SOI) Toposheet

14.2.3 Generation of Spatial Database

The generation of a spatial database for the study has been carried out using ArcGIS version 10.1 software and Google Earth has also been used for identification of location and routes. The flowchart of database generation has been shown in Fig. 14.2.
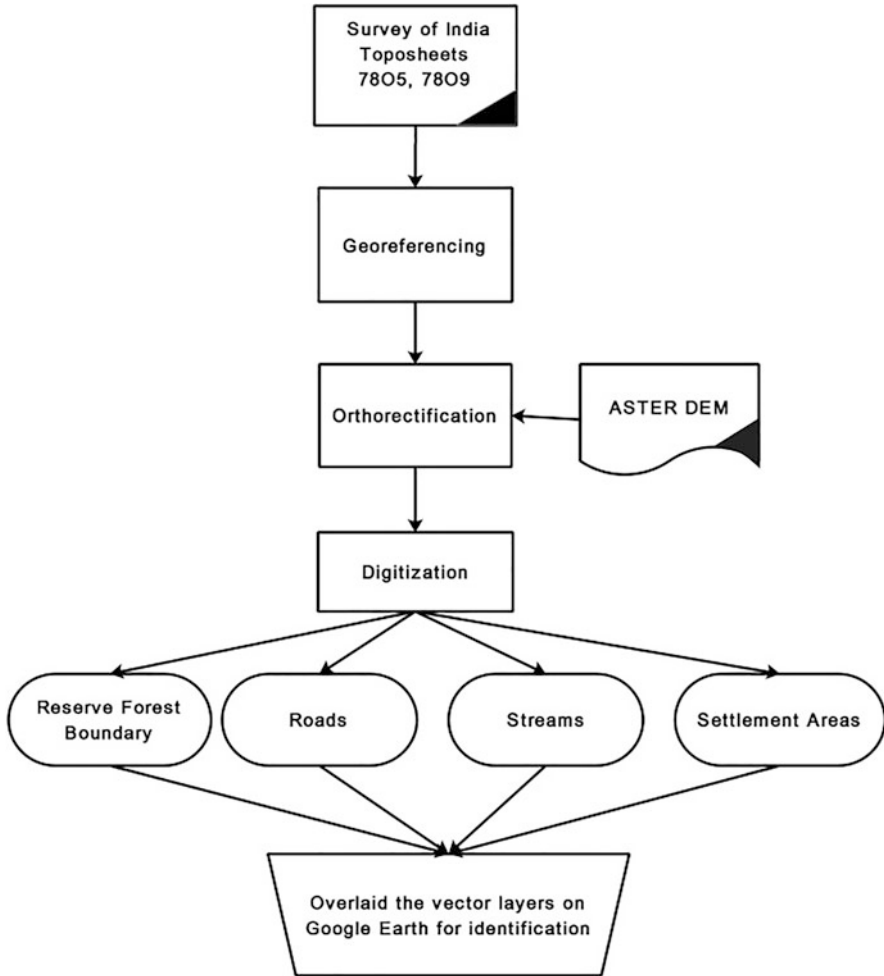
Fig. 14.2 Flowchart showing the generation of spatial database

14.2.4 Preparation of Forest Type, Forest Cover and Forest Strata Layers

Spatial analysis for the generation of forest type, forest cover and forest strata layers has been carried out using ERDAS Imagine version 2013 and ArcGIS version 10.1 software. The flowchart has been shown in Fig. 14.3.
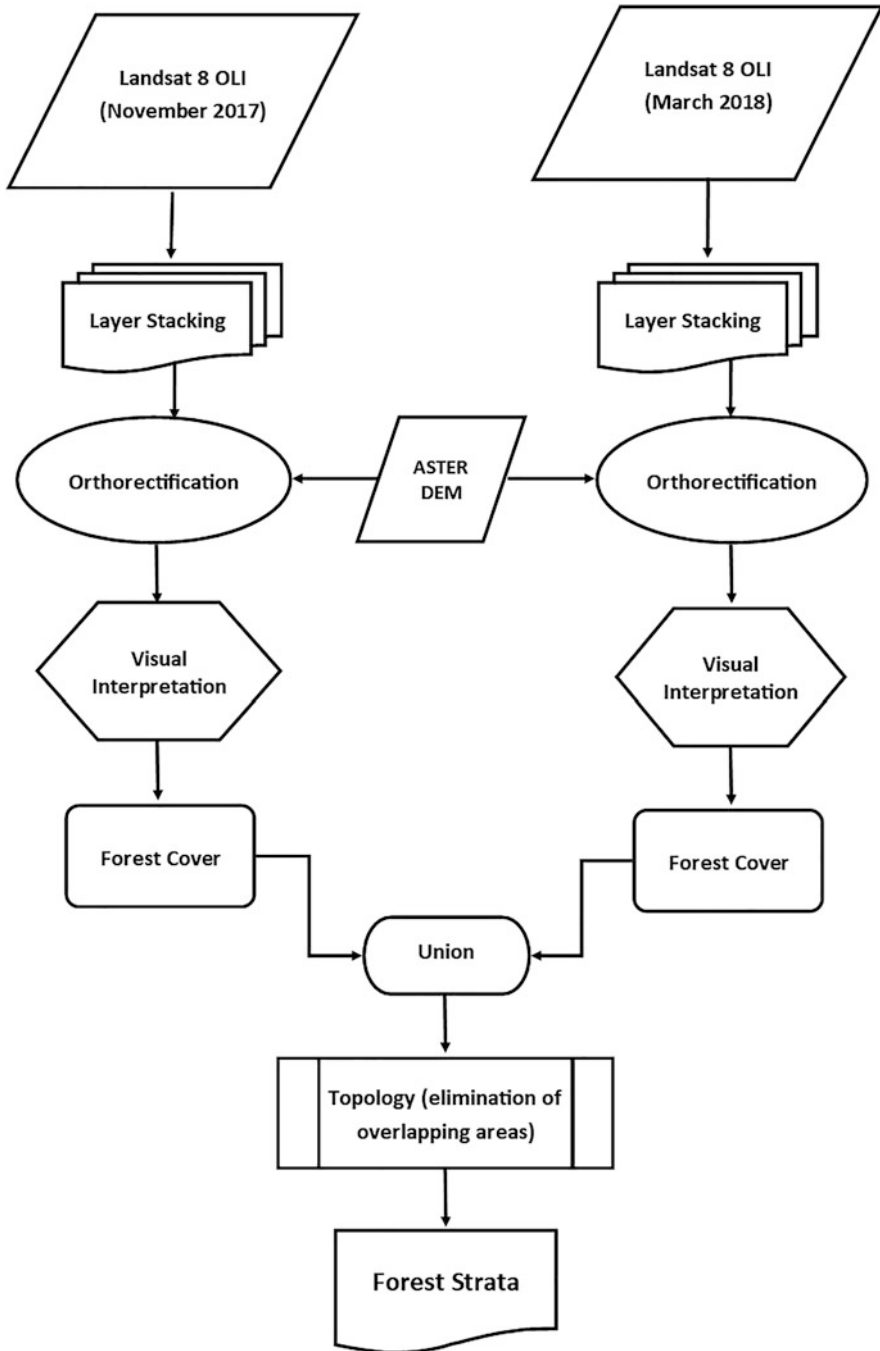
Fig. 14.3 Flowchart of the generation of forest cover, forest and forest strata spatial layers

14.2.5 Collection of Field Information

Barduar RF and Mayang Hill RF lie in the Loharghat Forest Range and the reserves consist of approximately 17 forest villages. A semi-structured interview and a group discussion were carried out with the village headman (*Gaon Bura*) along with the members of various committees, natives of all the forest villages, officials and staff of the Forest Department, Govt. of Assam, to gain insight into human-elephant conflict (HEC) in the two RFs. The information recorded were most frequently Asian elephant-sighting places, pathways of movement of herd as well as lone bulls, assembly points, season and locations of crop raiding and property damage, locations of human-elephant coincidence and injury or death of humans.

14.2.6 Field Survey

Based on the inputs received from the interview and group discussion with the natives and other literature, a field survey based on centre line transect was conducted. The Chandubi Lake where the herds of the gigantic mammal are mostly spotted was taken as the centre and line transects of $n = 15$ of 5 km and 10 km long and 100 m wide (based on terrain feasibility) were covered on foot to trace elephant footprints, dung and other signs of elephant movement (Fig. 14.4).

14.2.7 Analytical Hierarchy Process (AHP) for Habitat Suitability Analysis

Analytical hierarchy process (AHP) is a very flexible and efficient decision-making tool introduced by Thomas L. Saaty in 1980. AHP works on the principle of decomposing the decision-making into criteria and sub-criteria and alternatives on which the decision-making is based (Malczewski 2006). The criteria and sub-criteria are compared pairwise in a matrix assigning weights based on their relative importance. In AHP the weights for different criteria and sub-criteria are assigned in such a way that if there are n number of criteria or sub-criteria ($C_1 \ldots C_n$) to be compared then the real matrix will be $n \times n$ with $n(n - 1)/2$ number of evaluations. A square matrix A is computed. Let each entry to the matrix A be a_{ij} where i and j are two criteria and $i \neq j$. If $a_{ij} > 1$, then the ith criterion is more important than the jth criterion, while if $a_{ij} < 1$, then the ith criterion is less important than the jth criterion. The entries a_{ij} and a_{ji} should be such that $a_{ij} \times a_{ji} = 1$. In the pairwise comparison matrix, the entry for the same criteria such as $a_{ii} = 1$ or $a_{jj} = 1$. The relative importance between two criteria is measured on a numerical scale from 1 to 9, as shown in Table 14.2.

If it is assumed that the ith criterion has strong importance over the jth criterion, then the entry in the matrix will be $a_{ij} = 5$, and for the jth criterion over the ith criterion, it will be a reciprocal, i.e. $a_{ji} = 1/5$. Such a matrix is said to be a reciprocal matrix. The weights are consistent and transitive such that a_{ik} for all i, j and k is
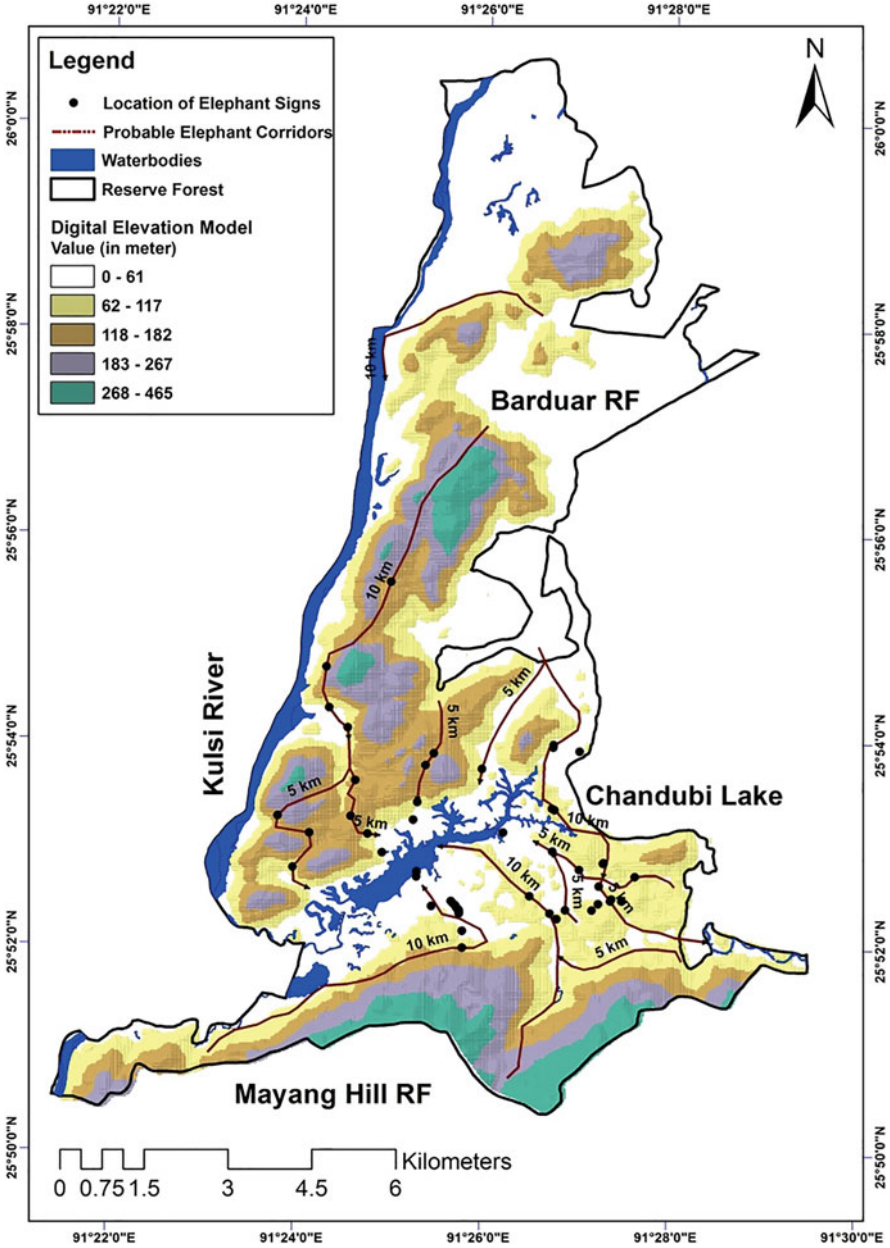
Fig. 14.4 Map showing line transects and points of elephant footprints and dung traced in the field study

Table 14.2 RCI values for different values of n

n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

$a_{ik} = a_{ij} \times a_{jk}$. The values in Table 14.2 are only suggestive and translate the decision-maker's qualitative evaluations of the relative importance between two criteria into numbers. AHP uses a 9-point measurement scale ranging from 1 to 9 wherein the odd values are absolute weights like 1 denotes equal importance, 3 is moderate importance, 5 is strong importance, 7 is very strong importance and 9 is extreme importance (Sanare et al. 2015). It is also possible to assign the even values which are intermediate values and do not correspond to a precise interpretation. AHP involves direct participation to find out the final result, and it has gained wide applications in different fields of decision-making such as suitability analysis, site selection, product selection, marketing and business, etc. (Ayalew et al. 2005). Once the pairwise matrix is computed, the geometric mean and normalized weights for the criteria or sub-criteria are obtained by dividing the weights assigned to each criterion by the sum of the weights of that criteria or sub-criterion (Chowdhury et al. 2010). After the normalized matrix is computed, the average weight for each criteria or sub-criteria is calculated which is the eigenvector ω (of order n) or priority or score for respective criteria or sub-criteria and λ is the eigenvalue, a comparison matrix is consistent if $\lambda = n$. For matrices involving human judgement, the condition like $a_{ik} = a_{ij} \times a_{jk}$ does not hold good as human judgements are inconsistent to a greater or lesser extent; in such cases if $\lambda_{max} = n$, then the judgements have turned out to be consistent. To calculate λ the eigenvector is multiplied with each of the entries in the judgement matrix and added:

$$\lambda = \sum_{j=1}^{n} a_{ij} \cdot \omega_j$$

The maximum eigenvalue ($\lambda_{max}\omega$) is divided by n to obtain λ_{max}:

$$\lambda_{max} = \frac{\lambda}{n}$$

Finally, a consistency index (CI) can be calculated from:

$$CI = \frac{(\lambda_{max} - n)}{(n - 1)}$$

It is necessary to calculate CI against judgements basically for random judgements. Saaty (1980) has calculated large samples of random matrices of increasing order and the CIs of those matrices. A true consistency ratio (CR) is calculated by dividing the CI for the set of judgements by the random consistency index (RCI) for the corresponding random matrix:

$$CR = \frac{CI}{RCI}$$

Saaty (1980) suggests that if that ratio is less than 0.1, the judgement is consistent and if it exceeds 0.1, the set of judgements may be too inconsistent to be reliable. In practice, CRs of more than 0.1 have to be accepted sometimes. But if CR equals zero, the judgement is perfectly consistent.

14.2.8 Habitat Suitability Analysis

Decision-making in the first place involves gathering information, Asiatic elephants require a large range of habitats and provision for suitable habitat is the key requirement for the survival of the gigantic mammalian population. Asiatic elephants prefer areas with greater landcover (Sanare et al. 2015) and heterogeneity (Datye and Bhagwat 1995; Desai and Hedges 2010; Mandal and Das Chatterjee 2021) in close proximity to water (Sharma et al. 2020) such as mixed forest and riverine forest since these types of forests are potential sources of food (Sukumar 2003; Yamamoto-Ebina et al. 2016). These gigantic mammals have a tendency towards lower slopes (Sharma et al. 2020) and avoid monoculture forests since this type of forest does not have much food variability. Elephants also avoid humans while searching for food in the forest (Gaynor et al. 2018). Based on their requirements and habitat characteristics, the suitability analysis hierarchy has been decomposed into the following levels, shown in Fig. 14.5 (Table 14.3).
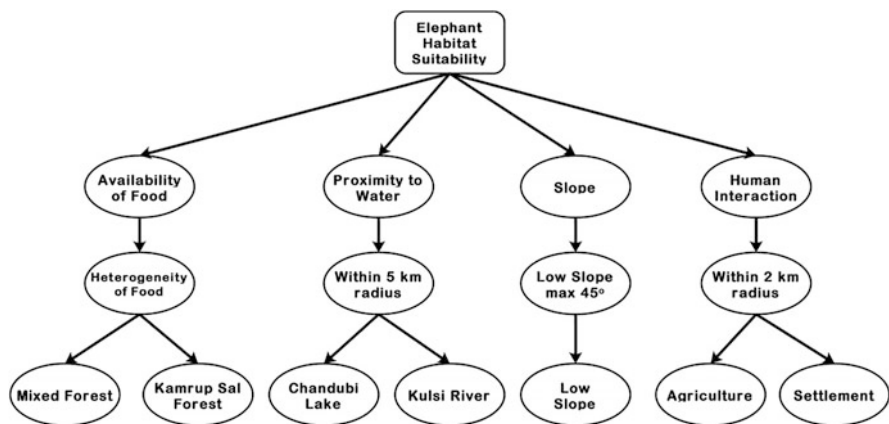

Fig. 14.5 Factors considered for elephant habitat suitability analysis

Table 14.3 Weighted factors considered for elephant habitat suitability analysis

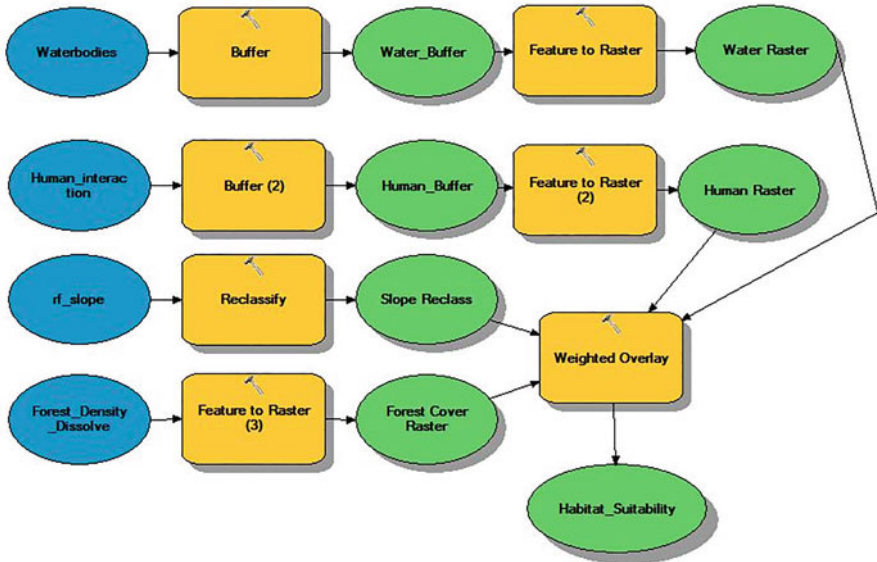| Landcover	Proximity to water	Human interaction	Slope	Suitability
Dense mixed forest	Within 5 km	2 km away	≤45°	9 (highly suitable)
Open mixed forest	Within 5 km	2 km away	≤45°	7 (strongly suitable)
Dense Sal forest	Within 5 km	2 km away	≤45°	5 (moderately suitable)
Open Sal forest	Within 5 km	2 km away	≤45°	3 (suitable)

Fig. 14.6 Process flowchart of the weighted overlay model for habitat suitability

14.2.9 Weighted Overlay Model

Weighted overlay model is a general overlay analysis process processed in a single tool which reclassifies the input raster values into a common evaluation scale of preference or suitability, risk, etc. The weighted overlay model only accepts raster as inputs such as different forest classes or landuse classes with different input integers as values. The model was built in ArcView 10.2, the weightage derived for each criterion from AHP was incorporated in the input raster layers and the model was processed to obtain the elephant habitat suitability map for the study area (Fig. 14.6).

14.3   Results and Discussions

14.3.1 Forest Type

The forest-type map has been prepared based on different spectral signatures taken from seasonal (mid-October to mid-January and end of January to end of March) satellite imageries and classified as per Champion and Seth's forest-type classification (1968) shown in Fig. 14.7. The forest-type area statistics show that 41.83% of
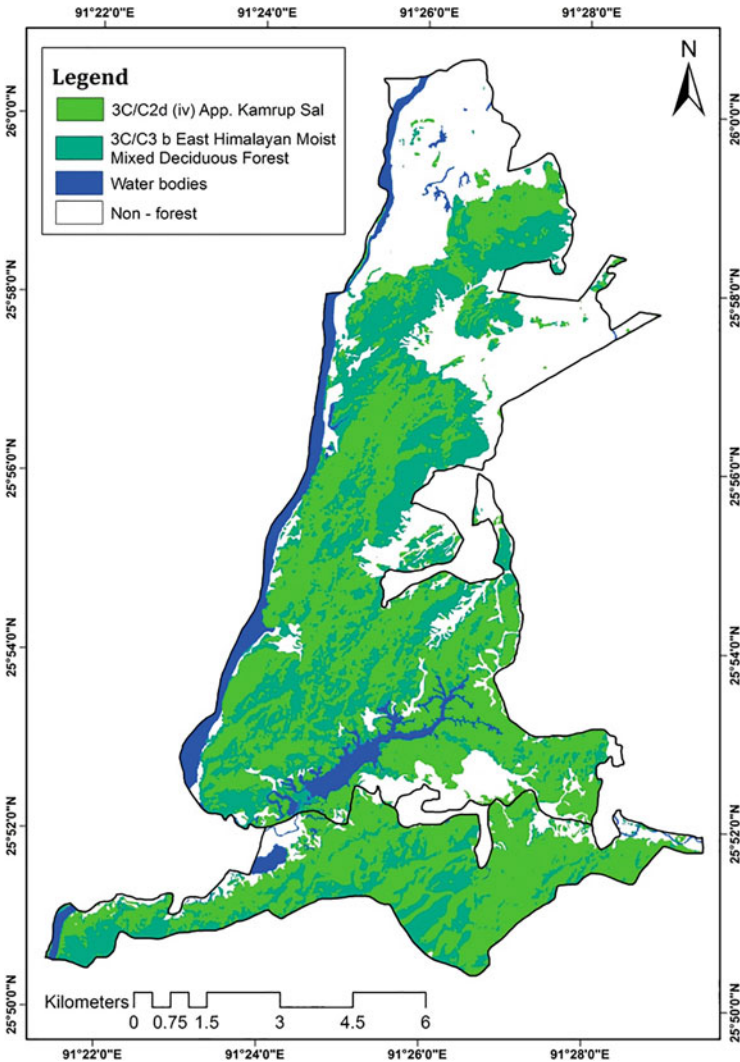

Fig. 14.7 Forest-type map of the study area

Table 14.4 Area statistics of forest types in the study area

Forest-type classes	Area (in ha)	Area (in %)
3C/C2d (iv) App. Kamrup Sal forest	3865.22	41.83
3C/C3b East Himalayan moist mixed deciduous forest	2432.07	26.32
Water bodies	560.33	6.06
Non-forest	2381.73	25.78
Total	9239.35	100

Table 14.5 Area statistics of forest cover and other landuse in the study area

Forest cover categories	Area (in ha)	Area (in %)
Dense forest	1840.60	19.92
Open forest	4456.69	48.24
Water bodies	560.33	6.06
Cropland	1563.63	16.92
Rural settlement	818.10	8.85
Total	9239.35	100

the area is dominated by 3C/C2d (iv) App. Kamrup Sal (Table 14.4) and 26.32% of the area is covered by 3C/C3b East Himalayan moist mixed deciduous forest. Water bodies cover 6.06% area, and 25.78% of the area is non-forest which attributes to other landuse classes such as cropland, settlement areas, etc.

14.3.2 Forest Cover, Water Bodies and Other Landuse

The Barduar and Mayang Hill RFs covering an area of 9239.35 ha have 19.92% of dense forest (Table 14.5) which exists mostly on the southern part of the forest stretch in the Mayang Hill RF (Fig. 14.8). Open forest dominates 48.24% of the area of which the majority lies in Barduar RF, and water bodies constitute 6.06% of the total area. Cropland and rural settlement occupy 16.92% and 8.85% of the area, respectively.

14.3.3 Forest Strata

In the present study, forest stratification refers to the horizontal stratification of the forest canopy. The forest strata map (Fig. 14.9) has been obtained by integrating the forest type and forest cover vector layers. The schema of the horizontal forest stratification has been shown in Table 14.6.

The forest strata area statistics of the two RFs (Table 14.7) show that Kamrup Sal open forest covers 24.52% and East Himalayan moist mixed deciduous open forest covers 23.72% of the total area. On the dense forest classification, Kamrup Sal dense forest covers 17.31% area, and East Himalayan moist mixed deciduous dense forest covers only 2.61% of the area.
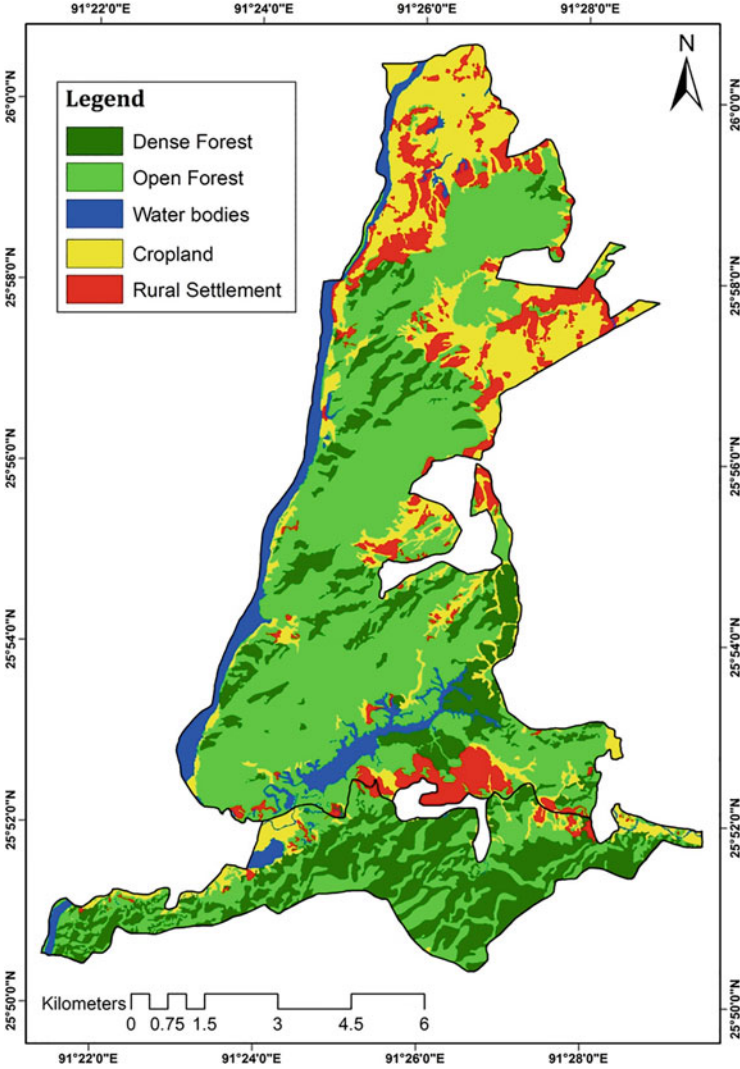
Fig. 14.8 Forest cover map of the study area

14.3.4 Identification of Suitable Habitat Zones

A pairwise comparison matrix was built based on the habitat suitability criteria for Asiatic elephants. The giant mammals prefer to dwell in dense vegetation covered in close proximity to water and away from human habitation. Table 14.8 shows the pairwise comparison matrix and the scores assigned to each pair of criterion.

After building the pairwise comparison matrix, a normalized matrix was computed, and the eigenvector for each criterion was derived. The priority
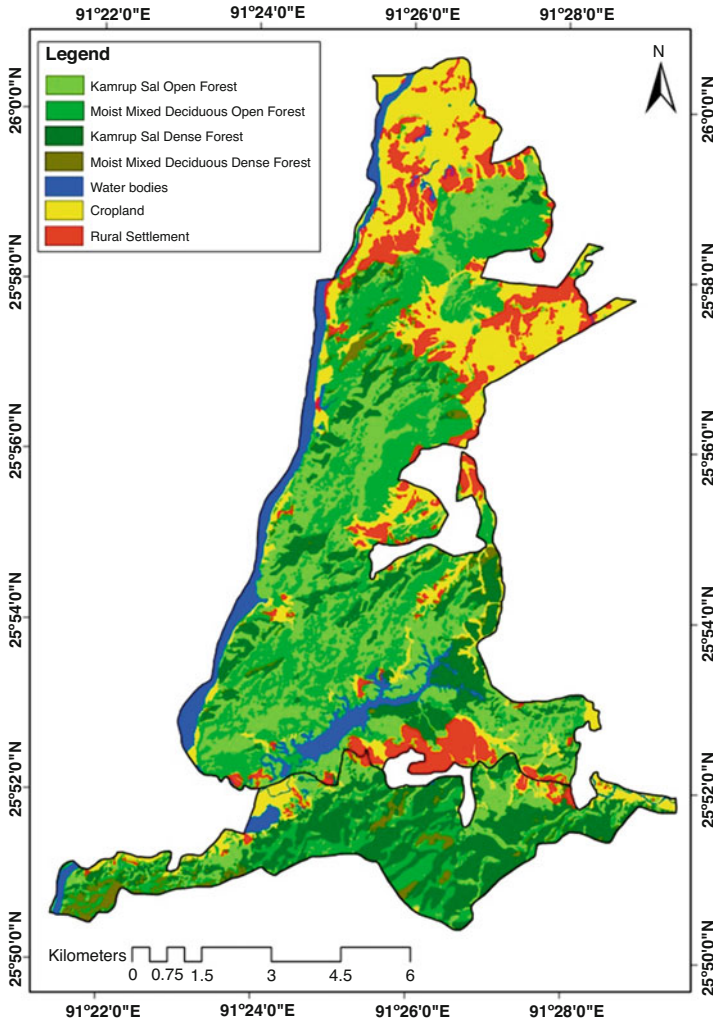
Fig. 14.9 Forest strata map of the study area

percentage shows (Graph 14.1) that for elephant habitat suitability the foremost factor is the availability of food in the forest which also shelters and sheds the gigantic mammals, followed by proximity to water, topography (slope) and disturbance or avoiding human interaction.

The eigenvalue (λ) for each criterion was as follows: forest (4.09), proximity to water (4.40), slope (4.11) and human interaction (4.25). The maximum eigenvalue (λ_{max}) was found to be 4.212, and the consistency index (CI) obtained was 0.070. The consistency ratio (CR) for this matrix $n = 4$ and $R = 0.90$ was 0.07. Since a CR for this matrix is less than 0.1, therefore the judgement is consistent.

Table 14.6 Forest strata classes based on the union of forest cover and forest type in the study area

Forest cover		Forest type	Forest strata
Forest	Dense	3C/C3b East Himalayan moist mixed deciduous forest	3C/C3b East Himalayan *moist mixed deciduous dense forest*
	Open		3C/C3b East Himalayan *moist mixed deciduous open forest*
	Dense	3C/C2d (iv) App. Kamrup Sal forest	3C/C2d (iv) App. *Kamrup Sal dense forest*
	Open		3C/C2d (iv) App. *Kamrup Sal open forest*
Water bodies	River	Water bodies	Water bodies
	Lake		
Other landuse	Cropland	Non-forest	Cropland
	Rural settlement		Rural settlement

Table 14.7 Area statistics of forest strata in the study area

| Forest strata classes	Area (in ha)	Area (in %)
Kamrup Sal open forest	2265.55	24.52
Mixed deciduous open forest	2191.16	23.72
Kamrup Sal dense forest	1599.67	17.31
Mixed deciduous dense forest	240.91	2.61
Water bodies	560.33	6.06
Cropland	1563.63	16.92
Rural settlement	818.10	8.85
Total	9239.35	100

Table 14.8 Pairwise comparison matrix

$j \rightarrow$ i $\downarrow$	Human interaction	Proximity to water	Slope	Forest	Geometric mean
Human interaction	**1**	0.33 (1/3)	0.33 (1/3)	0.2 (1/5)	0.39
Proximity to water	3	**1**	4	0.5 (1/2)	1.57
Slope	3	0.25 (1/5)	**1**	0.25 (1/5)	0.66
Forest	5	2	4	**1**	2.51
Total	12	3.58	9.33	1.95	–

14.3.5 Asian Elephant Habitat Suitability

The respective weights derived for each criterion from AHP (Table 14.9) were fitted in the model, and the weight overlay model (Fig. 14.6) was executed to obtain the elephant habitat suitability map (Fig. 14.10) which has been classified into four categories, viz., low, moderate, moderately high and high.

The Asian elephant habitat suitability area statistics for the study (Table 14.10) show that 24% of the area has high habitat suitability for Asian elephants, 12.73% of
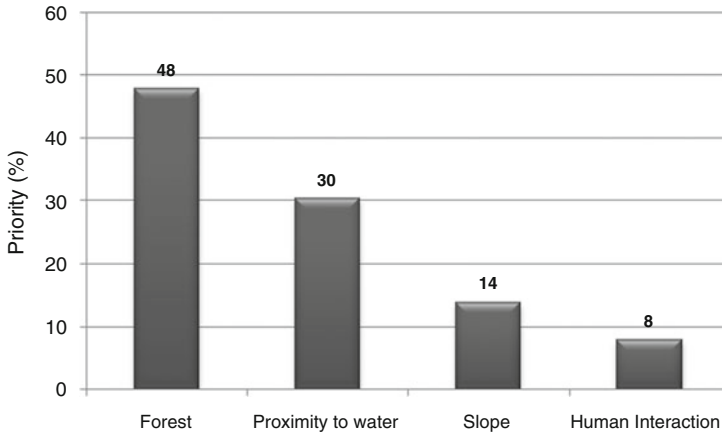
Graph 14.1 Priority (in %) of the habitat suitability factors

Table 14.9 Area statistics of the suitable habitat for Asian elephants in the study area

Habitat suitability categories	Area (in ha)	Study area (in ha)	Area under suitability categories (in %)
High	2217.15	9239.35 (i.e. 100% of the area)	24.00
Moderately high	1176.54		12.73
Moderate	3229.57		34.95
Low	1302.55		14.10
Total (low suitability has not been considered)	6632.26		71.68

the area is moderately suitable and 34.95% is moderately suitable in the study area. Only 14.10% of the area has low suitability. Of the total study area, 71.68% is suitable for the Asian elephants as a habitat. Forest cover is one of the important factors for Asian elephants' habitat suitability along with other factors like forest cover density, less fragmented forest, food variability and availability of water. Elephants have a tendency to rest and stay in moist dense forest areas of relatively low temperatures (Forman 1995; Mandal and Chatterjee 2018, 2019). Therefore, it is very crucial that the contiguous forest stretch of Mayang Hill RF on the Assam-Meghalaya state border and Barduar RF adjoining the Kulsi River and Chandubi Lake be given due emphasis for conservation and restoration of the areas under low suitability to intensify the habitat suitability in the area.

14.3.6 Pathways of Elephant Movement and Identification of Human: Elephant Conflict Areas

Based on the information received from the informants and field data of locations of elephant traces and HEC places, the pathways of elephant movement and areas of HEC have been generated in the GIS environment (Fig. 14.10). In Fig. 14.10 the orange-coloured dots represent the locations of elephant sighting, assembling points
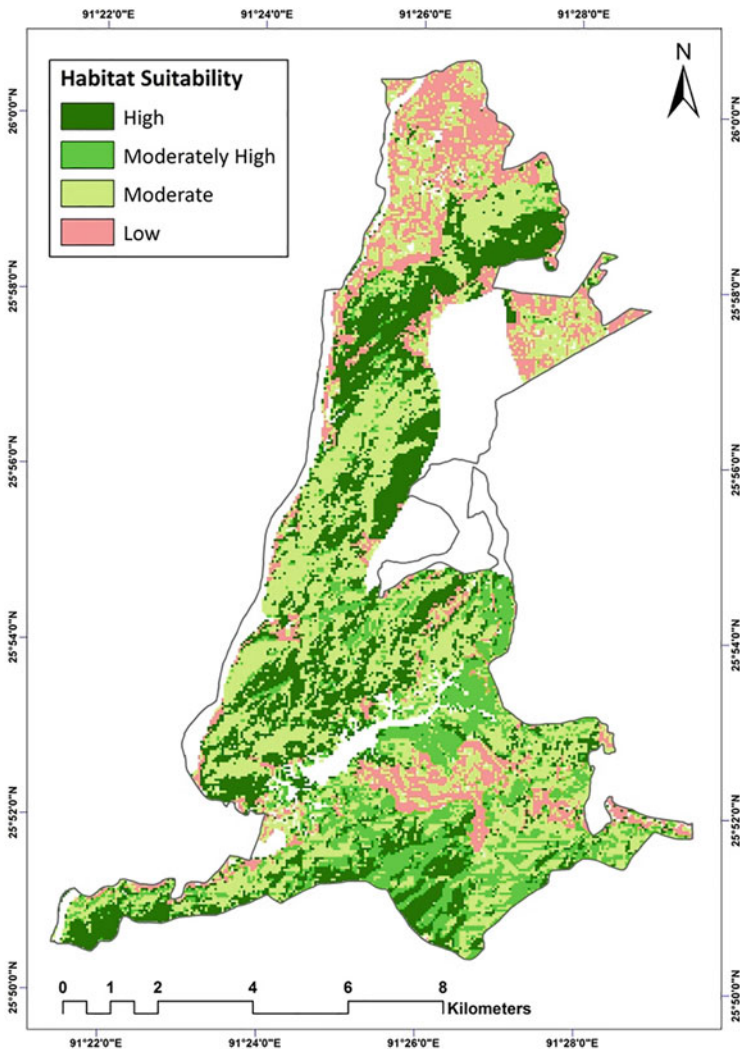
Fig. 14.10 Asian elephant habitat suitability map of the study area

and traces like footprints, faeces, etc., and the red-dotted lines represent the pathways of elephant movement in the area which have been traversed on the field and connected with the orange dots in GIS environment. Most of the human-elephant interaction occurs near the road passing along the Chandubi Lake between Barduar and Mayang Hill RF (Fig. 14.11). The point marked A, B and C in Fig. 14.11 are the locations where so far human casualties have been reported due HEC in the study area (Fig. 14.12).

Table 14.10 Normalized matrix

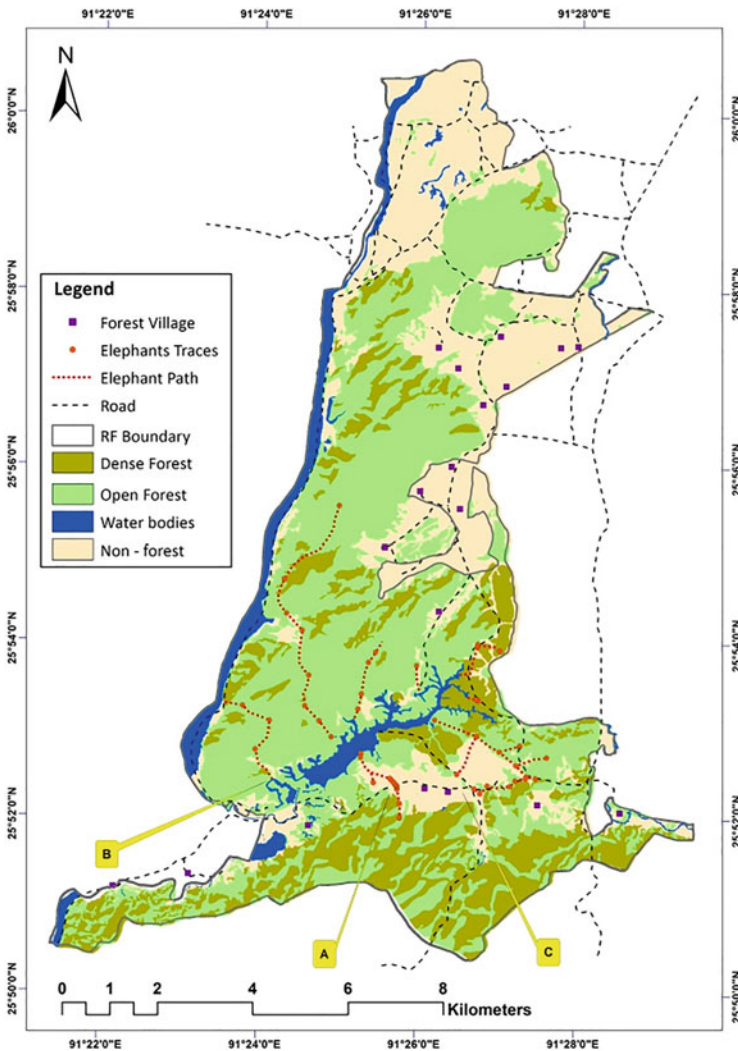| Criterion	Human interaction	Proximity to water	Slope	Forest	Eigenvector (ω)	Priority (%)
Human interaction	0.083	0.093	0.036	0.103	0.079	8
Proximity to water	0.250	0.279	0.429	0.256	0.304	30
Slope	0.250	0.070	0.107	0.128	0.139	14
Forest	0.417	0.558	0.429	0.513	0.479	48
Total	1	1	1	1	1	100

Fig. 14.11 Pathways of elephant movement of HEC in the study areas
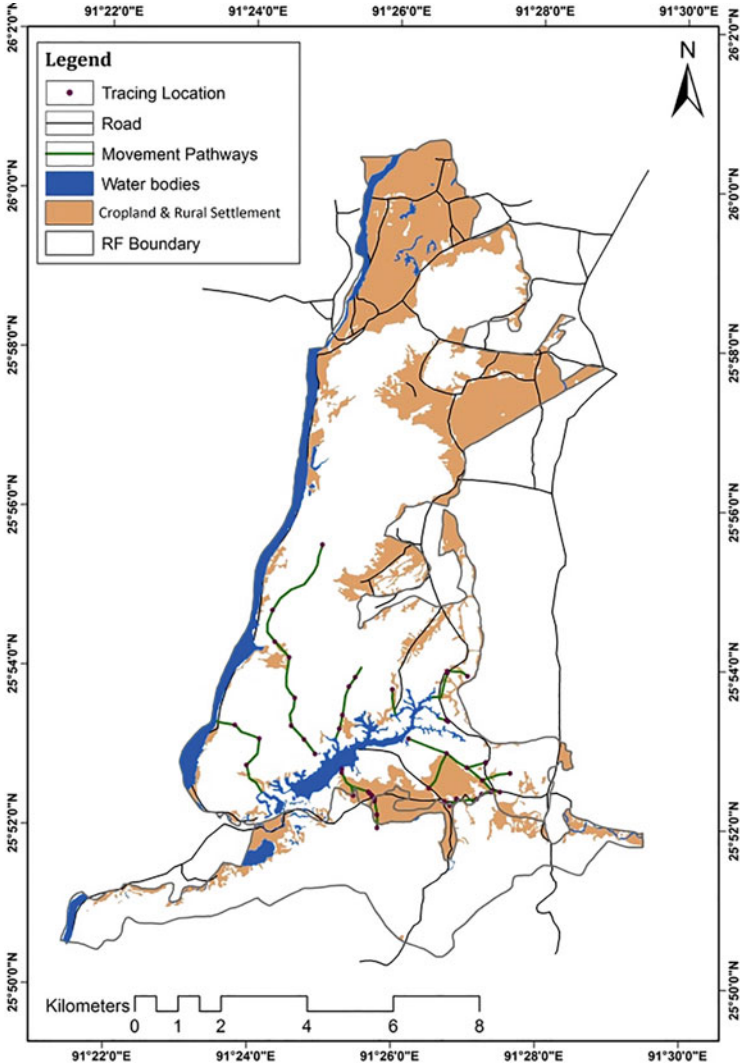
Fig. 14.12 Asian elephant movement pathways and coincidence with cropland and rural settlement

14.4   Conclusion

The study finds some of the ecological factors essential for the survival and habitat suitability of Asian elephants and demarcates the habitat suitability areas using geospatial tools. The gigantic mammals find areas suitable for the habitat with sufficient food, shade for resting and secured shelters away from disturbance.

Therefore, forest cover and availability of food are crucial for movement and habitat selection. Elephants are long-ranging animals which move in search of food and shelter from low suitability areas to suitable or highly suitable areas and given the presence of humans and road networks in the forest areas in many instances result in HEC (Koirala et al. 2016; Kumara et al. 2017). The study will be useful for improving the habitat quality and conservation of Asian elephant habitat in the present study area. The demarcated habitat suitability areas will help ecologists, conservationists, foresters and the government for managing elephant movement pathways, enhance forest and food sources for elephants and check on HEC in the present area. The study may also be useful for further research in this field.

Declaration The authors declared that this is an original research work and no part of it has been produced or published anywhere.

Conflict of Interest The authors declare no conflict of interest.

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