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Geospatial modeling to assess elephant habitat suitability and corridors in northern Chhattisgarh, India

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Abstract: We used remote sensing data and geospatial modeling techniques to assess the elephant habitat suitability and dispersal corridor in northern parts of Chhattisgarh, Central India. This region is frequently visited by elephants from the neighboring states of Orissa and Jharkhand in search of better habitat and often enter human habitations and agricultural fields resulting in conflicts with humans. Satellite images and ground information were used for land use/ land cover mapping and identification of conflict zones. Analytic Hierarchy Process (AHP) was used to assign weights to the three factors, viz., type of vegetation cover, proximity to water body and proximity to human habitation. Based on the analysis a corridor for elephant movement and migration has been identified which could be notified and managed by the state government in order to minimize human - elephant conflicts in the region.

Resumen: Usamos datos de percepción remota y técnicas de modelado geoespacial para evaluar la idoneidad del hábitat de los elefantes y los corredores de dispersión en porciones norteñas de Chhattisgarh, centro de la India. Esta región es visitada con frecuencia por elefantes provenientes de los estados vecinos de Orissa y Jharkhand en busca de mejores hábitats; con frecuencia entran en zonas de habitación humana y campos agrícolas, lo cual resulta en conflictos con los humanos. Se usaron imágenes de satélite e información del terreno para el mapeo de la cobertura y el uso del suelo, y la identificación de zonas de conflicto. Se utilizó el Proceso Jerárquico Analítico (AHP, siglas en inglés) para asignar pesos a los siguientes tres factores: cubierta de tipo de vegetación, proximidad a un cuerpo de agua y proximidad a zonas de habitación humana. Con base en el análisis se identificó un corredor para el movimiento y la migración de los elefantes, el cual podría ser notificado y administrado por el gobierno estatal son el fin de minimizar los conflictos humano - elefante en la región.

Resumo: Usaram-se dados de detecção remota e técnicas de modelação geoespacial para avaliar a adequação do habitat para o elefante e a dispersão dos corredores nas partes norte de Chhattisgarth, Índia Central. Esta região é frequentemente visitada por elefantes provenientes dos estados vizinhos de Orissa e Jharkhand à procura de melhor habitat e frequentemente entram nas habitações dos habitantes e nos campos agrícolas de que resultam conflitos com as populações. Imagens de satélite e informação de terreno foram utilizados para mapeamento do uso/cobertura do solo e identificação de zonas e conflito. Usaram-se processos analíticos hierárquicos (AHP) para afectar o peso aos três factores, como o tipo de cobertura de vegetação, proximidade das fontes de água e proximidade das habitações da população. Com base nesta análise foi identificado um corredor para a movimentação e migração dos elefantes, a qual pode ser assinalada e gerida pelo governo do Estado com o fim de minimizar na região os conflitos homem - elefante.

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Key words: Analytic Hierarchy Process (AHP), corridor, habitat suitability analysis, human - elephant conflict, Project Elephant.

Introduction

Human - Elephant conflict (HEC) has emerged as a major issue in the field of wildlife management in India (Easa 2002; Kushwaha & Hazarika 2004; Singh *et al.* 2002; Sukumar 1994). Asian Elephant (*Elephas maximus*), once widely distributed in Indian sub-continent, has now been categorized as "endangered" species as per IUCN red list. Conversion of forested land into settlements, agriculture, other infrastructure such as dams has led to fragmentation, shrinkage and degradation of elephant habitat as well as loss of traditional movement paths resulting in increased HEC (Singh 2002; Sukumar 1994; Singh *et al.* 2002). Elephants, in search of food and water tend to enter human habitations and in the process, often come into direct conflicts humans by destroying crops, live-stock or property and sometimes by even killing people (Kushwaha & Hazarika 2004; Sukumar 1994). In retaliation, the elephants also get killed by the local communities. Preservation and restoration of corridors are an important means of reducing the adverse effects of habitat fragmentation (Khanna *et al.* 2001; Nandy *et al.* 2007; Venkataraman 2002). Corridors are narrow strips of forests connecting two larger forest areas and thereby facilitating movement and dispersal of animals between these patches (Beier & Noss 1998).

Preservation of wildlife requires a complete knowledge of their habitat requirements. It also requires knowledge of past and current area under different land use practices such as agriculture, forestry and human habitations that alter vegetation cover, land surface, biogeochemistry, hydrology and biodiversity (Ellis 2007). Vegetation forms an integral component of terrestrial ecosystem and wildlife habitat (Khanna *et al.* 2001). Information on the nature and extent of vegetation, therefore, greatly helps in assessment of wildlife habitat and identification of dispersal corridors. The advent of geospatial tools, viz., Geographical Information System (GIS) and remote sensing have facilitated such studies as these techniques allow assessment of temporal variations in the spatial data and provide relevant and reliable information needed for conservation planning and wildlife management (Kushwaha *et al.* 2000; Kushwaha & Roy 2002). Various studies have highlighted the role of geospatial tools in habitat evaluation and also in identification and management of wildlife corridors (Khanna *et al.* 2001; Kushwaha & Hazarika 2004; Kushwaha *et al.* 2000; Nandy *et al.* 2007).

Northern Chhattisgarh in Central India has been home of Asian elephants since historical times. However, in the early part of the 20th century they became locally extinct (Singh 2002). In 1988 elephants migrated from the prime elephant habitat of Jharkhand (erstwhile Bihar) into Chhattisgarh (erstwhile Madhya Pradesh) and caused extensive damage to life and property. Since then, HEC cases have been increasing due to straying of migratory elephants in the state (Singh 2002). The number of wild elephants in the year 2007-08 in the state estimated to be 122 (MoEF 2008 www. envfor.nic.in/pe/pe.html*)*. Major reason for prolonged stay of elephants in the state could be better (44 %) forest cover, heavy mining, habitat degradation and deforestation in the states of Jharkhand and Orissa (Singh 2002; Earth Matters Foundation 2008). Even the state of Chhattisgarh is primarily inhabited by tribal communities dependent largely on agriculture and minor forest produce. Increasing human pressure on forested areas is resulting in increased incidences of human-elephant conflicts. This necessitated a detailed assessment of habitat suitability and dispersal corridor for elephants in the area. We used remote sensing and GIS based modeling approach following Analytic Hierarchy Process (AHP) to assess these parameters in the above mentioned area. In this paper, we present the results of this study along with management implications.

Study area

The state of Chhattisgarh, located in Central India, was carved out of the erstwhile state of Madhya Pradesh in 2000. The state lies between latitudes 17° 47' and 24° 06' N and longitudes 80° 15' and 84° 24' E. Forming a part of Deccan biogeographic province, the state harbors rich and unique biological diversity. The state has a total geographic area of 135191 km^2, which constitutes 4.1 % of the total land area of the country (FSI 2005; Government of Chhattisgarh 2008b http:// cgforest.nic.in / forest_resources.htm).

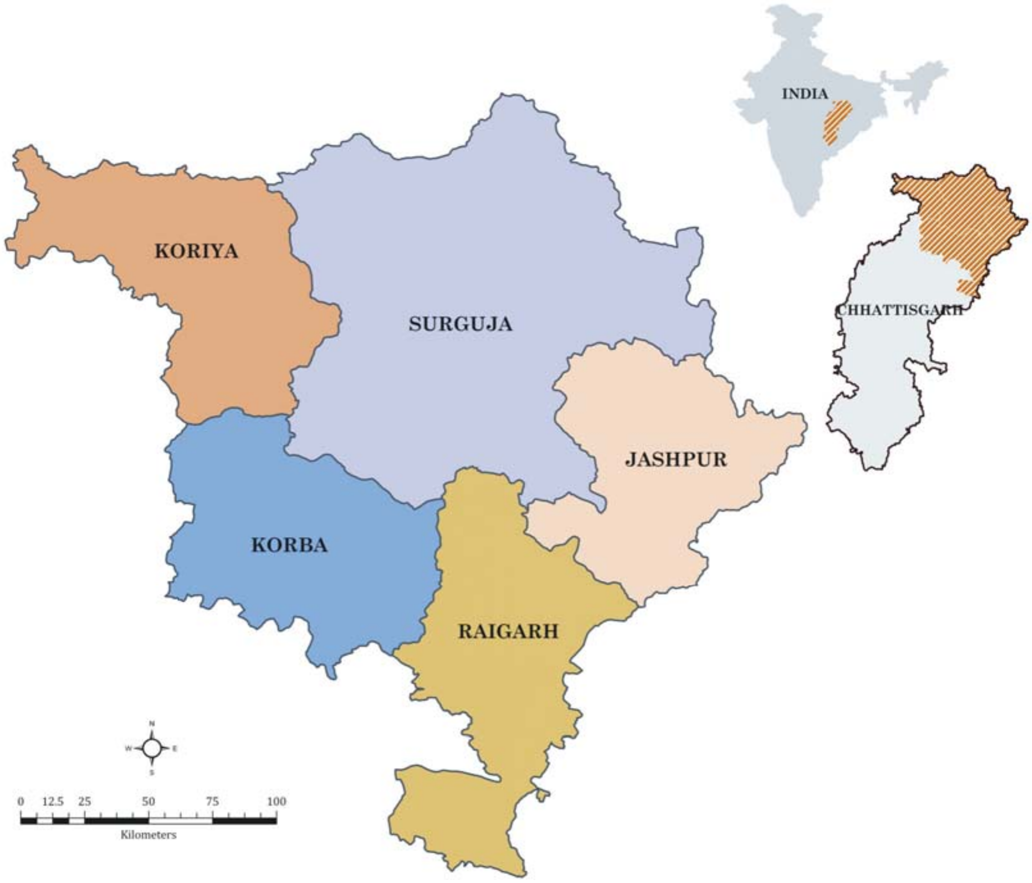


Fig. 1. Location map of northern part of Chhattisgarh.

The study area is bordered by Uttar Pradesh in the north, Jharkhand in the north-east, Orissa in the east and Madhya Pradesh in the west. Five districts in the region were selected for the present study viz., Korba, Koriya, Jashpur, Sarguja, and Raigarh, with high HEC cases (Fig. 1). Northern Chhattisgarh experiences tropical monsoon type of climate with maximum rainfall during June to October. Remaining months witness very short spells of rain. Summer months are extremely hot with temperature ranging from 35 °C to 45 °C. Geologically all the five districts have common attributes as they lie on the Satpura Range. Rocks are from Archean to recent era. The region lies on the edge of the great Indo-Gangetic plain and is drained by Rihand River, a tributary of the Ganges. The whole region thus forms part of the Mahanadi River drainage basin. Its average height is below 300 m. Part of the study area also falls under Baghelkhand Plateau. Peneplains – the flat subsurface table land (Mesa), are also found in this region. The soil is mainly basaltic (red) and in some parts black cotton soil is prevalent. Paddy is the main crop in the area. Rich mineral reserves of coal, bauxite, dolomite, gold and diamond also occur in the northern region of the state (Earth Matters Foundation 2008; Government of Chhattisgarh 2008a http://cgforest.nic.in/ About CG.htm).

The human population is unevenly distributed in the study area. The local communities belong to various tribes such as Kanwars, Kamar, Baiga, Halba, Pando, Paharikoraba and many others. Agricultural sector followed by mining and allied industries provide employment to majority of the local population (Earth Matters Foundation 2008).

The recorded forest area of the state is 59,772 km^2, which is 44.2 % of the total geographic area of the state and 7.77 % of the forest area of the country. The forests of the state fall under two major classes as per classification by Champion & Seth (1968), viz., Tropical Moist Deciduous and Tropical Dry Deciduous which are further divisible into 22 sub-groups. Most of the state forest is concentrated in the northern and southern parts of the state. In terms of species dominance four categories of forests can be identified in the state, viz., Teak (*Tectona grandis*), Sal (*Shorea robusta)*, Bamboo and Miscellaneous forests. Northern Chhattisgarh covers an area of 41858 km^2 (31 % of the total geographic area of the state) with total forested area of 19406 km^2, which is 46.3 % of the total area of the region. The rich forest cover support a wide variety of faunal species including tiger (*Panthera tigris*), leopard (*Panthera pardus*), gaur (*Bos gaurus*), sambar (*Cervus unicolor*), chital (*Axis axis*), nilgai (*Boselaphus tragocamelus*) and many others (FSI 2005; Government of Chhattisgarh 2008b http://cgforest.nic.in/forest_resources.htm).

Materials and methods

Creation of spatial database

Twelve Survey of India toposheets of 1:250,000 scale were required to cover the entire area of study. IRS-P6 LISS III satellite imageries with spatial resolution of 23.5 m were procured from NRSC, Hyderabad for the study area. The list of the input data used is provided in Table 1.

Table 1. List of input data.

Input	Data	Scale
Satellite images (IRS-P6 LISS III)	102-55, 102-56, 103-55, 103-56 and 104-56 (November, 2007)	23.5 m
Survey of India toposheets	63H, 63L, 63P, 64E, 64I, 64J, 64K, 64M, 64N, 64O, 73A and 73B	1:250,000

The toposheets were geo-referenced based on the coordinate information given in the maps. Using Autocad 2000i, ArcMap 9.2 and ArcView 3.2 the thematic layers (boundaries, roads, railway lines, drainage, water bodies, reserve forest boundaries and contour lines) were digitized from the toposheets to create spatial database for the concerned area. The satellite imageries were geometrically corrected on the basis of the referenced toposheets using map to image geo-rectification process. The rectified scenes were mosaiced and subsequently the study area was clipped from the mosaiced image on the basis of the district boundaries using AOI tool in ERDAS (version 9.0).

Land use/Land cover classification

Land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil and man made structures. The satellite data was processed to extract land use/land cover (LULC) of the study area for 2007 on the basis of visual interpretation technique and field survey using ERDAS (version 9.0). The mosaiced image was first classified using unsupervised classification technique. The classified output was compared with the respective satellite image and was cleaned using recode process. Settlements, water body and rivers were captured separately using AOI tools and subsequently recoded. The LULC map was verified in the field. The five districts under study were surveyed to collect information on LULC and major centers of HEC. Field survey was carried out in the post monsoon season from 1st September to 9th September, 2008. Random points were selected and at each location the existing land use pattern and the coordinate information was noted down with the help of Global Position System (GPS). The information on LULC were used for accuracy assessment. In addition, different sites of elephant movement in the region and sites of HEC were visited to get relevant information on habitat conditions, forage and water availability. The information collected from the field were incorporated into GIS domain and overlaid on LULC map for better analysis.

Habitat suitability analysis

The habitat requirements of the elephants and the variables related to these requirements were established based on the existing information available on the species, especially with reference to the study area. Three factors (Table 2) were identified as being the most important in determining the suitability of an elephant habitat. Each factor was then subdivided into three levels of suitability.

Each of the factors was assigned weights based on Saaty's multi-criterion evaluation Analytic Hierarchy Process (AHP). The AHP uses a nine point measurement scale where 1 represents equal importance, 3 represents weak importance, 5 represents strong importance, 7 represents demonstrated importance, and 9 represents absolute importance (Kushwaha & Roy 2002). The other values of 2, 4, 6 and 8 constitute intermediate values between two adjacent judgments. This AHP is based on the assumption that some factors are more important than others in a particular circumstance. Each variable was given a

Table 2. Habitat suitability factors and variables with levels of suitability.

Vegetation type	Proximity to water body	Proximity to human habitation	Suitability
Dense Forest	Within 1 km	More than 3 km	3 (highly suitable)
Open Forest	1 - 1.5 km	2 - 3 km	2 (moderately suitable)
Non-Forest	More than 1.5 km	Less than 2 km	1 (not suitable)

Table 3. Factors weighting using Analytic Hierarchy Procedure.

	Vegetation	Proximity to water body	Proximity to human habitation	GP	Relative weights
Vegetation	1	1	4	1.59	0.46
Proximity to water body	1	1	3	1.44	0.42
Proximity to human habitation	0.25	0.33	1	0.44	0.13
TOTAL				3.46	

value in comparison with another. After the matrix was filled by values of relative importance, the geometric progression (GP) values for each row were calculated. Then each factor was assigned a relative weight (Table 3). Thematic layers depicting each of the three factors were also generated. Multiple ring buffers generated at a distance of 0.5 km and 1 km were used to represent the two variables i.e. proximity to water body and human habitation respectively. Vegetation layer was prepared as a part of the LULC classification.

The set of input layers were run on ArcMap 9.3 using weighted sum spatial analyst. Input set of factors in the raster format were run using weighted sum approach. As such, the vector layers converted into raster format. In this module each of the input raster is multiplied with a corresponding factor weight, derived from AHP and then summed to arrive at a final suitability map. The comparisons are made using a scale to represent how much more one element dominates another with respect to a given attribute. The derived priority scales are synthesized by multiplying them by the priority of their parent nodes and adding for all such nodes (Saaty 2008). Based on the habitat suitability, a corridor and migratory route was proposed for further notification and management of stray elephants.

Results and discussion

Land use/Land cover mapping

Eight LULC classes were derived from satellite data interpretation for the area of study, viz., Dense forest, Open forest, Scrub, Agricultural land, Built up area, Industrial area, Open land/ Barren land and Water body (Fig. 2).

Dense forests are characterized by > 40 % canopy density, while forests with canopy density between 10 % and 40 % are defined as Open forests. Scrub areas represent forests with less than 10 % canopy density (FSI 2005). Forest cover was largely confined to the hilly tracts of the region while the relatively flat areas were occupied by agricultural land. Agricultural area includes area under crop cultivation and plantation as well as those lands which have been left fallow for regeneration. Industrial areas and built up areas comprise human settlements, confined to plain areas. Human habitations in the hilly and forested tracts were more dispersed and occurred as small hamlets. Open or barren land denotes areas devoid of

Table 4. Area under different land use/land cover classes in northern Chhattisgarh.

Land use/ Land cover	Area (km^2)	Area (%)
Dense forest	11773.54	32.33
Open forest	4926.2	14.25
Scrub land	2305.89	6.67
Agriculture	11440.95	33.09
Built up area	490.62	1.42
Industrial area	89.54	0.26
Open/Barren land	4926.2	14.25
Water body	467.38	1.35
Total area	36420.32	100

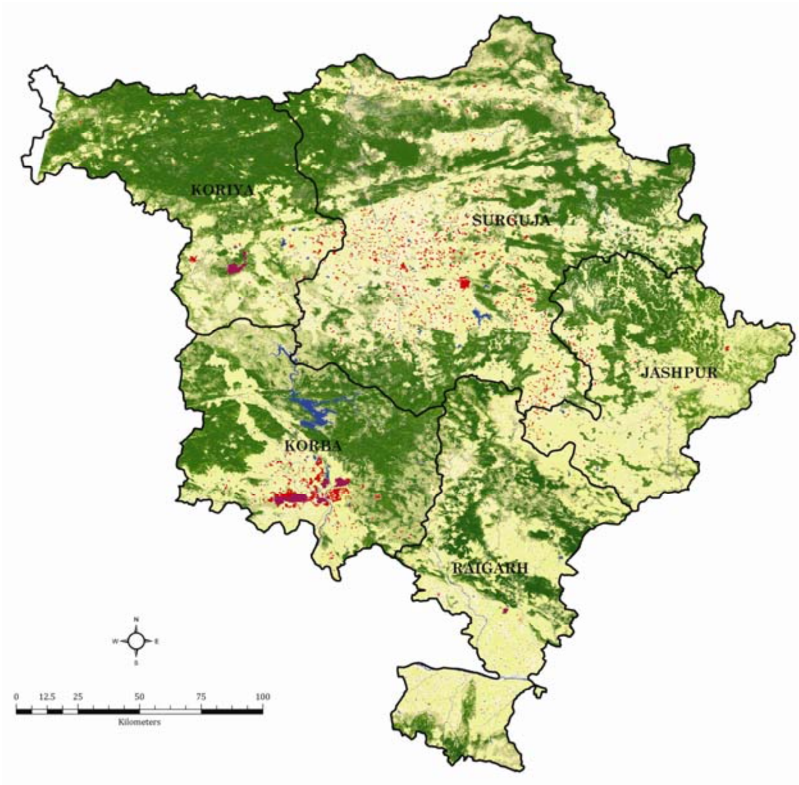
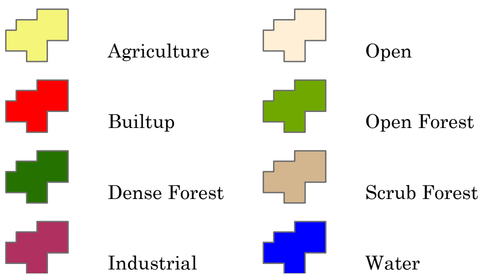


Fig. 2. Land use/Land cover map of northern Chhattisgarh region.



any particular land use, which are usually referred as wastelands. This form of land was found at the edges of forests, primarily because of deforestation for various purposes. Open/Barren land was also recorded in and around the built up and industrial areas suggesting degradation of land due to over exploitation (Table 4).

The field data were then used to calculate the accuracy of the LULC map generated using satellite image. The overall accuracy of the map was 78.89 %. The detailed error matrix and kappa statistics calculated are given in Table 5.

As per the details obtained from field survey regarding the HEC zones, it can be said that most of these conflicts occur at sites along the forest edges. These are the areas where human encroachments have been taking place in terms of extension of cropland and built up area. Elephants often deviate from their original route of movement and enter these hamlets leading to conflict situations.

Habitat suitability and corridor identification

Three levels of suitability were depicted in the map showing levels of suitability with reference to elephant habitat (Fig. 3). Areas away from main centers of human habitations with good vegetation cover and in close proximity to water bodies were categorized as highly suitable while areas with very less vegetation cover, away from major water bodies and in proximity to human habitations were depicted as least suitable for elephant habitat.

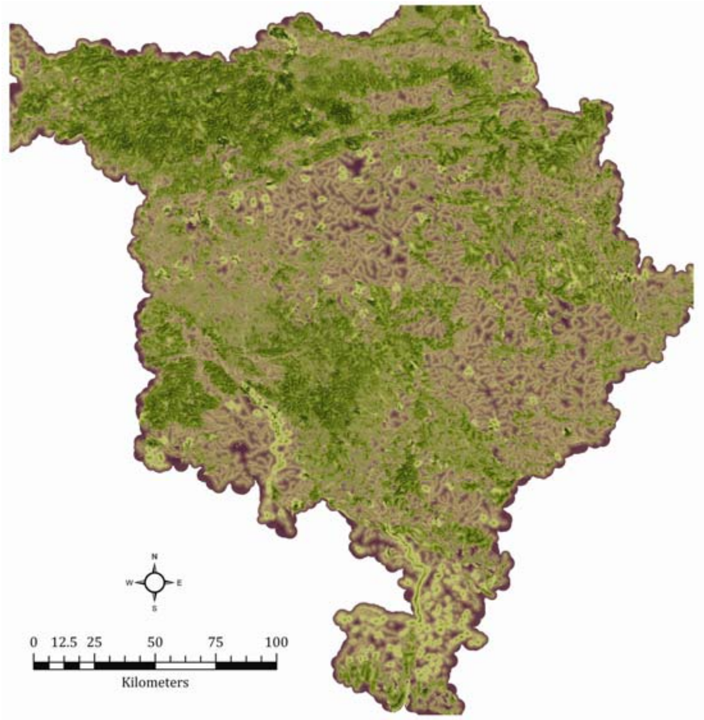


Fig. 3. Map depicting elephant Habitat Suitability in northern Chhattisgarh.

Thus suitable sites for elephant habitat should be endowed with abundant water and food source so that it can be sustainable home for these large bodied mammals; a large area to roam, less populated area so that there is less displacement (Earth Matters Foundation 2008).

Table 5. Accuracy assessment of LULC map.

Class name	Error Matrix		Kappa statistics
	Producer's accuracy (%)	User's accuracy (%)	
Dense forest	95.45	77.78	0.71
Water	82	79.30	0.69
Agricultural	85	86.05	0.76
Open forest	40	66.67	0.65
Industrial	100	100	0.00
Open	88.89	72.73	0.70
Scrub forest	66.67	50	0.48
Built up	50	50	0.49
OVERALL	78.81		0.70

Based on the habitat suitability analysis, a migratory route (the path used by elephants for migration) and a corridor (providing connectivity between forest patches) was proposed (Fig. 4) which would ensure free movement without causing much disturbance to human population residing in the region. The corridor was proposed on the basis of the fact that the vegetation cover within the corridor had good connectivity, which is an important factor in securing wildlife corridors and the water bodies present that are naturally replenishable which can sustain large elephant herds for all seasons. Besides, the slope varying between 0° - 30° and elevation of about 500 m were considered to be suitable for elephant movement. About 90 villages were identified to be present along the proposed elephant migratory route. Temporary fencing or relocation of these villages can be done for securing the corridor. There are plans of building artificial water storage tanks (on the basis of elevation and sited of river confluence) to cater to the need of the elephants. Suggestions have also been made to set up "Elephant Villages"

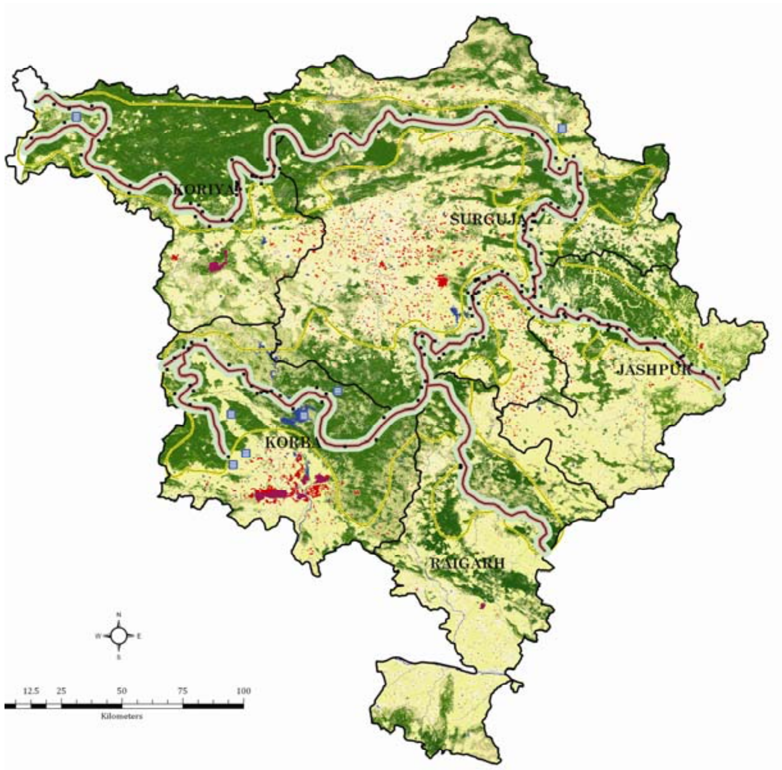


Fig. 4. Corridor proposed for elephants based on Habitat Suitability Analysis.

Villages Affected
Proposed Waterbody/Waterholes
Route of Elephant Movement
Buffer Region
Proposed Elephant Corridor
Study Area
Dense Forest
Open Forest
Scrub Forest

in the proposed corridor area (Times of India 2009 http://timesofindia. indiatimes.com/home/environment/flora-fauna/Wild-elephants-attack-C). If the corridors are notified and properly managed (by creating elephant - proof fences at strategic locations), the number of HEC cases can be reduced. This would also require cooperation from the local communities in terms of reducing biomass extraction from the elephant habitats and corridors (Earth Matters Foundation 2008). Improvement of habitat conditions in such areas would certainly reduce frequency of crop and house raiding. Thus, a combination of traditional methods and modern technological methods such as satellite tracking of elephants and monitoring their habitats would go a long way in combating HEC in the state.

Conclusions

Integration of GIS, Remote sensing and GPS technologies have proved to be effective in assessment of habitat quality and dispersal corridors for wide ranging species such as Asian elephant. Using geospatial modeling the entire area of northern Chhattisgarh was divided into three levels of suitability. It can be concluded from the study that there is a strong relationship between density of vegetation cover, availability of permanent sources of water, presence of human settlements and distribution of elephants. Effective management of corridors would go a long way in ensuring symbiotic relationship between elephants and human in the state.

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