



# Geospatial based AHP analysis for habitat suitability of elephants and the effects of human elephant conflict in a tropical forest of Western Ghats in India

P. Vineetha<sup>1</sup> · S. Sarun<sup>2</sup> · S. Selvakumar<sup>3</sup> · Reghunath Rajesh<sup>1</sup>

Received: 29 March 2024 / Revised: 8 May 2024 / Accepted: 8 July 2024 / Published online: 23 July 2024  
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2024

## Abstract

In Kerala, human-elephant conflicts (HEC) are reported in almost all parts of the Western Ghats region, exceptionally high in Wayanad. In recent years, there has been a notable surge in HEC occurrences throughout the state, leading to the loss of property, animals, and life. The dependency of humans on enclosures, the transformation of natural areas into plantations, and the fragmentation of natural ecosystems are the main reasons for the escalating conflict between people and elephants. As a result, it is necessary to study the suitability of habitat for elephants and ensure their conservation. The study aims to identify suitable elephant habitats in the Wayanad Wildlife Sanctuary using geospatial data based on their known association with environmental variables. This study employs the Analytic Hierarchy Process (AHP), an approach to determining the weightings of individual parameters in assessing habitat suitability. The analysis findings indicated that the central portion of the study area within the Sultan Bathery (43.63 sq. km), range represents the most suitable area for elephant habitat followed by Kurichat (33.59 sq. km) and Tholpetti (19.45 sq. km). The final output of the study, the Habitat Suitability Map was validated by adding the human-elephant conflict locational data, which illustrates that the Kurichat range recorded the highest HEC conflict (50%), followed by Muthanga (29%), Sulthan Bathery (12%), and Tholpetti (9%). The map could assist in managing, conserving, and protecting forest resources and aid in decision-making activities.

**Keywords** AHP techniques · Wayanad · Habitat suitability · GIS · Land use changes · NDVI

## Introduction

Habitat is a term that refers to a specific species and possibly even a specific plant or animal population (Morrison, 2006). Wildlife habitat is a space combined with resources like food and water and environmental factors like temperature, precipitation, and the presence or absence of predators and rivals dispersed horizontally and vertically across the landscape. They are areas with uniform vegetation cover inhabited by specific plant communities and grouped according to some dominant species. The wildlife habitat pattern is dominated by physical and cultural influences. Due to the unprecedented pressure of anthropocentric economic development, wildlife habitats worldwide are becoming narrower in both time and space. As part of this, wildlife habitats are continuously transforming into agriculture, monoculture, settlements, and many developmental activities (Talukdar et al. 2020). A growing human population is imposing more pressure on the fragmented natural wildlife habitats,

---

✉ P. Vineetha  
vineetha@keralauniversity.ac.in  
S. Sarun  
sarun@ssus.ac.in  
S. Selvakumar  
geoselvas@gmail.com  
Reghunath Rajesh  
rajeshgeologist@gmail.com

<sup>1</sup> Inter University Centre for Geospatial Information Science and Technology, University of Kerala, Thiruvananthapuram, Kerala, India

<sup>2</sup> Centre for Disaster Studies, SreeSankaracharya University of Sanskrit, Kalady, Ernakulam, Kerala, India

<sup>3</sup> Department of Environmental Sciences, University of Kerala, Thiruvananthapuram, Kerala, India

disintegrating or being converted to other land uses. As a result, numerous species have undergone significant population declines, eventual extinction from specific locations, and even extinction. Moreover, the species that depend on those habitats are inevitably threatened. According to a significant report by the conservation organization WWF, wildlife numbers have decreased by more than two-thirds in less than 50 years on a global scale.

Asian elephants (*Elephas maximus*) are the continent's largest terrestrial mammals. They were once widely dispersed across the Indian subcontinent but are now listed as the world's most seriously endangered species of large mammals on the IUCN red list (Natalie Diemer, 2003). In thirteen range countries covering South and Southeast Asia; they live in dry to wet forest and grassland landscapes. A rapid fall in wild populations and severe habitat fragmentation threaten the Asian Elephant, which was previously common in tropical south and south-east Asia (Choudhury 1999). With the growing human population and their desire for a higher quality of life, the elephant is threatened by habitat loss and fragmentation (Pearson et al. 1996). Moreover, they are exposed to habitat loss and fragmentation due to the increased human population, and these elephant habitats are being cleared for human settlement, agriculture and logging. As a result, elephants, in search of food and water, tend to enter human habitations and, in the process, often come into direct conflicts with humans by destroying crops, livestock, or property and sometimes by even killing people (Areendran et al. 2011; Kushwaha and Hazarika 2004; Sukumar 1994). The elephants in Asia have lost so much of the former habitat that they are often forced to invade the displaced communities, leading to increased conflicts with men (Natalie Diemer, 2003, Santiapillai, 2010). The greatest dangers to the elephant's survival are changes in its habitat and a decline in its suitable habitat, both of which are brought on by increased human activity (Sharma et al. 2020; Zhang and Wang 2003).

According to the Project Elephant (2017), the estimated population of wild Asian elephants in India is 29,964. The figures are lower than those from the 2012 census estimate. According to the 2017 elephant census, Karnataka, Assam, and Kerala are the states with the most elephants. In Kerala the elephant population shows a decreasing trend from 6177 to 5706 from 2012 to 2017 (MoEFCC 2017). The Western Ghats are famous for their incredible list of larger mammals, which includes 25% of the Asian elephant worldwide population. (Baskaran 2013). Most of the elephant ranges in the southern Western Ghats regions are mountainous areas with tropical wet evergreen, semi-evergreen, moist deciduous, dry deciduous and dry thorn forests in addition to high altitude Shola grasslands and plantations. Due to a rise in human population and the resulting clearing of

forest land for the establishment of industries, hydroelectric projects, irrigation dams, and mining, the elephant population and distribution reduced to isolated habitats inside the Ghats throughout the 20th century (Baskaran 2013). Asian elephants can adapt to various environments, ranging from dense forests and grassy plains, and often concentrate where there are perennial water supplies and vegetation (Prasad et al. 2011). But the increased forest degradation and fragmentation of the natural elephant habitat due to human encroachment results in the worst problem, the "Human Elephant conflict" (HEC) which is the major issue in India's wildlife management field (KFRI 2002). In Kerala, the HEC is reported in almost all districts and was particularly high in Wayanad, Palakkad and Kannur (Sengupta, 2020). The dependency of humans on enclosures and fringes has caused fragmentation and depredation, which has increased the frequency of human-wildlife conflicts. Moreover, vast areas of natural forests have been transformed into teak, rubber, and other monoculture plantations for economic purposes, fragmenting natural ecosystems and escalating conflict between people and elephants. The increased Human-Elephant Conflict (HEC) has recently been the area's primary social and environmental problem. Little study has been done on the area's habitat analysis and human-elephant conflict. In this context, it is necessary to evaluate how well the habitat suits the elephant species. Habitat suitability analysis is an approach for determining whether a place will be suitable for a specific species or group of species based on their known interaction with environmental variables (Rowden, 2017). An analysis of habitat suitability is performed by evaluating the attributes of the habitat to determine the habitat's suitability for a particular species. GIS and Remote Sensing techniques have been widely used to determine the habitat of a particular species (Mandal et al., 2021; Huiyi et al. 2021; Bukombe et al. 2022). Analytic Hierarchy Process (AHP) is a decision-making tool that can be used to assess the suitability of a habitat for a particular organism or group of organisms. AHP allows for the prioritization of multiple criteria and the determination of their relative importance in a systematic and consistent manner. By utilizing these tools, complicated linkages between factors can be evaluated, as well as ecosystem management (O'Neill 1996). With the application of geospatial analysis, the present study aims to identify suitable habitat for elephants in the Wayanad Wildlife Sanctuary.

## Description of the study area

Wayanad Wildlife Sanctuary, established in 1973, formed an integral part of India's first biosphere reserve, the Nilgiri Biosphere Reserve (NBR). Nilgiri Biosphere Reserve

was the first from India to be included in the UNESCO-designated World Network of Biosphere Reserves (designated in 2012). It is a contiguous protected area connected to Nagarhole and Bandipur of Karnataka in the northeast and Mudumalai in Tamil Nadu in the southeast (Fig. 1). Administratively, the forest ranges in the Wayanad Wildlife Sanctuary are divided into Sulthan Bathery, Muthanga, Kurichiad, and Tholpetty (Deepu et al., 2019), with an undulating terrain and the altitude ranges from 650 to 1158 m. The Wayanad Wildlife Sanctuary is abundant in both diversity and richness of animals. Almost all of Peninsular India's big animals have been seen in the area, and the elephants (*Elephas maximus*) are prominent species in the region. Wayanad Elephant Reserve has the greatest elephant density (0.57 per km) in the state, followed by Anamudi, Periyar and Nilambur Elephant Reserve according to the results of the 2010 wild elephant census (KFRI 2012). The sanctuary is comprised of moist and dry deciduous forests, interspersed with plantations, agricultural areas, and settlements (Fig. 2). The Protected Area is rich in diversity of flora and fauna with many endangered, threatened, and rare species. Wayanad District, as such, is distinct with a preponderance of tribes and has a high density of human settlements within the Protected Area. As a result, the forest area is in the stage of deterioration, resulting in deforestation, wildfires, and the spread of invasive plant species, leading to habitat fragmentation. The amount and pace of forest conversion to other types of land use during 1950–1982 have accelerated the man-wildlife conflict and forest degradation in Wayanad Wildlife Sanctuary (KFRI 2001). Elephants are an umbrella species protected in the sanctuary; thus, their habitat suitability was analysed to determine the suitable

habitats inside the sanctuary based on their known association with environmental variables.

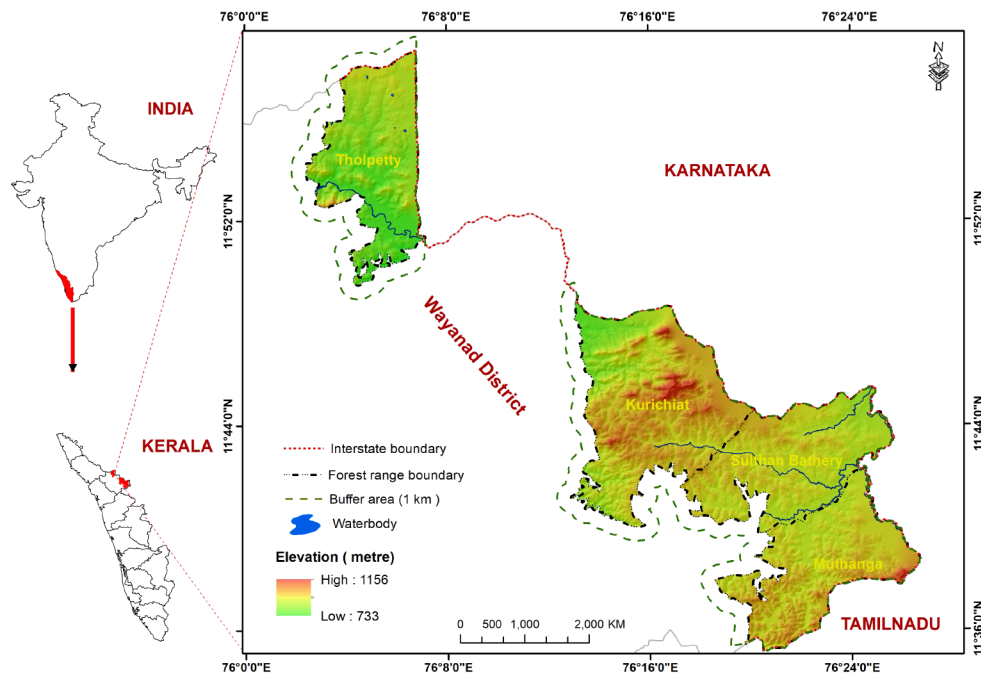
## Materials and methods

The movement and distribution of an elephant's home range are influenced by a variety of parameters, including physical and anthropogenic, biotic and abiotic, and variables related to spatial or geographical information (Suhaida, 2015). Identifying these parameters based on the examination of prior research and knowledge is the first stage in evaluating the habitat suitability analysis. The suitability of the habitat for elephants in Wayanad Wildlife Sanctuary was investigated through the establishment of parameters, which were based on primary and secondary data. The distribution of the elephant data was evaluated in a GIS environment using seven habitat parameters: land use, Normalized Difference Vegetation Index (NDVI), distance from water bodies, distance from roads, slope, and elevation. Each habitat factor was identified and analyzed in the raster format in Arc. GIS software. Each factor is divided into sub-parameters to analyze the elephant habitat interaction (Fig. 3).

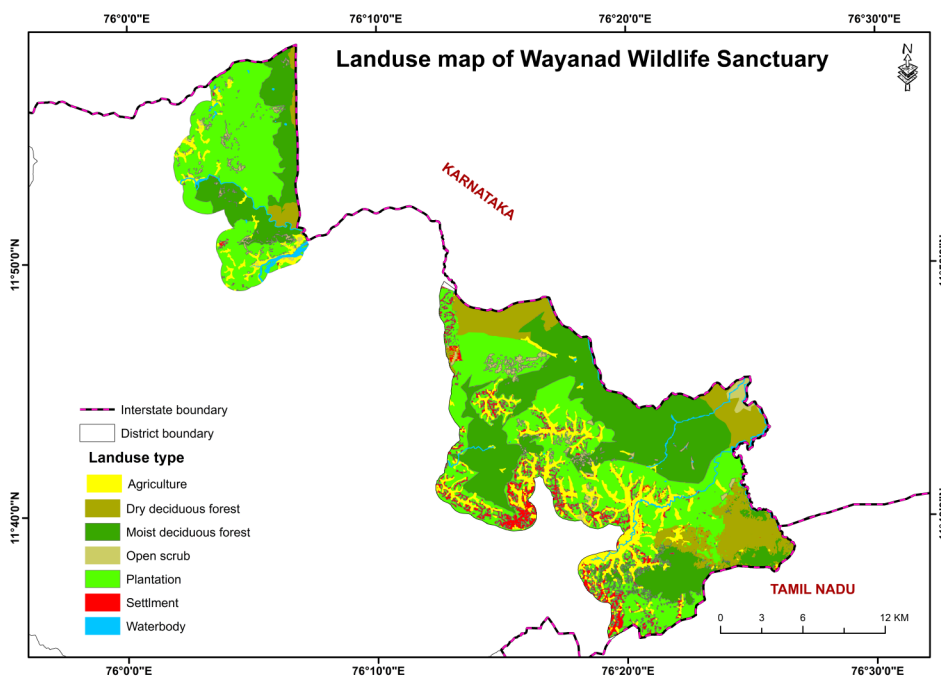
## Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is an effective method for dealing with setting priorities in decision-making that has the benefit of verifying the consistency of the expert's assessment. The ranking is done about an overall aim and broken down into criteria using a nine-point scale of measures, 1 = equal significance, 3 = moderate importance,

**Fig. 1** Location map of the study area



**Fig. 2** Land use and Land cover map of the study area



5=strong importance, 7=very strong importance, and 9=extreme importance (Mandal 2021). The pair wise relative assessments of the parameters without inconsistent decision-making make the methodology more accurate for habitat susceptibility mapping. For efficient conservation planning and habitat suitability evaluation methods, it is critical to identify the parameters that affect the spatial distribution of elephants. Pair wise comparison scores are standardized to create the standardized comparison matrix for mapping elephant habitat suitability (Table 1). The pair-wise comparison matrix shows the relative importance of different factors that affect habitat suitability for elephants.

$$A = (a_{ij}) = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \quad a_{ii} = 1, a_{ji} = \frac{1}{a_{ij}}, a_{ij} \neq 0 \quad (1)$$

The assumption of the set of criteria is  $C = \{C_j \mid j=1, 2, \dots, n\}$ . The output of the pairwise comparison is summarized to an  $(n \times n)$  evaluation matrix  $A$  in which every element  $a_{ij}$  ( $i, j=1, 2, \dots, n$ ) is the quotient of weights of the criteria(1). Following that, the weights are calculated using the arithmetic mean form, which is expressed as (2)

$$Aw = \lambda maxw \quad (2)$$

The consistency ratio (CR) was determined using the following Eq.

$$CR = \frac{CI}{RI} \quad (3)$$

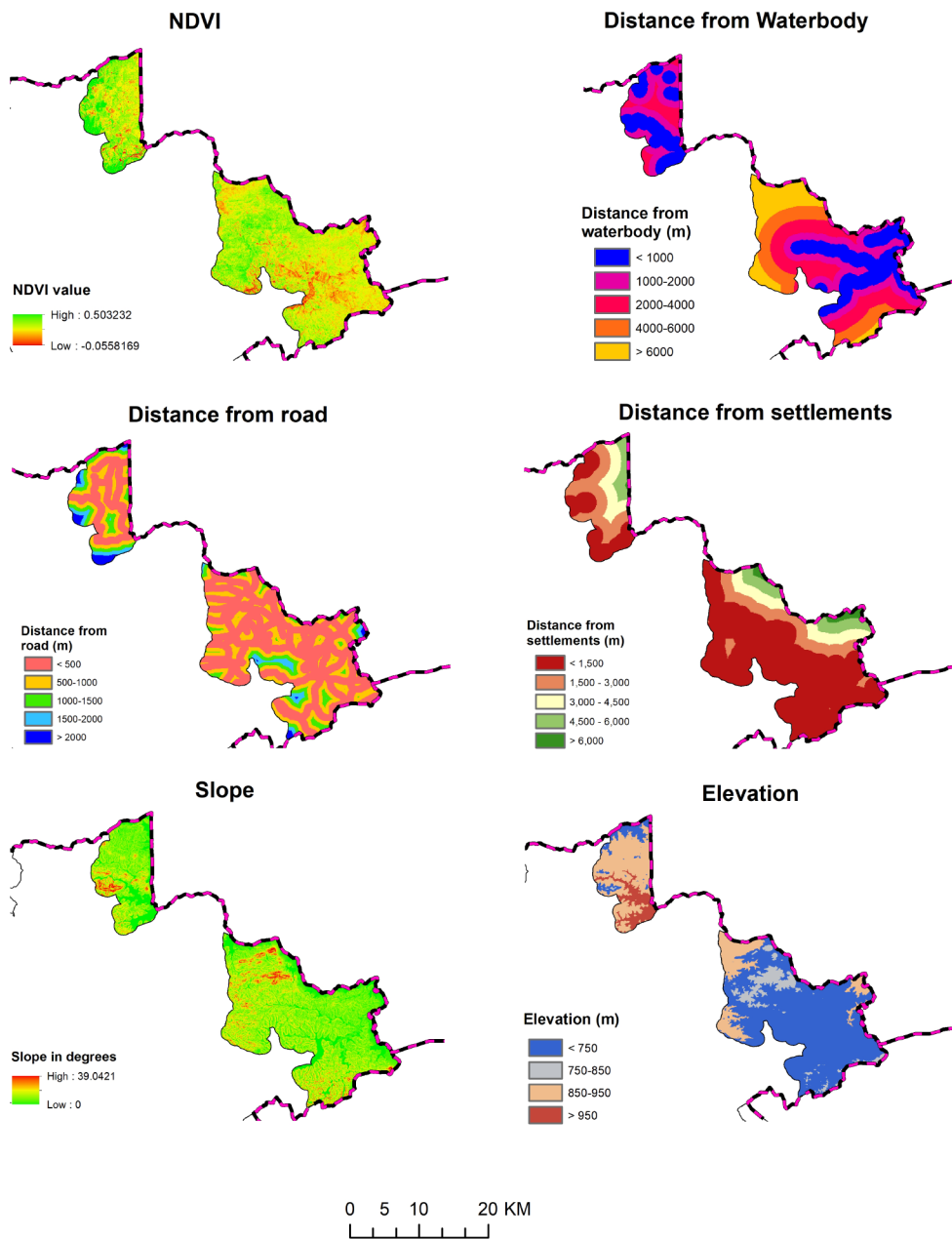
$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

The  $CR$  represents consistency ratio (0.055951),  $CI$  denotes consistency index (4) of,  $\lambda_{max}$  is the main matrix eigen value (0.07),  $RI$  for random index (1.32) and  $n$  stands for the number of matrix criteria. Each parameter was evaluated independently and divided into many subcategories for the habitat suitability analysis. Several suitability criteria were offered to each subgroup according to relative priority using the analytical hierarchy process (Table 2). Finally, using the method based on the weighted linear sum, the individual parameters are combined with their acquisitive weights to create a single habitat suitability map (Fig. 4).

### The habitat suitability index map

The habitat suitability Index Map was generated by calculating and evaluating the statistical significance and preference weights of the chosen parameters acquired from the AHP analysis. The derived weightages are combined to produce the habitat suitability Index map, categorized into four zones: very low suitable, low suitable, medium suitable and very high suitable (Table 3). According to the habitat suitability analysis, out of the 454.22 sq. km area, 107.27 sq. km is highly suitable for elephant habitat. About 112.71 sq. km are classified as highly suitable, whereas 167.15 and 67.07 are classified as low and very low suitability, respectively.

**Fig. 3** Identified parameters for Elephant Habitat Suitability



**Table 1** Pairwise comparison matrix for calculating parameter weight in AHP

0.00	LULC	NDVI	DW	DR	DS	SLOPE	ELEVATION
LULC	1.00	2.00	4	5	6	7	8
NDVI	1/2	1.00	3	4	5	6	8
DW	1/4	1/3	1.00	2	3	4	6
DR	1/5	1/4	1/2	1.00	2	3	5
DS	1/6	1/5	1/3	1/2	1.00	2	3
SLOPE	1/7	1/6	1/4	1/3	1/2	1.00	2
ELEVATION	1/8	1/8	1/6	1/5	1/3	1/2	1.00



**Table 2** Parameters sub-criteria classes and its significant weight generated from AHP calculation

Causal factors	Sub-factors	Weights	CR
LANDUSE	MD Forest	0.35	0.03
	DD Forest	0.24	
	Waterbody	0.16	
	Plantation	0.11	
	Open scrub	0.07	
	Agriculture	0.05	
	Settlement	0.03	
NDVI	> 0.7	0.45	0.08
	0.60–0.70	0.31	
	0.50–0.60	0.14	
	0.40–0.50	0.06	
	< 0.5	0.04	
DISTANCE FROM WATER	< 1000	0.42	0.04
	1000–2000	0.30	
	2000–4000	0.15	
	4000–6000	0.07	
	> 6000	0.04	
DISTANCE FROM ROAD	> 2000	0.42	0.03
	1500–2000	0.23	
	1000–1500	0.17	
	500–1000	0.11	
	< 500	0.07	
DISTANCE FROM SETTLEMENT	> 6000	0.46	0.03
	4500–6000	0.26	
	3000–4500	0.15	
	1500–3000	0.08	
	< 1500	0.05	
SLOPE	< 5	0.37	0.01
	5–10	0.24	
	10–15	0.17	
	15–25	0.12	
	25–35	0.06	
	> 35	0.03	
ELEVATION	< 750	0.50	0.02
	750–850	0.26	
	850–950	0.16	
	> 950	0.08	

The study revealed that the northern and central portions of the study region had the highest habitat suitability with less anthropogenic disturbance. The largest area for suitable habitat was found in the Sultan Bathery range followed by Kurichat and Tholpetti (Table 4). The very high suitable area covers the central part of the study area in the Sultan Bathery range and comprises moist deciduous forest with a moderate slope and elevation. Medium suitable areas include the Kurichat and Tholpetti range. The Muthanga range in the southern part exhibits the smallest area of for suitable habitat. The elephant habitat in this area is highly fragmented, appearing as tiny, isolated patches, and the connection between habitat patches is minimal in this location.

## Validation of the habitat suitability map

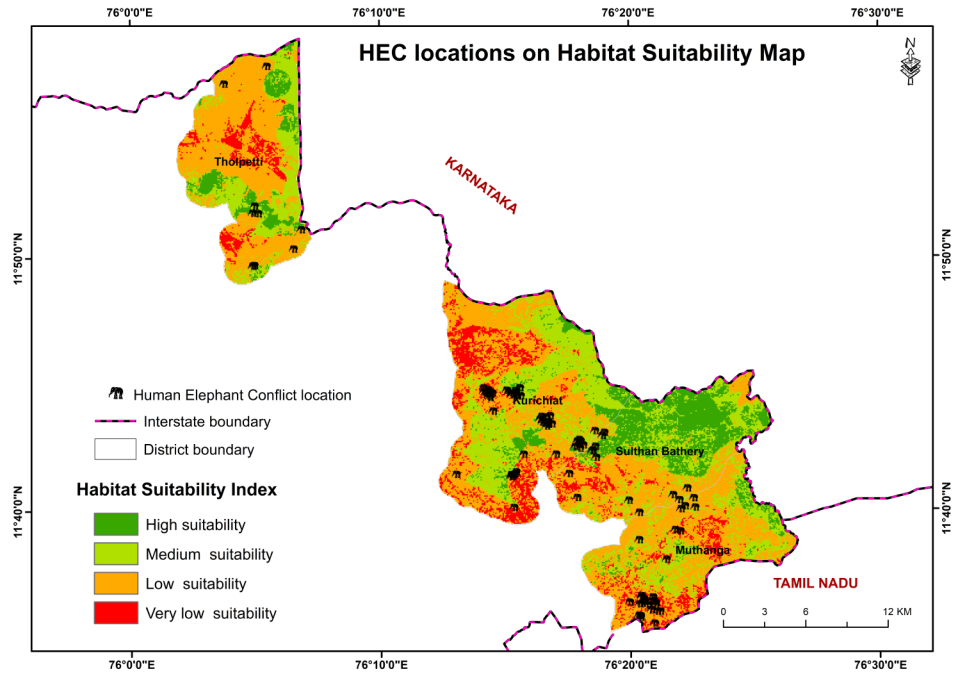
The habitat suitability map was validated by adding the human-elephant conflict location data (Fig. 5). It was generated from the records of the forest department, Wayanad compensation records, field visits, and a questionnaire survey. Incorporating the HEC locations into the habitat suitability map allows for the identification of human-elephant hotspots. The validation illustrates that the Kurichat range recorded the highest HEC conflict (50%), followed by Muthanga (29%), Sulthan Bathery (12%), and Tholpetti (9%). The majority of the conflict sites, according to the data analysis, were agricultural fields close to the settlement and none of the HEC points fell in the predicted suitable habitat zones, proving the higher accuracy of the Habitat Suitability Map. The map could assist in the decision support system for forest managers and aid them in their decision-making activities, better managing, conserving, and protecting valuable species of fauna.

## Results and discussion

The movement and distribution of an elephant's home range are influenced by a variety of parameters, including physical and anthropogenic, biotic and abiotic, and variables related to spatial or geographical information (Suhaida 2015). Identifying these parameters based on the examination of prior research and knowledge is the first stage in evaluating the habitat suitability analysis. The spatial pattern of elephant data was evaluated on the GIS platform using the recognized habitat parameters, including land use, NDVI, distance to the road, distance to the water body, and distance to the settlement, slope, and elevation. Each habitat factor was identified, and each factor was divided into sub-parameters to analyze the elephant habitat interaction.

Land use and land cover features create a heterogeneous habitat pattern, which also greatly influences habitat selection and ecosystem function (Mandal 2021). The land use and NDVI were generated from the Landsat 8 OLI satellite imagery obtained from the USGS Earth Explorer data portal. The land use types of Wayanad wildlife sanctuary are divided into dry and moist deciduous forest, plantations, open scrub, agriculture, settlements, and water bodies. The forest is the best example of a deciduous forest, and teak plantations dominate the region. The prominence of bamboo breaks, along with the dryness, is one of the area's most notable characteristics. Elephants frequently favour areas with grass growth and other fodder (KFRI 1994). The land use map indicates the majority of the region is occupied by agricultural land, mainly close to water resources. The agricultural

**Fig. 4** Elephant Habitat Suitability Map



**Table 3** Suitable habitat zones

Class	Area (sq. km)	% of suitable habitat zones
Very low suitability	67.07	14.76
Low suitability	167.15	36.80
Medium suitability	112.71	24.81
Very high suitability	107.27	23.61

**Table 4** Area of suitable habitat ranges in wayanad wildlife sanctuary

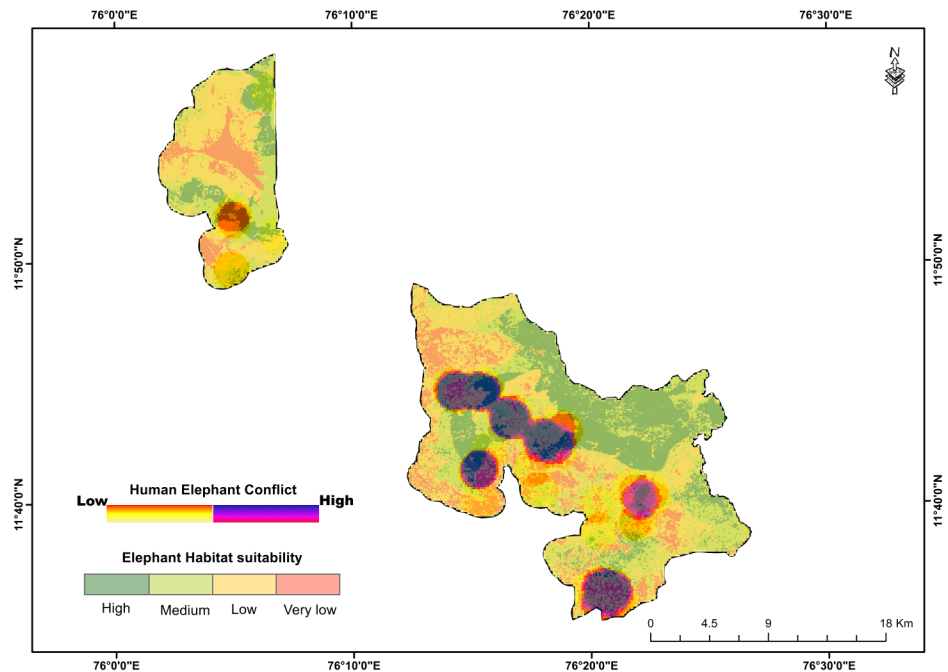
Range	Area of (sq. km) suitable habitat ranges			
	Very high suitability	Medium suitability	Low suitability	Very low suitability
Muthanga	10.49	30.65	39.20	13.76
SulthanBathery	43.63	21.11	23.00	9.68
Kurichat	33.59	35.49	56.62	26.36
Tholpetti	19.45	25.31	48.22	17.20

crops in the region include plantains, arecanuts, paddy, coffee, elephant yam, colocasia, purple yam, etc. These areas experience crop raiding and frequent human-elephant conflicts. NDVI determines the vegetative cover in the area and differentiates between forest and non-forested areas. The NDVI value shows that the central and northern portions have abundant, healthy vegetation, which is the elephants’ natural home. The low NDVI in the southern portion indicates the loss of green cover and forest degradation due to human interference. Elephants prefer the areas with the greatest NDVI value and high vegetative growth.

One factor determining habitat choice is proximity to a water source (Ngene et al. 2009; Alfred et al. 2001). The availability of water may be significantly influenced by

the distribution of elephants. They prefer perennial water bodies and avoid those with temporary human dwellings (Pastorini, 2010). A raster buffer distance from the water body of 1000–6000 m was created. The buffer distance from water bodies was analyzed, and a significant correlation was revealed with the water sources. Elephants in the region get their drinking water from streams and rivers, while habitat suitability decreases with distance from the water source. The Kabini River, Noolpuzha, Manjarthodu, and Bavelipuzha drain the region. The elephants always prefer areas close to water bodies; hence, it is ideal for their habitat. The water bodies mainly drain the central and southern portions of the study area; hence, the preferences for ideal habitat will be high in this area. It is crucial to consider human disturbances when evaluating habitat suitability since human activities are becoming more and more vital for the survival of wild animals. The settlement data was acquired from classified satellite imagery. A total of 107 settlements are distributed within the 57 enclosures inside the Wayanad Wildlife Sanctuary. These settlements are inside the sanctuary, near the agricultural land and water bodies. Most of the settlements in the area were identified along the southern part of the sanctuary. A raster buffer distance from settlements of 1500–6000 m was generated. When the anthropogenic activity inside the habitats expanded, the habitats became more fragmented, causing the elephants to move outside the area (Ngene et al. 2009; Alfred et al. 2001). They were forced to abandon the dense forest and move to nearer settlements due to habitat loss. Moreover, the effective

Fig. 5 HEC and EHS



area that elephants may inhabit is being reduced by the invasion of alien species. As a result, several native species decline, and less food, water, and shade will likely be available in the ecosystem, which may tempt elephants to wander into nearby human settlements and cause conflict. One of the worst manifestations of the human-animal conflict reported in the study region is crop raiding. Crop raiding has also reportedly been caused by an increase in elephant populations and local overabundance that has deteriorated habitat. The main crop raiders in the region were elephants, wild boar, gaur, sambar deer, spotted deer, etc. Among them, elephants were responsible for 75.85% of crop robberies. Paddy was the most frequently raided crop, followed by ginger, coconut, plantains, arecanuts, and coffee due to trampling, followed by feeding. The seasonal occurrences of crop raiding reveal that most crop raiding occurred during the wet season, with the remaining occurring in the summer (KFRI 2001). Crop raiding and the associated conflict events were more frequently reported in enclosures than in peripheral settlements (Menon, 2020).

The presence of many human settlements within the area and a large number of road networks disturbs the elephant habitat. The impact of highways and settlement areas inside the sanctuary breaks the previously continuous ecosystems and results in the loss of potential habitats (Zhang et al. 2021). The open street map (OSM) format obtained the road layer inside the sanctuary. The number of roads in an area greatly impacts habitat loss, degradation, and fragmentation. The roads in the study

area include highway, metalled, and unmetalled roads. Most of the roads are unmetalled fair-weather jeepable roads, and the total length of the road network inside the study area is 270.65 km. The influence of forest roads was analyzed using a raster buffer with a distance ranging from 500 to 2000 m. A major elephant corridor runs through the northern part of the Tholpetti range between Thirunelli and Kudrakote. The wildlife in the forest region closer to the road is disturbed by heavy vehicle movement, loudness, and the frequency of human activity. The high road frequency in the forest area has a negative impact on habitat loss and fragmentation. Most of the settlements in this research region are scattered over the surrounding forest and agricultural areas. Road proximity is a sign of higher disturbances, whereas habitats further from these elements showed fewer disturbances (Arendran et al. 2011). The close proximity to the road network disturbs the western part of the study region. Elephant density and suitable habitats are constrained by increasing elevation and slope (Ochieng 2015). The DEM was used to calculate the elevation and slope using ArcGIS software. The area's elevation ranges from 733 to 1156 m, with a slope of 39.04 degrees. Topographic elements like slope and elevation constrained the distribution of elephants. Generally, elephants avoid high elevation and steep slopes because of their large body size and prefer medium elevation and moderate slopes.



## Conclusion

Habitat fragmentation and loss due to human activities have resulted in the decline of wildlife populations, including the endangered Asian elephant species. As the human population continues to grow and development activities expand, more wildlife habitats are being converted into agricultural, settlement, and other land uses, leading to severe habitat fragmentation and loss. The human-elephant conflict (HEC) is a significant issue in Wayanad, Kerala, and has resulted in habitat fragmentation and degradation. The protected area is home to many endangered, threatened, and rare species, but the high density of human settlements within the protected area has led to deforestation, wildfires, and the spread of invasive plant species. The habitat suitability analysis is necessary to identify suitable habitats inside the sanctuary based on the elephants' known associations with environmental variables. The study's results can be used for ecosystem management and the development of conservation strategies to reduce human-elephant conflict and preserve elephant habitats. The impact of highways and settlement areas inside the sanctuary breaks the previously continuous ecosystems and results in the loss of potential habitats. The study highlights the importance of considering human disturbances when evaluating habitat suitability, as human activities are becoming increasingly vital for the survival of wild animals, and crop raiding and associated conflict events are more frequently reported in enclosures than in peripheral settlements. The study revealed that the northern and central portions of the study region had the highest habitat suitability, with the Sultan Bathery range having the largest area of suitable habitat. The Habitat Suitability Map was validated using human-elephant conflict locational data, which proved its accuracy. The study ultimately delineates elephant habitat suitability zones using geographic and ecological parameters. The findings of this research may help address socio-economic problems involving animals and habitat quality. Planners and managers may benefit from a map of demarcated suitability zones for controlling migratory elephant patterns and the management of wildlife by conserving and protecting valuable species of fauna.

**Author contributions** Vineetha P: Original draft, Data collection, Methodology, Software, Formal analysis, visualization, writing. Sarun S: Writing – review & editing, resource, visualization. S. Selvakumar: review, editing, data curation & visualization. Reghunath Rajesh: Writing – review & editing, supervision.

**Funding** No funding was received for conducting this study.

**Data availability** No datasets were generated or analysed during the current study.

## Declarations

**Ethical approval** This material is the authors' own original work, which has not been previously published elsewhere. The paper is not currently being considered for publication elsewhere. The paper reflects the authors' own research and analysis in a truthful and complete manner. The paper properly credits the meaningful contributions of co-authors and co-researchers. The results are appropriately placed in the context of prior and existing research. All sources used are properly disclosed (correct citation). Literally copying of text must be indicated as such by using quotation marks and giving proper reference. All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

**Competing interests** The authors declare no competing interests.

## References

- Alfred JRB, Kankane PL, Kumar A, Roy PS, Singh S, Verma M (2001) Habitat suitability analysis of chinkara, *Gazella Bennettii* in Rajasthan: a remote sensing and GIS approach. *Records of the Zoological Survey of India, Kolkata, India*
- Areendran G, Krishna R, Mazumdar, Sraboni, Munsu, Madhushree, Govil H, Sen PK (2011) Geospatial modeling to assess elephant habitat suitability and corridors in northern Chhattisgarh, India. *Trop Ecol* 52(3):275–283. <https://doi.org/10.11609/JoTT.03634.4854-70>
- Baskaran N (2013) An overview of Asian elephants in the western ghats, southern India: implications for the conservation of western ghats ecology. *J Threatened Taxa* 5(14):4854–4870. <https://doi.org/10.11609/JoTT.03634.4854-70>
- Bukombe J et al (2022) Viability assessment of the Wami -Mbiki Game Reserve to Nyerere National Park wildlife corridor in southern Tanzania, *Global Ecology and Conservation*, V39
- Choudhury AU (1999) Status and conservation of the Asian elephant (*Elephas maximus*) in northeastern India. *Mammal Rev* 29:141–173. <https://doi.org/10.1046/j.1365-2907.1999.00045.x>
- DeepuSivadas MP, Geethakumary, Prakashkumar R (2019) Impact of landslides on the forest ecosystems in Wayanad district, Kerala, with special reference to floristic wealth. *J Trop Nat Resour Biodivers*, 10(8)
- Huiyi S, Manjit B, Mingshi L (2021) Mapping habitat suitability for Asiatic black bear and red panda in Makalu Barun National Park of Nepal from MaxEnt and GARP models. *Sci Rep* 11(10364). <https://doi.org/10.1038/s41598-021-93540-x>
- KFRI (2012) Wayanad Wildlife Sanctuary Management Plan
- KFRI (2002) Research Report No. 236. Management strategies for promoting succession in plantations of Parambikulam and Wayanad Wildlife sanctuaries
- KFRI (2001) Research Report Study on Man-Wildlife Interaction in Wayanad Wildlife Sanctuary, Kerala
- KFRI (2001) Study on Man-Wildlife Interaction in Wayanad Wildlife Sanctuary, Kerala
- KFRI (1994) Project No 173/92, Project Elephant: Management plan for elephant reserves in Kerala
- Kushwaha SPS, Hazarika R (2004) Assessment of habitat loss in Kameng and Sonitpur Elephant reserves. *Curr Sci* 87(10):1447–1453
- Mandal M, Das, Chatterjee N (2021) Geospatial approach-based delineation of elephant habitat suitability zones and its consequence in Mayurjharna Elephant Reserve, India. *Environ Dev Sustain* 23(10):17788–17809

- Menon V, Ganguly U, Tiwari SK, Stewart-Cox B, Melidonis C, Gandhi T (2020) Safe passage, safe habitation: securing the Thirunelli-Kudrakote Elephant Corridor through Voluntary Relocation. Conservation Action Report, Wildlife Trust of India, National Capital Region
- MoEFCC (2017) Annual Report 2017-18. <https://moef.gov.in/wp-content/uploads/2019/04/22-03-18.pdf>
- Morrison ML, Marcot BG, Mannan RW (2006) Wildlife-habitat relationships: concepts and applications, 3rd edn. Island, Washington, DC
- Natalie D (2003) Environmental Suitability Analysis for Asian Elephants in Southern India, Master of Science Thesis, International Institute for Geo-information Science and Earth Observation, Netherlands
- Ngene 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* v 47:234–243
- 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
- Ochieng EO (2015) Characterizing the spatial distributions of elephants in Mpala, Kenya. MS thesis. University of Twente
- Pastorini J, Nishantha HG, Janaka HK, Isler K, Fernando P (2010) Water-Body Use by Asian elephants in Southern Sri Lanka. *Tropical Conservation Science.*, pp 412–422. <https://doi.org/10.1177/194008291000300406>
- Pearson SM, Turner MG, Gardner RH, O'Neill RV (1996) An organism-based perspective of habitat fragmentation. *Biodivers Manag Landscapes: Theory Pract*, 77–95
- Prasad G, Shiny R, Reghunath R, Prasannakumar V (2011) A GIS-Based spatial prediction model for Human-Elephant conflicts (HEC). *Wildl Biology Pract* v7(2):30–40
- Project Elephant (2017) Estimated population of wild Asian elephants in India. Retrieved from <https://www.theelephantproject.net/>
- Rowden AA, Anderson Owen F, Georgian Samuel E, Bowden David A, Clark Malcolm R, Arne P (2017) Miller Andrew High-Resolution Habitat Suitability Models for the Conservation and Management of Vulnerable Marine Ecosystems on the Louisville Seamount Chain, South Pacific Ocean, *Frontiers in Marine Science.*, v. 4. DOI=10.3389/fmars.2017.00335
- Santiapillai C, Wijeyamohan S, Bandara G, Athurupana R, Disanayake N, Read B (2010) An assessment of the human-elephant conflict in Sri Lanka. *Ceylon J Sci* v39 21–33. <https://doi.org/10.4038/cjsbs.v39i1.2350>
- SenguptaAsmita. VV (2020) Binoy.,Radhakrishna, Sindhu. Human-Elephant Conflict in Kerala, India: a Rapid Appraisal Using Compensation Records. *Human Ecology.*, V. 48. 10.1007
- Sharma P, Panthi S, Yadav SK, Bhatta M, Karki A, Duncan T, Poudel M, Acharya KP (2020) Suitable habitat of wild Asian elephant in Western Terai of Nepal. *Ecol Evol* 10(12):6112–6119
- Suhaida A, Mohd S, Salman (2015) Analysing elephant habitat parameters using GIS, remote sensing and analytic hierarchy process in Peninsular Malaysia. *Pertanika J Sci Technol* 23(1):37–50
- Sukumar R (1994) *Elephant days and nights*. Oxford University Press, New York, USA
- Talukdar NR, Choudhury P, Ahmad F (2020) Habitat suitability of the Asiatic elephant in the trans-boundary Patharia Hills Reserve Forest, northeast India. *Model Earth Syst Environ* 6:1951–1961. <https://doi.org/10.1007/s40808-020-00805-x>
- Zhang L, Wang N (2003) An initial study on habitat conservation of Asian elephant (*Elephas maximus*), with a focus on human-elephant conflict in Simao, China. *Biol Conserv* 112(3):453–459
- Zhang XG, Wang B, Xue M, Zhang Z, Tan Z (2021) Dynamic landscapes and the driving forces in the Yellow River Delta Wetland region in the past four decades. *Sci Total Environ* 787:147644

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.