**ORIGINAL ARTICLE**

# Habitat suitability of the Asiatic elephant in the trans-boundary Patharia Hills Reserve Forest, northeast India

Nazimur Rahman Talukdar[1,2] · Parthankar Choudhury[1,2] · Firoz Ahmad[3] · Raihan Ahmed[4] · Firoz Ahmad[5] · Hassan Al-Razi[6]

## Abstract

Throughout the tropical regions, raising demands for the land due to the exponential growth of the human population has resulted in habitat loss and fragmentation for wildlife. Consequently, wild animals come out from the fragmented habitats and compete with the human for resources. In order to reduce this conflict, sustainable habitat management balancing the socioeconomic needs of the people is of the utmost importance. The present study is an effort to assess the elephant's habitat suitability in the trans-boundary forested areas of India and Bangladesh, Patharia Hills Reserve Forest. This is an important study considering the increased human–elephant conflict in the area, and also the area is home to many IUCN's red-listed animals including Chinese pangolin, spectacled monkey, capped langur. Field surveys were conducted to collect the elephant distribution data and identify potential anthropogenic disturbances. Remote sensing and geographic information system along with analytical hierarchy process were used in the methods for modeling habitat suitability to identify habitat parameters and preparation of suitability maps. Vegetation status (32.50%), settlements (23.30%), elevation (17.20%) and water sources (12.70%) were found to be the most weightage parameters for the movement of the elephant. The study on elephant habitat suitability mapping in the trans-boundary forest revealed that 6.88% area of the habitat is highly disturbed, 36.07% area is somehow disturbed, 35.38% area is moderately suitable and only 21.67% area is most suitable for the Asiatic elephants. Identification of suitable areas and potential factors disturbing the habitats is important for conserving and management of wildlife for particular species and in particular sociophysical conditions. Sustainable management strategies can be fixed based on the findings for the long-term conservation of elephants and other wildlife of the area.

**Keywords** Asiatic elephant · Habitat suitability model · India–Bangladesh · Juri Range

## Introduction

Wildlife habitats are continuously being transforming into agriculture, monoculture, settlements and many developmental activities. Besides, modernization, globalization and urbanization coupled with subsequent human population explosion and demand for land have created huge interference in their wild habitats (Fahrig 2003; Fletcher et al. 2018). In India, land use land cover (LULC) transformation is continuously increasing as every year approx. 15.6 million human populations are added to the current population of India (UN 2017) and more land is required for their food and shelter. The human population density of India was 138 per km² in 1955, which reached 460 per km² in 2019 (UN 2019; Worldometers 2019) and is expected to increase continuously to become the world's most populous country by the coming five years (UN 2019). This obviously indicates

✉ Parthankar Choudhury
parthankar@rediffmail.com

1    Wildlife Research and Conservation Laboratory, Department of Ecology and Environmental Sciences, Assam University, Silchar 788011, India

2    Centre for Biodiversity and Climate Change Research, Udhayan, Hailakandi 788155, India

3    Birsa Agricultural University, Kanke, Ranchi, Jharkhand, India

4    Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi 110025, India

5    Vindhyan Ecology and Natural History Foundation, Mirzapur, Uttar Pradesh, India

6    Faculty of Life and Earth Science, Department of Zoology, Jagannath University, Dhaka, Bangladesh

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consistent increasing pressures on the wildlife habitats. Habitat loss, increasing habitat fragmentations, edges and patches are common consequences (Fletcher et al. 2018). Fragmentation causes an increase in animal migration to the nonforested lands (Haddad et al. 2015) and impels conflict with human. Large migratory animals are affected more due to their relatively higher home range and increase conflict with the human. For instances, human–elephant conflict (HEC) has raised an alarming rate throughout its geographical distribution (Parker et al. 2007; Wahed et al. 2016; Gunaryadi and Sugiyo 2017; Shaffer et al. 2019) and is a major problem in elephant conservation in India (Sukumar 1994; Easa 2002; Singh et al. 2002; Kushwaha and Hazarika 2004). Almost 40,000 elephant populations are distributed across its ranges; India alone holds almost 60% of them. The state of Assam is the second largest number of elephant population (5719) after Karnataka (6049) in India (MoEF 2017). Only a few proportions of the populations are sustaining in the protected areas, while remaining major percentages of the total population are struggling to survive in the unprotected, disturbed and fragmented habitats (Choudhury et al. 2008; MoEF 2017). Habitat loss and fragmentation are the major causes of the decline of the population besides poaching, killing, poisoning, electrocution, etc. (Leimgruber et al. 2003; Hedges et al. 2005; Choudhury et al. 2008; IUCN 2012). Conflict between human and elephant causes crop raiding, injuries, deaths to humans and elephant's death by retaliating, food poisoning, electrocution and poaching (Sukumar 1989, 1991; Hoogesteijn et al. 1993; Hoare 1995; Cozza et al. 1996; Naughton-Treves et al. 1998; O'Connell-Rodwell et al. 2000; Choudhury 2004). On average, every day one human being is facing death due to elephant attack and more than 100 elephants are being killed per year due to HEC in India (Lenin and Sukumar 2011; George 2017).

HEC mitigation is a vital solution to conserve the endangered elephant as well as the protection of human and property. A lot of techniques have been utilized in different geographical ranges but a holistic solution to this problem is yet to achieve due to lacking science-based approaches (Desai and Riddle 2015; Parker et al. 2007; Wahed et al. 2016; Gunaryadi and Sugiyo 2017; Shaffer et al. 2019). HEC solutions would be feasible only after wild habitats are protected. Thus, sustainable wildlife management (SWM) is the vital solution that ideally acts as the efficient management of wild species, their habitats, balancing with human needs and aspiration (FAO 2015). Such protection of habitats needs proper management focusing on the factors influencing their distribution and movement. The parameters may be biotic or abiotic, natural or anthropogenic (Porwal et al. 1996; Kushwaha et al. 2001; Sanare et al. 2015; Dash et al. 2015), which are allied with the geographical features or information (Aini et al. 2015). Geographical information systems (GIS) and remote sensing (RS) are widely used for obtaining information (Ahmad and Goparaju 2016; Ahmad

et al. 2017) and identifying land use transformation on the Earth's surface. The tools are now being extensively used in monitoring habitats for different species in different protected areas of India and outside (Areendran et al. 2011; Porwal et al. 1996; Yamada et al. 2003; Parihar and Panigrahy 1986; Kushwaha et al. 2001; Sanare et al. 2015; Dash et al. 2015) to fix appropriate strategies. RS and GIS can be used to gather information pertaining to the physical parameters of habitat or landscape. Complex attachments among the parameters can also be assessed with these technologies incorporating the parameters in the hierarchy process for decision making and management at the ecosystem level (O'Neill 1996; O'Neil et al. 2005). Analytical hierarchy process (AHP) introduced by Saaty (1980) is widely used to assess both subjective and objective parameters in choosing the best alternatives in various fields (Lee et al. 2001; Qureshi and Harrison 2003).

Currently, habitats under protected areas are only safeguarded by the governments by creating Protected Areas (PA) such as National parks and Wildlife Sanctuaries. Habitats outside protected areas are not considered with due importance for conservation, and these are mostly lined with human settlement. These types of habitats are easier to encroach and hence deteriorating at a faster rate with increasing HEC. Conservation and management are crucial in such kinds of habitats for the long-term sustenance of the elephants. Most of the conflicts in those small fragmented areas are not even reported. About 45–50 elephants existed in the Patharia Hills Reserve Forest (RF) of Assam, India, which are now restricted to only five female elephants. The absence of a male elephant has limited their propagation, and the species is in serious threats due to various anthropogenic activities both in habitat and along their migratory corridor. India–Bangladesh International Border (IB) continues through the Patharia Hills RF, and different parts of the IB are open for elephant migration. The elephants often migrate through the trans-boundary India–Bangladesh border. Unfortunately, habitats of the elephants have been deteriorating because of diverse anthropogenic activities and hence need special attention for long-term conservation of the herd. Keeping this backdrop, the prime concern of the present study is to identify the habitat suitability levels of the Asiatic elephant in the Patharia Hills RF, characterizing threats with the geospatial approach and exploring the viable solution to protect it. Therefore, habitat suitability model was used in this study to assess the existing elephant habitat and inventory for future management.

## Methods

### Study area

The study was carried out in the Patharia Hills RF of Karimganj district, Assam, India, and its adjoining Juri Range of

Moulavibazar district, Bangladesh (Fig. 1). The southern part of the area shares a boundary with the state of Tripura, India, and Biani bazar and Karimganj town at the north while Moulavibazar town, Bangladesh, at the west and Patharkandi town, Assam, at the eastern side of the area. Long rainy summer and short dry winter is the climatic condition of the area. Annual average temperature ranges from 21 to 39 °C. The coldest month is December when temperature even falls to 10 °C, and June–July are the warmest months having temperature of 39 °C. Humidity varies from 80 to 90% in the morning and 40 to 50% at night. Annual precipitation is greater than 2800 mm, which is mostly the monsoon rainfall occurring during May–July or August. The topography of the valley is comprised of large numbers of small undulating hills with water sources at the middle. Bangladesh's largest waterfall 'Madabh-kunda' originated from the area. Tropical evergreen and semievergreen forests are the characteristics of the vegetation of the areas lying in both Indian and Bangladesh territories (Champion and Seth 1968, Muzaffar et al. 2007).

The dense vegetation of the area along with many perennial water sources is the home of many wild fauna (IUCN 2004; Talukdar and Choudhury 2017b; Talukdar et al. 2018) including eight varieties of primate and endangered Asiatic elephant. Khasi, Tripuri, Manipuri and Bengali communities are surviving in and around the forest. Among them, many families of the first three communities were the forest dwellers from the last many decades and many have migrated. Khasi communities are well-known forest dwellers in the area, and their livelihood completely depends on the forest ecosystems. The communities in the area cleared forest to plant beetle leaf and beetle nut as the source of cash crops. Besides, slash-and-burn practices (locally known as Jhum) are prevalent in the area. Major roads connecting villages in and around the forest create disturbance in the habitats and provide easy excess to illegal logging and collection of nontimber forest products (NTFP).

Both India and Bangladesh signed Memorandum of Understanding (MoU) in 2015 (TOI 2015) to conserve Endangered Phayre's leaf monkey ( *Trachypithecus phayrei*) in the area; however, no such initiative was taken for conservation of the Asiatic elephant, which is the need of the hour. Human settlements, construction of roads, electricity and other LULC conversion are prevalent in the area,
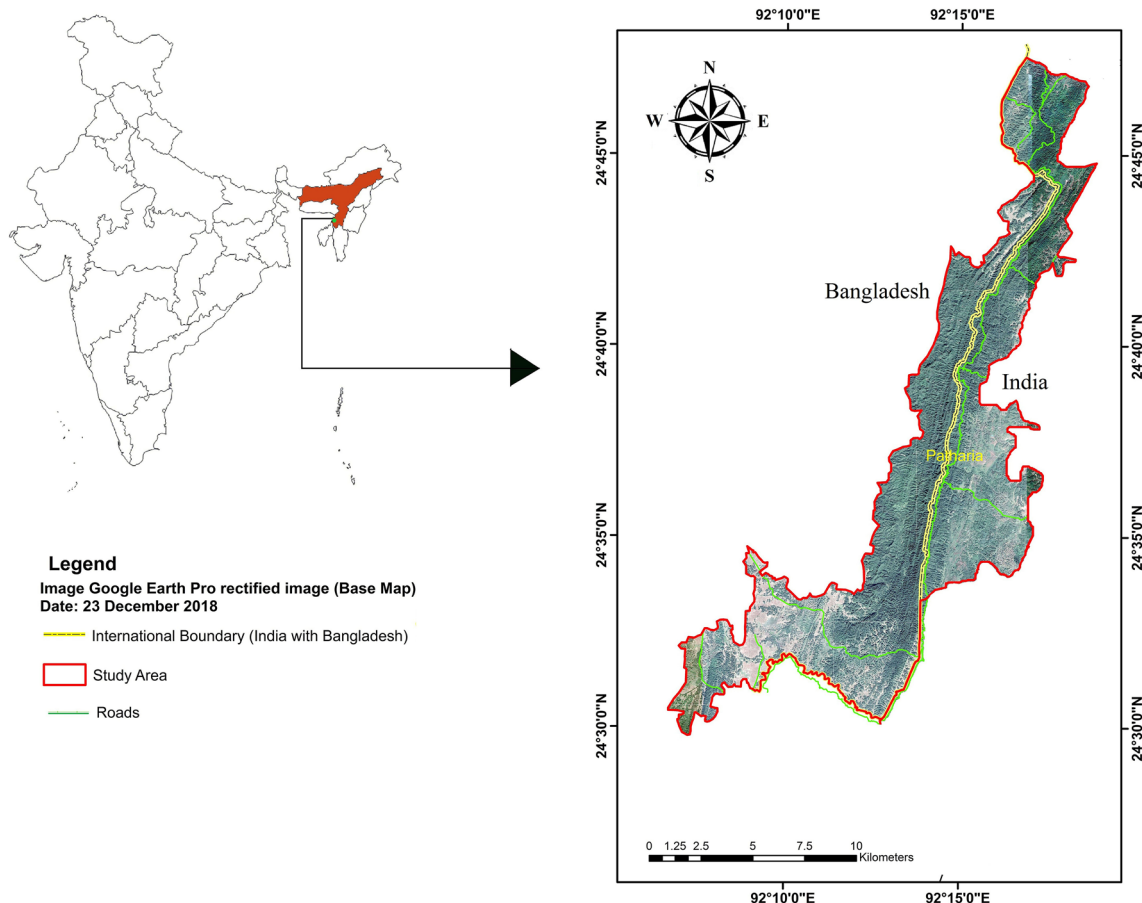


**Fig. 1** Map of India showing the state of Assam and the study area

forcing HEC. Large areas of agricultural lands are affected by the HEC, and many areas were kept barren to cot the crop raiding.

## Habitat suitability analysis

### Data collection and preprocessing

Data were collected from November 2015 to June 2019 as per (Nath et al. 2009; Nath et al. 2013; Rahman et al. 2012; Matleb et al. 2016). Two groups were arranged along with the first and fourth authors comprising three community members in each group who were trained to collect all the incidents spots, secondary sources such as their trails, pugmark and fecal deposits spots. These community members were selected from three locations to widespread cover of the study area. The members collected information especially in summer and winter seasons as most of the human–elephant conflict occurs at these seasons. Elephants often come out of the forest at night, but their movements were traced following their indications on conflict incidents, trails, pugmarks and fecal deposits. Members visited their respective areas every day from 8.00 to 10.00 in summer, while in winter, elephants were followed from 14.00 to 17.00 based on their visible movements through the small forest patches and tea gardens. Their presence was confirmed from the residents and tea laborers, and then their movements were followed from 14.00 to 17.00, i.e., until the elephants approach the crop field at dusk. Global Positioning System (GPS) which recorded all the locations confirmed the presence of elephants. After the completion of field study, Targeted Group Discussions (TGD) were accomplished with the Border Security Forces (BSF), Forest Staff (FS), HEC victims and local communities to collect the relevant information. Besides, major disturbances such as roads and settlements within the study area were noted with GPS coordinates. Major roads defined here are the vehicular roads causing problems to the elephant movement. However, Jhum cultivation (slash-and-burn type) identified in the survey was not taken separately as it is reflected in the Normalized Difference Vegetation Index (NDVI) analysis.

### Habitat suitability analysis

Habitat suitability analysis of the elephants in Patharia Hills RF was studied establishing parameters based on the primary and secondary data available on the elephants in the Patharia Hills RF. Distribution of the elephant data was analyzed in GIS environment with six identified habitat parameters, namely Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Digital Elevation Model (DEM), slope, settlements and major roads, to study the habitat utilization of elephants. The former four parameters are important for habitat suitability (Kushwaha and Roy 2002; Areendran et al. 2011, Aini et al. 2015), while the latter two parameters are the prevailing elephant disturbance collected during the field survey.

The Landsat image (path/row: 136/43) of the time December 2018 was downloaded from the USGS Web site. Downloaded imagery was cloud-free, and preprocessing of the imagery was done by the Dark Object Subtraction method for atmospheric haze reduction. This image was used for classifying the Patharia and Juri Forest landscape. The imagery was used to create an NDVI map, which significantly highlights the vegetation health. The continuous NDVI image was used for density slicing over the FCC for getting the various vegetation class threshold value, which was later converted to four classes, namely dense forest, medium forest, open forest and nonforest. The NDWI (Gao 1996) was generated from the satellite image to identify the water bodies and finally to create water buffer. The settlement area and major roads were digitized using high-resolution satellite imageries of Google Earth, and toposheets were then converted to vector layer in GIS software. The DEM was used to generate the elevation and slope map. All thematic layers representing the factors were then generated. Furthermore, multiple ring buffers for representing the proximity to the variables were created at a particular distance based on the field observations (Ahmad et al. 2018). Maps were simplified using the spatial analysis tool in GIS software.

The findings of the distributional data analysis were used in assigning weights to evaluate Saaty's analytical hierarchy process (AHP) (Saaty 1980) (Table 1). AHP is the most used multicriteria decision-making method to derive weightage for assigning, in particular, habitat parameters (Kushwaha and Roy 2002; Zhixi et al. 1995; Areendran et al. 2011, Aini et al. 2015; Dash et al. 2015; Sarkar et al. 2014; Carrilho 2015), which is based on the assumption that few parameters are higher influential than others in certain circumstances. Each parameter was assigned a value compared with another relative importance for selecting the best, and then the values of geometric progression (GP) were calculated for each row. Reciprocal matrix and then normalized matrix were calculated (Table 2) for constructing a priority rating of all the habitat parameters. Then, consistency ratio (CR) was tested using the following formula

$$CR = CI/RI \tag{1}$$

where RI is random index (value depends on order of the matrix) and CI is consistency index. The CI is obtained through the following equation:

$$CI = \frac{\lambda_{max}}{n - 1} \tag{2}$$

**Table 1** Pairwise comparison matrix using analytical hierarchy procedure

| Habitat parameters | Priority (%) | Rank | NDVI | Settlements | Elevation | NDWI | Road | Slope |
|---|---|---|---|---|---|---|---|---|
| NDVI | 32.50 | 1 | 1 | 2.00 | 3.00 | 2.00 | 3.00 | 4.00 |
| Settlements | 23.30 | 2 | 0.50 | 1 | 2.00 | 3.00 | 2.00 | 3.00 |
| Elevation | 17.20 | 3 | 0.33 | 0.50 | 1 | 2.00 | 3.00 | 3.00 |
| NDWI | 12.70 | 4 | 0.50 | 0.30 | 0.50 | 1 | 2.00 | 3.00 |
| Road | 8.70 | 5 | 0.33 | 0.50 | 0.33 | 0.50 | 1 | 2.00 |
| Slope | 5.70 | 6 | 0.25 | 0.33 | 0.33 | 0.33 | 0.50 | 1 |

Principal eigenvalue = 6.29

Eigenvector solution = 5 iteration, delta = 8.8E−8

Number of comparisons = 15

Consistency ratio = 4.7%

**Table 2** Assigned ranks (AR) and normalized ranks (NR) for habitat suitability

| Factors | Class | AR | NR |
|---|---|---|---|
| Major roads | Below 100 m | 4 | 0.4 |
| | 100–200 m | 3 | 0.3 |
| | 200–300 m | 2 | 0.2 |
| | Disturbance free | 1 | 0.1 |
| Settlements | Below 100 m | 4 | 0.4 |
| | 100–200 m | 3 | 0.3 |
| | 200–300 m | 2 | 0.2 |
| | Disturb free | 1 | 0.1 |
| NDWI | Other than water buffer | 2 | 0.67 |
| | Water buffer (< 100 m) | 1 | 0.33 |
| NDVI | Non forest | 4 | 0.4 |
| | Grassland | 3 | 0.3 |
| | Open forest | 2 | 0.2 |
| | Dense forest | 1 | 0.1 |
| Elevation | Below 36 m | 5 | 0.33 |
| | 36–75 m | 4 | 0.27 |
| | 75–114 m | 3 | 0.2 |
| | 114–153 m | 2 | 0.13 |
| | Above 153 m | 1 | 0.07 |
| Slope | > 36° | 5 | 0.33 |
| | 26°–36° | 4 | 0.27 |
| | 16°–26° | 3 | 0.2 |
| | 6°–16° | 2 | 0.13 |
| | < 6° | 1 | 0.07 |

where $\lambda$ is the biggest eigenvalue of the framework and can be effectively decided from the specified matrix and n is the number of habitat suitability factors. The CR must be below 0.1 (Saaty 1980; Malczewski 1999).

The special scale was used to compare the factors dominating one another to a given attribute and derive priority scales (Saaty 1980). Assigned rank (AR) value 1 means it is highly suitable, whereas higher values mean it is least suitable. Finally, potential parameters were integrated with the GIS domain (Ahmad et al. 2018) for determining the different levels of habitat suitability of the elephant. Each of the vector layers was converted into raster format and multiplied with the corresponding derived weight of all the factors. Subsequently, the derived raster layer values were regrouped to get the final habitat suitability area (map). A novel habitat suitability model was used to extract the suitable habitat area based on the weighted analysis method.

$$
\begin{aligned}
\text{Suitable habitat area (SHA)} = & \left[ \left( \text{Mr}_w \text{Mr}_{nr} \right) + \left( \text{St}_w \text{St}_{nr} \right) \right. \\
& + \left( \text{NDWI}_w \text{NDWI}_{nr} \right) \\
& + \left( \text{NDVI}_w \text{NDVI}_{nr} \right) + \left( \text{DEM}_w \text{DEM}_{nr} \right) \\
& \left. + \left( \text{El}_w \text{El}_{nr} \right) + \left( \text{Sl}_w \text{Sl}_{nr} \right) \right]
\end{aligned}
$$
(3)

where Mr is major roads, St is settlements, NDWI is the Normalized Difference Vegetation Index, NDVI is the Difference Water Index, DEM is the Digital Elevation Model, El is Elevation and Sl is the slope. The subscripts w and nr represent weights and normalized value, respectively, of individual habitat suitability factors.

## Results

A total of 567 spots were recorded throughout the study. Suggested priority ranking was computed with AHP based on the elephant distributional data, and six factors were found to be playing significant roles in the elephant distribution of the study area. Analyzing elephant distribution data revealed that vegetation status (32.50%), settlements (23.33%), elevation (17.20%) and water sources (12.70%) were the most influential parameters in distribution and selection of an area for foraging (Fig. 2a). Most of the elephant distribution records were in the area with dense forest cover, higher elevation, proximity to water sources and free from anthropogenic activities and developments. Among the all aforesaid parameters, vegetation status was found to be significantly influencing the distribution of the

elephants ($\chi^2 = 29.76$, $df = 5$, $p < 0.001$). Roads (8.70%) and slope (5.70%) were not major parameters in the distribution of the elephants in the Patharia Hills RF; however, these parameters collectively played an important role in the distribution of the elephants. The CR in AHP was 4.7%, which is much lesser than the reasonable levels of acceptance (Table 1). Multiple rasters and vector layers of each parameter are shown in Fig. 2b. Elephant distributed data reveal that most of the distributions (92.59%) were recorded within 57.06% area of the habitat, while only 7.41% of the distributions were recorded from 42.94% area of the total habitats (Fig. 3) indicating priorities on different parameters. Considering all the parameters, elephant habitat suitability within the trans-boundary forest was mapped (Fig. 4), which shows that 6.88% of the habitat areas was highly disturbed, 36.07% was somehow disturbed, 35.38% was moderately suitable and only 21.67% was most suitable for the Asiatic elephants.

## Discussion

The results of the study indicate the vegetation is the most influencing parameter in the distribution of elephants in the study area (Fig. 2a). Elephants were mostly restricted to the dense vegetation of the study area. This is coinciding with other studies (Areendran et al. 2011; Aini et al. 2015; de Beer and van Aarde 2008; Ngene et al. 2009; Alfred et al. 2001) as the elephants are safe in such type of area for getting food and free from disturbances. Once the habitats of the area were very good and large number of elephants survived (Talukdar and Choudhury 2017a, b; Talukdar et al. 2018), however, increased anthropogenic activities within the habitats resulted in increased fragmentation, forcing the elephants to travel outside the landscape. Shrinking of habitats forced them to come out of the dense forest. They forage in the areas with open forest and sometimes associated forest patches of the Bhubrighat Tea Estate (TE), Putni TE and Piplagool TE (Talukdar et al. 2019) adjoining with the human settlements. Unlike vegetation cover, settlements were found negatively correlated with elephant distribution in the study area. More distributional records were found from the areas away from the settlements and major roads, whereas fewer records were in the close proximity of the two parameters. Settlements affect the habitats in many ways such as creating minor and major roads and collecting non-timber forest products (NTFP) and increase LULC transformation (Wilkie et al. 2000; Lindenmayer and Fischer 2006; Talukdar et al. 2019).

Elephants were distributed more in the higher elevated areas rather than the lower elevated areas of the study areas. This might be due to the fact that the landscape does not vary too much in the area, and it was reported that elephants are capable of moving a wide range of elevation (Wheelock 1980; Sukumar 1989; Choudhury 1999). Coinciding with our findings, Rood et al. (2010) also found that elephants' optimal niche is related to areas of high vegetation and productivity. The higher elevation of the study areas is covered with dense vegetations which are free from disturbances, whereas vegetation at the lower elevated areas of the landscape is affected by disturbances. However, lower elevated areas were mostly found in using for their migration and in search of water.

Similar to the elevation, the availability of water plays a crucial role in the distribution of elephants. Water is important for habitat preferences (Areendran et al. 2011; Aini et al. 2015) and distribution of the elephants (de Beer and van Aarde 2008; NgeneNgene et al. 2009; Alfred et al. 2001; Claudia et al. 2012). Analyzing NDWI with elephant distribution data in the study area revealed significant correlation with the water sources. The southern parts of the area are covered with many water sources, and the preferences of the area for the elephants are more.

Roads in the habitats were not found to be creating too many obstacles for elephant distribution as vehicular roads in the area are at the peripheral or outside of the forest and associated with the settlements. Only International Border Road is the major vehicular road within the study area which is not creating disturbances as random people are not allowed to access the road. Close proximity to roads is the indicator of more disturbances, whereas habitats away from these factors implied fewer disturbances (Areendran et al. 2011; Aini et al. 2015). The slope was also found in creating disturbances to the elephant distribution although to a lesser extent due to lower elevated landscape. However, elevation combining with slope influences the distribution to a large extent and hence usually elephants do not use the northern part of the area. Besides, the extreme northern part of the RF is covered with settlements and monocultural activities creating unsuitable habitats.

Following the identified six significant factors and GIS image processing through weightage overlay methods, four potential habitat categories in the study area were identified (Fig. 4); areas with close proximity to the dense forest, elevated areas, areas with available water sources and areas free from disturbances were identified as most suitable habitats, whereas areas away from water, having less vegetation, having higher slope with elevation and in close proximity to settlement and roads were considered unsuitable. The scale of suitable categories was different from other studies (Govil 2011; Kushwaha and Roy 2002; Aini et al. 2015) as it is related to the distributional data, habitats conditions and LULC of an area.

Although most of the habitats were found to be moderate to highly suitable (57.06%), the ranges of somehow disturbed (36.07%) and highly disturbed (6.88%) habitats
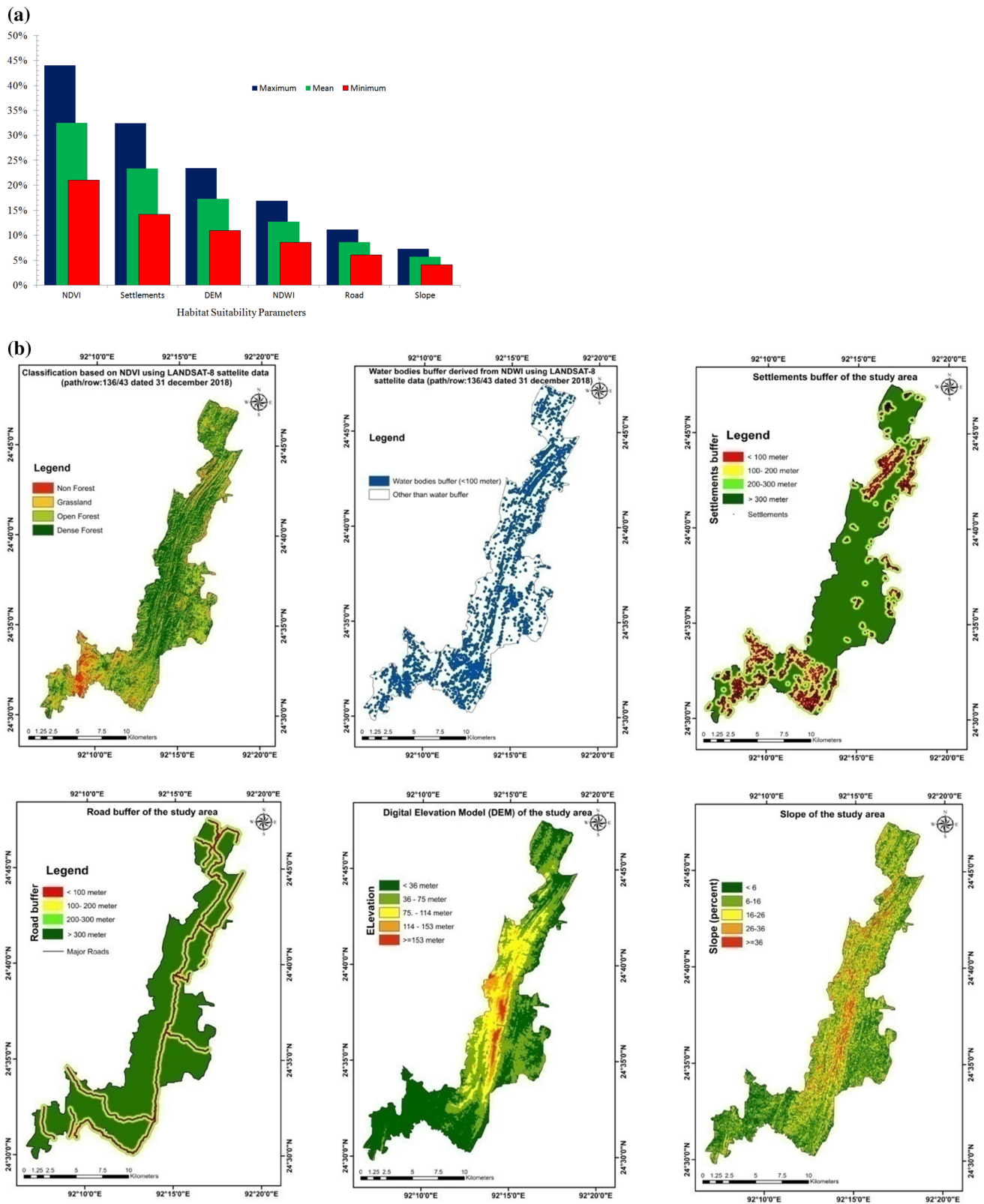
**(a)**



**(b)**



**Fig. 2** Six identified parameters for elephant habitat suitability. **a** Weightage of the identified parameters, **b** different categories of the parameters
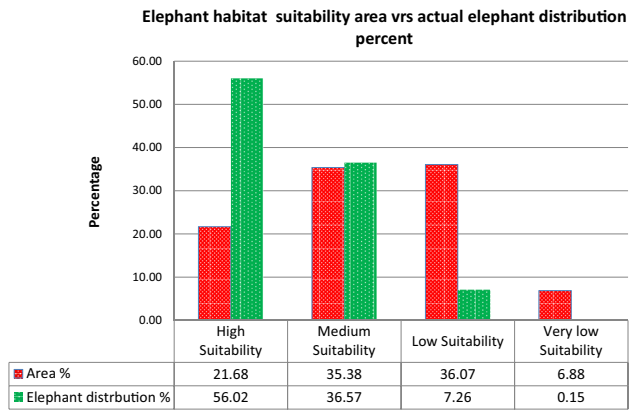
**Elephant habitat suitability area vrs actual elephant distribution percent**



| | High Suitability | Medium Suitability | Low Suitability | Very low Suitability |
|---|---|---|---|---|
| Area % | 21.68 | 35.38 | 36.07 | 6.88 |
| Elephant distrbution % | 56.02 | 36.57 | 7.26 | 0.15 |

**Fig. 3** Distribution of elephant in different categories of habitat suitability
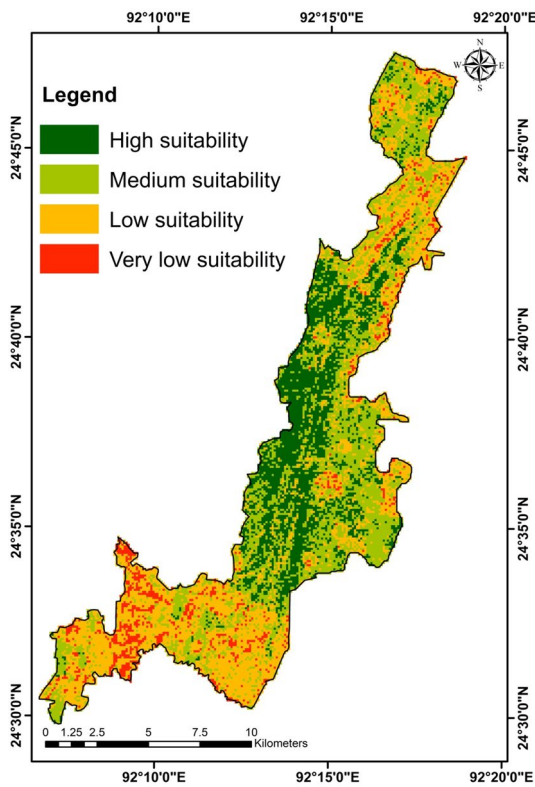


**Fig. 4** Habitat suitability map for the Asiatic elephant of Patharia Hills RF

were very high, indicating an urgent need for habitat restoration and protection. This is due to the fact new settlements have increased in the recent past and the present disturbed areas may turn into highly disturbed areas in the near future. This scenario is very bad for any wildlife,

especially large animals like elephants which require a large amount of diet to sustain, and this might be the reason for recent increasing HEC (Talukdar et al. 2019).

## Implication for conservation

Habitat suitability mapping for the conservation of particular species is very essential to identify suitable and disturbed habitats and therefore management. RS and GIS can help in such an approach as RS provides accurate time frame data to map and model with the GIS. In this study, habitat suitability model provides existing suitable elephant habitat as well as disturbed area which can be replicated in other areas as well. Since most of the endangered elephant populations are distributed outside the protected areas (Choudhury et al. 2008; MoEF 2017) where they are threatened by many anthropogenic activities and it is projected that climate change is going to rapidly decline the habitats of the Asiatic elephant (Kanagaraj et al. 2019), in that situation, such approach in the trans-boundary forest is crucial where their habitat management will increase the chances of survival of other wildlife as well. Important parameters such as vegetation status, water sources and settlements should be given high priority while planning management strategies. A large percentage of areas were found to be somehow disturbed and highly disturbed predicting more HEC in the upcoming days if the management activities would not be taken into consideration. Least and moderately suitable areas should be taken into consideration in afforestation programs to increase more suitable areas to reduce HEC. Besides, demarcating the lands is of the utmost importance to reduce encroachment and LULC transformation. Tea garden owners of Assam are encroaching into forest, impelling the habitat loss and fragmentation (BBC 2018), which may be reduced through demarcating the forest lands. In many areas, it was noted that the forest was not under governmental control and rubber plantation was carried out. Considering the importance of trans-boundary conservation, the study approached to identify and map suitable areas of the habitats falling under the jurisdiction of both India and Bangladesh that should be used in future policy-making in the study area for the long-term conservation of the Asiatic elephants.

## Compliance with ethical standards

**Conflict of interest** The authors have declared that no competing interests exist.

**Ethics statement** The study was reviewed and approved by the Institutional Ethical Committee, Assam University, Silchar (IEC/AUS/NAZIMUR/2018/06).

**Consent for publication** All the participants have their consent to publish the findings.

## References

Ahmad F, Goparaju L (2016) Geospatial Technology in Urban Forest suitability: analysis for Ranchi, Jharkhand, India. Ecol Quest 24:45–58

Ahmad F, Goparaju L, Qayum A (2017) Agroforestry suitability analysis based upon nutrient availability mapping: a GIS based suitability mapping. AIMS Agric Food 2:201–220

Ahmad F, Goparaju L, Qayum A (2018) Wild life habitat suitability and conservation hotspot mapping: remote sensing and GIS based decision support system. AIMS Geosci 4(1):66–87. https://doi.org/10.3934/geosci.2018.1.66

Aini S, Sood AM, Saaban S (2015) Analysing elephant habitat parameters using GIS, remote sensing and analytic hierarchy process in Peninsular Malaysia. Pertanika J Sci Technol 23(1):37–50

Alfred JRB, Kankane PL, Kumar A, Roy PS, Singh S, Verma M (2001) Habitat suitability analysis of chinkara, *Gazellabennetti* in Rajasthan: a remote sensing and GIS approach. Records of Zoological Survey of India, Occasional Paper No. 189, Zoological Survey of India, Kolkata

Areendran G, Raj Krishna, Mazumdar S, Munsi M, Govil H, Sen PK (2011) Geospatial modeling to assess elephant habitat suitability and corridors in northern Chhattisgarh, India. Trop Ecol 52(3):275–283

BBC (2018) The human-elephant conflict in India's tea state Assam. https://www.bbc.com/news/science-environment-42733022. Accessed 17 Jan 2020

Carrilho MAP (2015) The use of analytical hierarchy process in spatial decision support system for land use management. J Am Psychoanal Assoc 56:1342–1348

Champion HG, Seth SK (1968) A revised survey of forest types of India. Govt. of India Press, New Delhi

Choudhury A (1999) Status and conservation of the Asian elephant *Elephas maximus* in north-eastern India. Mammal Rev 29:141–171

Choudhury A (2004) Human–elephant conflicts in Northeast India. Hum Dimens Wildl 9:261–270

Choudhury A, LahiriChoudhury DK, Desai A, Duckworth JW, Easa PS, Johnsingh AJT, Fernando P, Hedges S, Gunawardena M, Kurt F, Karanth U, Lister A, Menon V, Riddle H, Rübel A, Wikramanayake E (2008) (IUCN SSC Asian Elephant Specialist Group). *Elephasmaximus*. *The IUCN Red List of Threatened Species* 2008: e.T7140A12828813. http://doi.org/10.2305/IUCN.UK.2008.RLTS.T7140A12828813.en. Downloaded 19 July 2019

Claudia P, Skidmorea AK, Hein AMJ, vanGils A, Herbert HT, Prins (2012) Identifying transit corridors for elephant using a long time-series. Int J Appl Earth Obs Geoinf 14:61–72

Cozza K, Fico R, Battistini L, Rogers E (1996) The damage- conservation interface illustrated by predation on domestic livestock in central Italy. Biol Conserv 78:329–337

Dash PP, Joshi PK, Roy PS et al (2015) Predictive habitat suitability modeling for prey and predator (Tiger) in Palamau Tiger Reserve, India. Int J Int Sci 6:2278–1145

de Beer Y, van Aarde RJ (2008) Do landscape heterogeneity and water distribution explain aspects of elephant home range in southern Africa's arid savannas? J Arid Environ 72:2017–2025

Desai AA, HS Riddle (2015) Human–elephant conflict in Asia. Supported by: U.S. Fish and Wildlife Service Asian Elephant Support

Easa PS (2002) Asian elephants in India: a review. In: Menon V, Tiwari SK, Easa PS, Sukumar R (eds) Right of passage: elephant corridors of India, Conservation Reference Series No. 3. Wildlife Trust of India, New Delhi, pp 14–22

Fahrig L (2003) Effects of habitat fragmentation on biodiversity. Annu Rev Ecol Evol Syst 34:487–515

FAO (2015) Sustainable wildlife management and human–wildlife conflict. CPW Factsheet no. 4

Fletcher RJ Jr, Didhamb RK, Banks-Leited C, Barlowe J, Ewersd RM, Rosindell J et al (2018) Is habitat fragmentation good for biodiversity? Biol Conserv 226:9–15

Gao BC (1996) (NDWI—a normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sens Environ 58:257–266

George N (2017) Human-wildlife conflict in India: 1 human killed every day. Phys.org. News and articles on science and technology. https://phys.org/news/2017-08-human-wildlife-conflict-india-human-day.html

Govil Sen PK (2011) Geospatial modeling to assess elephant habitat suitability and corridors in northern Chhattisgarh, India. Trop Ecol 52(3):275–283

Gunaryadi D, Sugiyo Hedges S (2017) Community-based human–elephant conflict mitigation: the value of an evidence-based approach in promoting the uptake of effective methods. PLoS ONE 12(5):e0173742. https://doi.org/10.1371/journal.pone.0173742

Haddad NM, Brudvig LA, Clobert J, Davies KF, Gonzalez A et al (2015) Habitat fragmentation and its lasting impact on Earth. Sci Adv 1:e1500052

Hedges S, Tyson M, Sitompul AF, Kinnaird MF, Gunaryadi D, Aslan (2005) Distribution, status and conservation needs of Asian elephant (*Elephasmaximus*) in Lampung Province, Sumatra, Indonesia. Biol Conserv 124:35–48

Hoare RE (1995) Determinants of human–elephant conflict in a land use mosaic. J Appl Ecol. https://doi.org/10.1046/j.1365-2664.1999.00437.x

Hoogesteijn R, Hoogesteijn A, Mondolfi E (1993) Jaguar predation versus conservation: cattle mortality by felines on three ranches in Venezuelan Llanos. In: Dunstone H, Gorman ML (eds) Mammals as predators. Symposia of the Zoological Society of London, Number 65. Clarendon Press, London, pp 391–406

IUCN (2004) Bangladesh, action research for conservation of Asian elephants in Bangladesh. The World Conservation Union, IUCN

IUCN SSC Asian Elephant Specialist Group, Rübel A, Wikramanayake E (2008). *Elephasmaximus*. In IUCN 2012. IUCN Red List of Threatened Species. Version 2012.1

Kanagaraj R, Araújo MB, Barman R, Davidar P, Dea R, Digal DK et al (2019) Predicting range shifts of Asian elephants under global change. Divers Distrib. https://doi.org/10.1111/ddi.12898

Kushwaha SPS, Hazarika R (2004) Assessment of habitat loss in Kameng and Sonitpur Elephant Reserves. Curr Sci 87:1447–1453

Kushwaha SPS, Roy PS (2002) Geospatial technology for wildlife habitat evaluation. Trop Ecol 43(1):137–150

Kushwaha SPS, Munkhtuya S, Roy PS (2001) Mountain goat habitat evaluation in Rajaji National Park using remote sensing and GIS. J Indian Soc Remote Sens 28:293–303

Lee WB, Lau H, Liu Z, Tam S (2001) A fuzzy analytical hierarchy process approach in modular product design. Expert Syst 18:32–42

Leimgruber P, Gagnon JB, Wemmer C, Kelly DS, Songer MA, Selig ER (2003) Fragmentation of Asia's remaining wild lands: implications for Asian elephant conservation. Anim Conserv 6:347–359

Lenin J, Sukumar R (2011) Action plan for the mitigation of elephant–human conflict in India. Final Report to the U.S. Fish and Wildlife Service, Asian Nature Conservation Foundation, Bangalore, India

Lindenmayer DB, Fischer J (2006) Habitat fragmentation and landscape change: an ecological and conservation synthesis. Island Press, Washington

Malczewski J (1999) GIS and multicriteria decision analysis. Wiley, New York, pp 177–192

Matleb MA, Ahmed MS, Islam H, Haque MA (2016) Atlas: elephants rotes and corridor in Bangladesh. IUCN: Internation Union of Conservation of Nature, Bangladesh, Country office, Dhaka, Bangladesh

MoEF (2017) Elephant census of India

Muzaffar SB, Islam MA, Feeroz MM, Kabir M, Sajeda Begum S, Mahmud MS, Chakma S, Hasan MK (2007) Habitat characteristics of the endangered Hoolock Gibbons of Bangladesh: the role of plant species richness. Biotropica 39(4):539–545

Nath NK, Lahkar BP, Brahma N, Dey S, Das JP, Sarma PK, Talukdar BK (2009) An assessment of human-elephant conflict in Manas National Park, Assam. India. J Threat Taxa 1(6):309–316

Nath NK, Dutta SK, Das JP, Lahkar BP (2013) Human-elephant interaction in villages around Manas National Park, Assam, India. Gajah 39:12–18

Naughton-Treves L, Treves A, Chapman CA, Wrangham RW (1998) Temporal patterns of crop raiding by primates: linking food availability in croplands and adjacent forest. J Appl Ecol 35:596–606

NgeneNgene SM, Skidmore AK, Gils HV, Douglas-Hamilton I, Omondi P (2009) Elephant distribution around a volcanic shield dominated by a mosaic of forest and savanna (Marsabit, Kenya). Afr J Ecol 47:234–245

O'Neil TA, Bettinger P, Marcot BG, Luscomb BW, Koeln GT, Bruner HJ, Barrett C, Pollock JA, Bernatas S (2005) Application of spatial technologies in wildlife biology. The Wildlife Society, Bethesda, pp 418–447

O'Neill RV (1996) Recent development in ecological theory: hierarchy and scale. Gap analysis—a landscape approach to biodiversity planning. American Society for Photogrammetry and Remote Sensing, Bethesda

O'Connell-Rodwell CE, Rodwell T, Rice M, Hart LA (2000) Living with the modern conservation paradigm: can agricultural communities co-exist with elephants? A five-year case study in East Caprivi, Namibia. Biol Conserv 93:381–391

Parihar JS, Panigrahy S (1986) Remote sensing based habitat assessment of Kaziranga National Park. In: Kamat DS, Panwar HS (eds) Wildlife habitat evaluation using remote sensing techniques. Indian Institute of Remote Sensing/Wildlife Institute of India, Dehra Dun, pp 157–164

Parker GE, Osborn FV, Hoarse RE (2007) Human–elephant conflict mitigation: training course for community-based approaches in Africa (Participant's Manual). Elephant Pepper Development Trust, Livingstone, Zambia, and IUCN/SSC African Elephant Specialist Group, Nairobi

Porwal MC, Roy PS, Chellamuthu V (1996) Wildlife habitat analysis for sambar (Cervus unicolor) in Kanha National Park using remote sensing. Int J Remote Sens 17:2683–2697

Qureshi ME, Harrison SR (2003) Application of the analytical hierarchy process to riparian revegetation policy options. Small-scale For Econ Manag Policy 2(3):441–458

Rahman S, Rahman SM, Motaleb MA, Sobhan I, Khan NA (2012) Geo-spatial techniques and route and corridor mapping of Asian elephants: a participatory initiative for consservation. In: Bangladesh forestry congress conference

Rood E, Ganie AA, Nijiman V (2010) Using presence only modelling to predict Asian elephant habitat use in a tropical forest landscape: implications for conservation. Divers Distrib 16:975–984

Saaty TL (1980) The analytic hierarchy process. McGraw-Hill International Book Co., New York

Sanare JE, Ganawa ES, Abdelrahim AMS (2015) Wildlife habitat suitability analysis at Serengeti National Park (SNP), Tanzania Case Study *Loxodonta* sp. J Ecosyst Ecogr 5:164

Sarkar A, Ghosh A, Banik P (2014) Multi-criteria land evaluation for suitability analysis of wheat: a case study of a watershed in eastern plateau region, India. Geospat Inf Sci 17:119–128

Shaffer LJ, Khadka KK, Van Den Hoek J, Naithani KJ (2019) Human–elephant conflict: a review of current management strategies and future directions. Front Ecol Evol 6:235. https://doi.org/10.3389/fevo.2018.00235

Singh AK, Singh RR, Chowdhury S (2002) Human–elephant conflicts in changed landscapes of south west Bengal, India. Indian For 128(10):1119–1132

Sukumar R (1989) The Asian elephant: ecology and management. Cambridge studies in applied ecology and resource management. Cambridge University Press, Cambridge

Sukumar R (1991) The management of large mammals in relation to male strategies and conflict with people. Biol Conserv 55:93–102

Sukumar R (1994) Wildlife-human conflict in India: an ecological and social perspective. In: Guha R (ed) Social ecology. Oxford University Press, New Delhi, pp 303–317

Talukdar NR, Choudhury P (2017a) Conservation status of Asiatic elephant in southern Assam, India. Gajah 47:18–23

Talukdar NR, Choudhury P (2017b) Conserving wildlife wealth of Patharia Hills reserve Forest, Assam, India: a critical analysis. Glob Ecol Conserv 10:126–138. https://doi.org/10.1016/j.gecco.2017.02.002

Talukdar NR, Singh B, Choudhury P (2018) Conservation status of some endangered mammals in Barak Valley, Northeast India. J Asia Pac C Biodivers 11:167–172. https://doi.org/10.1016/j.japb.2018.01.011

Talukdar NR, Choudhury P, Barbhuiya RA (2019) Migration pattern of the Asiatic elephant along international border in Patharia Hills reserve forest. JoTT, Assam. https://doi.org/10.11609/jott.4245.11.1.13168-13170

TOI (2015) India–Bangladesh join hands to protect spectacled langur. http://timesofindia.indiatimes.com/articleshow/47043057.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst

UN (2017) World population prospects: the 2017 revision, key findings and advance tables. Working Paper No. ESA/P/WP/248. United Nations, Department of Economic and Social Affairs, Population Division

UN (2019) World Population Prospects 2019. EMBARGOED until Monday, 17 June 2019, 12 noon EDT. https://population.un.org/wpp/Publications/

Wahed MA, Ullah MR, Irfanullah HMd (2016) Human–elephant conflict mitigation measures: lessons from Bangladesh. IUCN, International Union for Conservation of Nature, Bangladesh Country Office, Dhaka

Wheelock ND (1980) Environmental sodium as a factor in the behavior and distribution of African elephants. Elephant 1(4):169–177. https://doi.org/10.22237/elephant/1521731760

Wilkie D, Shaw E, Rotberg F et al (2000) Roads, development, and conservation in the Congo Basin. Conserv Biol 14:1614–1622

Worldometers (2019). https://www.worldometers.info/world-population/

Yamada K, Elith J, Mccarthy M et al (2003) Eliciting and integrating expert knowledge for wildlife habitat modelling. Ecol Model 165:251–264

Zhixi L, Hongga L, Feng L (1995) Evaluation of Asian elephant habitat. GIS Development ASPRS/ACSM, Baltimore

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