REPORT

ON

HUMAN–ELEPHANT CONFLICT AND ITS MITIGATION ASSESSMENT IN RAJAJI–CORBETT LANDSCAPE OF SHIWALIK HILLS

SUBMITTED
BY

SANJAY BABU

UNDER

THE RUFFORD SMALL GRANTS SCHEME

(2018 - 2019)

INTRODUCTION

The Shiwalik hills which run parallel to the lesser Himalayas (northward) and the Gangetic plains (southward) are known to be the youngest of all mountains in India (Sivakumar, et al., 2010). Due to sandwich between these two biogeographic regions, the area not only exhibits the presence of a diverse range of faunal and floral species but also faces huge anthropogenic pressure due to ever increasing human population and their associated developmental activities from both the sides (Sivakumar, et al., 2010). Because of increasing human pressure, the forest ecosystem is continuously degraded and its existing wildlife corridors are shrinking (Joshi & Singh, 2008). Hence, the movement of wildlife species especially large bodied animals like elephant, leopard and tiger which require large area to survive, is greatly affected in the region and they are pushed to live in fragmented habitats. Resulting which there are increased cases of human-wildlife conflicts in the recent past decades.

The study is primarily focused on the issues related to Asian elephant, which is wide ranging, conflict prone mega-herbivore and, has existed in this landscape since pre-historic times. Previously, the migratory route of elephant was encompassed of the vast tracts of forest that ran across its historical range (from Tigris-Euphrates in west to the entire Indian sub-continent in east) and had allowed it to roam through varied habitats in search of food and water. But the increasing demands for sustaining ever-growing human population have resulted in change in land use configuration and shrinking habitat islands interspersed within a human dominated landscape (Goswami, et al., 2014). However, step like development of wildlife corridors that facilitate the wildlife species movement from one forest patches to another, is taken time to time so that risks of inbreeding and extinction are reduced and they continue to persist in their natural habitats (Venkataraman, 2005).

This region had a notable population of elephants in two major protected areas i.e., Rajaji National park and Corbett National park in the North-Western region of India which migrated to Nepal from Terai regions of Uttarakhand and Uttar Pradesh. The extreme land use change activities especially due to linear development in the vicinity of forest areas in forms of urban and agriculture expansion, road, canals and railways construction; have created obstruction in the movement of elephants and gives rise to foraging and migratory issues (Singh & Sharma, 2001).

Therefore, the study is framed in such a way so that assessment of factors such as land use land cover (LULC), forest canopy density (FCD), fragmentation pattern, habitat suitability of elephant are done and they can be incorporated to address the problem of human-elephant conflict with aid of field cum geospatial technology.

STUDY AREA

The study area lies between 29° 47' to 30° 05' N latitude and 78° 28'to 79° 20' E longitude and covers an area of about 10,000 km^2. The altitude varies from 150 m in the southern boundary to 1,150 m above sea level in the northern boundary. The Kosi river forms its eastern boundary while River Ganges which pass through Rajaji NP forms the western most boundary **(Figure 1)**. This whole area is divided in following Forest divisions: (a) Rajaji Tiger Reserve, (b) Corbett TR, (c) Haldwani forest and (d) Haridwar forest division. There are total eight corridors exist in the studied landscape i.e., Motichur-Chilla, Kansrao–Barkot, Chilla–Motichur and Kotdwar–Lansdowne etc, which are frequently used by elephant and other wildlife species. This whole range is fragmented into three units-west of Ganga, between the Ganga and Koh river and between Koh and Kosi river. North to south this elephant range is divisible broadly into outer Himalaya and Shiwalik hills; the latter forms nearly 70% of the elephant habitat.

The study area has Tropical Moist Deciduous Forest, Dry Deciduous Forest, Subtropical Pine forest types. Tree species like *Shorea robusta*, *Anogeissus latifolia*, *Mallotus philippensis* and *Acacia catechu* dominate the vegetation in Shiwalik region. *Dendrocalamus strictus*, one of the bamboo species was once abundant throughout this tract has been entirely vanished. Alien and indigenous weeds species like Lantana and Parthenium highly invade this entire region. Grasslands are restricted to riverine areas and hill slopes.

Fauna species like Tiger, Leopard, Jungle cat, Elephant, Asiatic black Bear, Wild boar, Chital, Sambhar, Rhesus macaque and Common langur etc. found throughout study area.

From socio-economic perspective, the area is considered as one of the most populated regions in India. The landscape is witnessed to major cities and towns like Haridwar, Rishikesh, Dehradun, Kotdwar and Ramnagar which always attract people due to their tourism importance. Additionally, the cities are also known to be the gateway of Char-Dham yatra. Hence, the people across the country visit these places throughout the year. As result of increasing human population and their related activities, the forest in the landscape is greatly affected and becoming fragmented due to which movement of wildlife especially elephants, between forest patches is hindered.

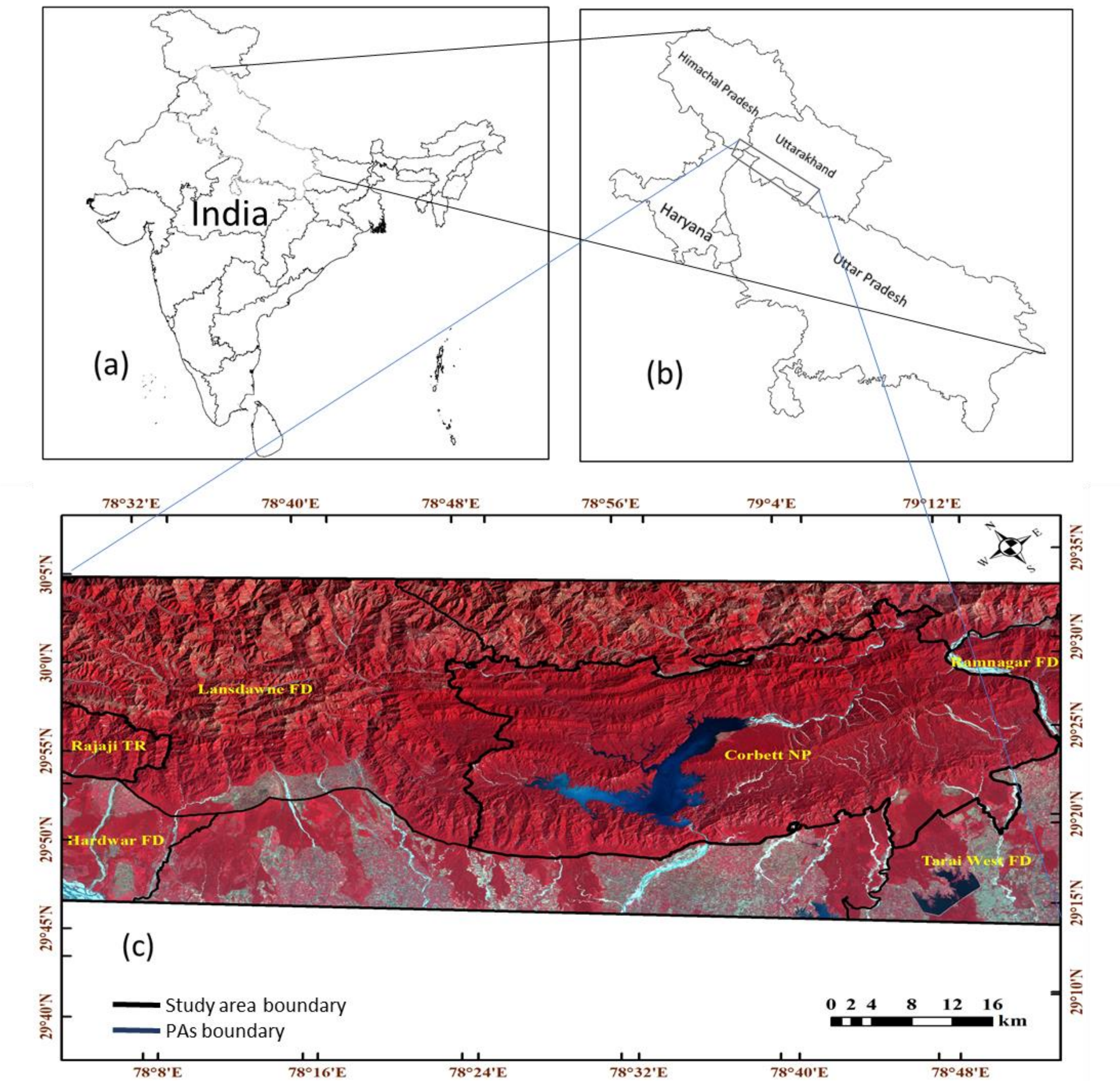


Figure 1. Map of the study area: (a) India, (b) different states encircling the study area and (3) the administrative boundary of the study area

METHODOLOGY

It involves activities such as field survey to collect the field data and, use of remote sensing and GIS software, particularly ERDAS imagine and ArcGIS for processing satellite imagery and, other software such as MS office Excel and SPSS for statistical analysis. Instruments such as Camera, GPS, Binocular, etc. were also used during field data collection.

Methods and the steps followed for accomplishing different objectives are discussed as follows:

Acquisition and Pre-Processing of the satellite images

Monitoring of LULC and FCD was done by downloading satellite images of different time periods. For LULC cover monitoring, Landsat satellite images of years 1991, 2003 and 2015 **(Table 1) and (Figures 2a, 3a & 4a)** were used whereas for FCD assessment, years 1992, 1998 and 2010 images **(Table 2) and (Figures 5a, 6a & 7a)** were used. Following download, pre-processing of each satellite image was done. Though, used satellite images were already georectified. Hence, only radiometric correction (pixel-wise conversion of Digital number to Radiance and further to Top of Atmospheric reflectance) was done before mapping.

1. Preparation and analysis of Land Use Land Cover (LULC)

Two Season images for each year i.e., 1991, 2003 and 2015 were stacked together. Land Use Land Cover maps for each of three years were prepared using unsupervised classification in ERDAS imagine software. The pure pixels were recoded and masked with the FCC and unsupervised classification was once again run on the image. This step involved iteration till every pixel was classified. A combination of Google Earth images and ground truth points collected during field survey are used for accuracy assessment. Error matrix were generated and the overall accuracy was calculated using Kappa Statistics.

2. Forest Cover Density (FCD) Mapping

For FCD mapping, images of post monsoon seasons for year 1991, 2001 and 2011 were used. Mapping was done using FCD Mapper software which involves use of various indices like advances vegetation index (AVI), bare soil index (BSI), and scaled shadow index (SCI) to calculate the canopy density in each pixel. The maps which were generated using software initially having 10 different classes of equal interval ranged between 1-100. However, the accuracy assessment and analysis were done merging these ten classes into four different categories i.e., 1-40% (open dense forest), 41-60% (moderate dense forest), 61-80% (high dense forest) and 81-100% (very high dense forest). For ground truth points collected during field survey were used for accuracy assessment.

Table 1. Satellite data used for LULC mapping

Satellite	Sensor	Path & Row	Acquired year	Spatial Resolution (m)	Spectral Band (μm)
Landsat 08	OLI & TIRS	146039 & 145040	2015	30	Band 2 (Blue): 0.452-0.512
					Band 3 (Green): 0.533-0.590
					Band 4 (Red): 0.636-0.673
					Band 5 (NIR): 0.851-0.879
					Band 6 (SWIR) 1: 1.566-1.651
					Band 7 (SWIR) 2: 2.08-2.35
					Band 9 (Cirrus): 1.363-1.384
					Band 10 (Thermal): 10.40-11.19
					Band 11 (Thermal): 11.5-12.51
				15	Band 8 (Panchromatic): 0.503-0.676
Landsat 7	Enhanced Thematic Mapper Plus (ETM$^+$)	146039 & 145040	2003	30	Band 1 (Blue): 0.45-0.52
					Band 2 (Green): 0.52-0.60
					Band 3 (Red): 0.63-0.69
					Band 4 (NIR): 0.76-0.90
					Band 5 (SWIR) 1: 1.55-1.75
				(60*) 30	Band 6 (Thermal): 10.40-12.50
				15	Band 7 (SWIR) 2: 2.08-2.35
					Band 8 (Panchromatic): 0.52-0.90
Landsat 4-5	Thematic Mapper	146039 & 145040	1991	30	Band 1 (Blue): 0.45-0.52
					Band 2 (Green): 0.52-0.60
					Band 3 (Red): 0.63-0.69
					Band 4 (NIR): 0.76-0.90
					Band 5 (SWIR) 1: 1.55-1.75
				(120*) 30	Band 6 (Thermal): 10.40-12.50
				30	Band 7 (SWIR) 2: 2.08-2.35

Table 2. Satellite data used for FCD mapping

Satellite	Sensor	Path & Row	Acquired year	Spatial Resolution (m)	Spectral Bands (µm)
Landsat 4-5	Thematic Mapper	146039 & 145040	2011	30	Band 1 (Blue): 0.45-0.52
					Band 2 (Green): 0.52-0.60
					Band 3 (Red): 0.63-0.69
					Band 4 (NIR): 0.76-0.90
					Band 5 (SWIR) 1: 1.55-1.75
				(120*) 30	Band 6 (Thermal): 10.40-12.50
				30	Band 7 (SWIR) 2: 2.08-2.35
Landsat 4-5	Thematic Mapper	146039 & 145040	2001	30	Band 1 (Blue): 0.45-0.52
					Band 2 (Green): 0.52-0.60
					Band 3 (Red): 0.63-0.69
					Band 4 (NIR): 0.76-0.90
					Band 5 (SWIR) 1: 1.55-1.75
				(120*) 30	Band 6 (Thermal): 10.40-12.50
				30	Band 7 (SWIR) 2: 2.08-2.35
Landsat 4-5	Thematic Mapper	146039 & 145040	1992	30	Band 1 (Blue): 0.45-0.52
					Band 2 (Green): 0.52-0.60
					Band 3 (Red): 0.63-0.69
					Band 4 (NIR): 0.76-0.90
					Band 5 (SWIR) 1: 1.55-1.75
				(120*) 30	Band 6 (Thermal): 10.40-12.50
				30	Band 7 (SWIR) 2: 2.08-2.35

3. Field Data collection

- **Fodder Species quantification**

Grid based vegetation sampling was done by dividing whole area in 4 km^2. For this, 10m radius circular plots are laid at 1km definite intervals along the trail of 5 km length in each grids of the different vegetation types. Elephant's fodder species analysis was done at forest habitat level Habitat wise by calculating indices such as Important Value Index (sum of relative density, relative frequency and relative dominance), diversity and richness index.

- **Elephant Presence Data**

While walking along the trail, direct and indirect (dung sign, debarking sign, hoof marks) evidences were observed and recorded with location Id. Presence points were then used to map spatial distribution of elephant along the different habitat gradients across the landscape.

- **Human Elephant Conflict Data**

Secondary data (questionnaire survey) regarding HEC incidences was collected from the villages adjacent (1–5 km distance) to the forest area or from the forest department for analyzing magnitude of HEC for each village.

4. Geospatial analysis

A spatial geodatabase was created for examining spatio–temporal pattern of elephant habitat uses and to assess human-elephant conflict in the landscape using Remote Sensing and GIS (RS/GIS).

RESULTS AND DISCUSSION

Land Use Land Cover (LULC) Analysis

Table 3 represents that each time periods LULC maps are comprised of 21 different classes. Among these, fourteen classes belong to forest category and seven classes to non-forest category. Year-wise area statistics analysis showed that highest area in the landscape was under other crops or agriculture (~1005 km^2 in year 1991 to ~926 km^2 in 2015) followed by Sal forest (~647 km^2) and hill Sal forest (~443 km^2) in all time periods. However, the lowest area was observed under classes such as open degraded land (<2km^2), orchards (~3 to 13 km^2) and built up (~7 to 18 km^2) for all periods.

Table 4 represents the change analysis of LULC classes between different time periods. The results indicate non-forest classes i.e., other crops, sugarcane, dry riverbeds were the most dynamic in landscape whereas forest classes i.e., Sal, hill Sal forest, Sal mixed forest, etc. did not show any change in their area. Land use classes such as sugarcane (~76 km^2), built up (~11 km^2) and orchards (~9 km^2) were found to increase highest due to loss in other crops (~80 km^2) between period 1991 and 2015. Also, in forest classes, the highest loss was observed for riverine grasslands (~18 km^2) and Teak (~5 km^2) for the same time period. Majority of forest class areas remained unchanged because the forest in the landscape fall under well conservation units i.e., protected area (PAs). Whereas the changes in non-forest areas especially agriculture land may be attributed by its conversion into built up and orchards due to increasing human population and their related activities in the landscape.

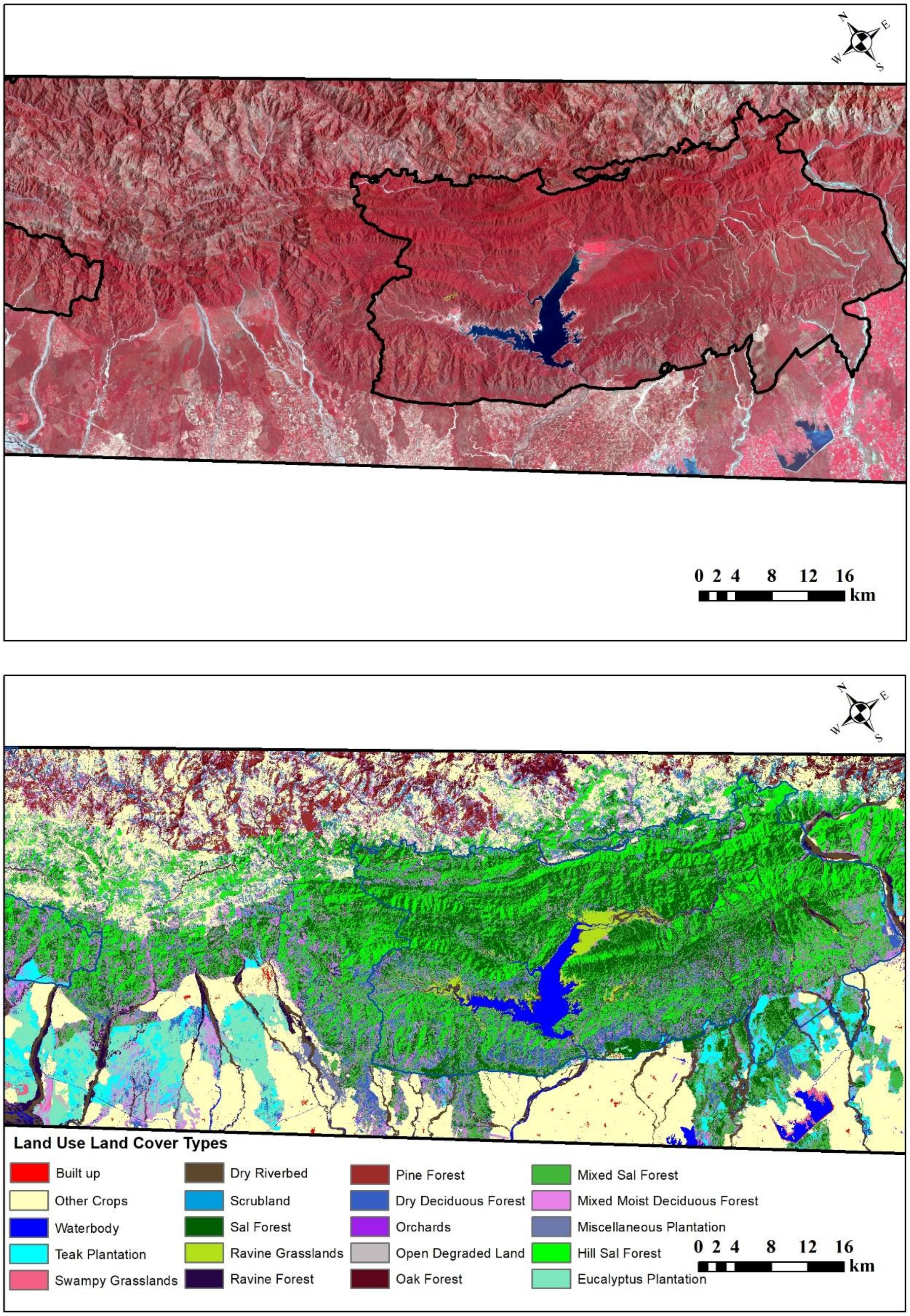
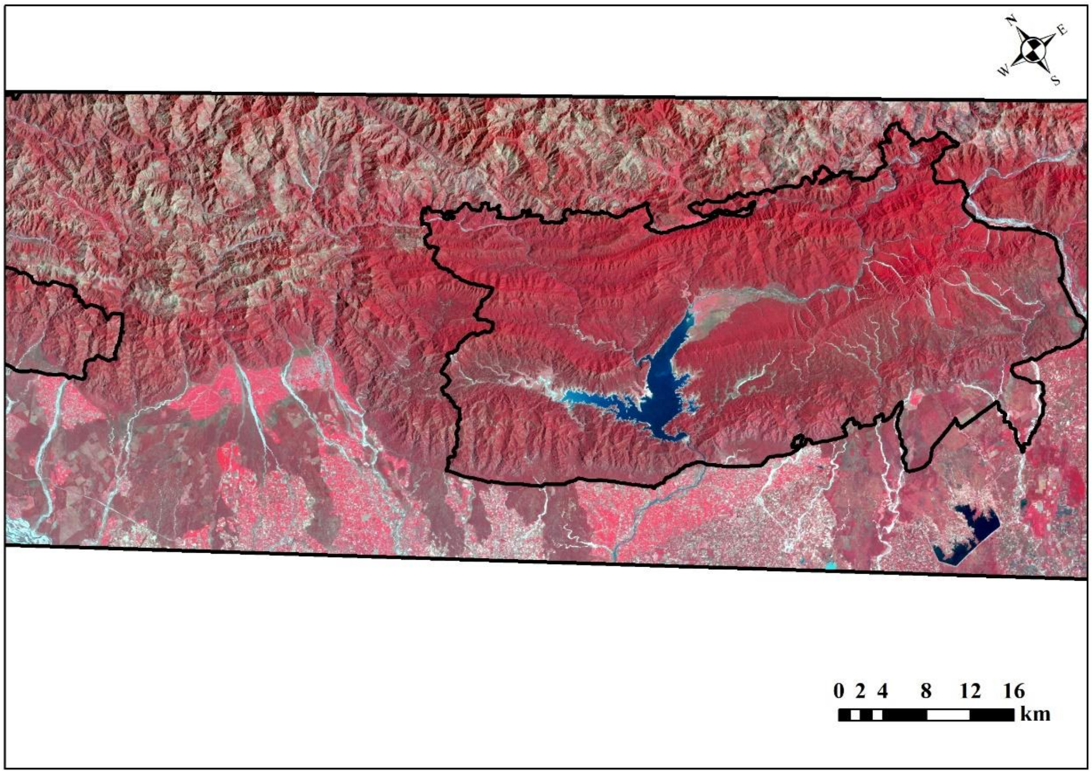


Figure 2. (a) False color composite (FCC) image and (b) LULC map for year 1991



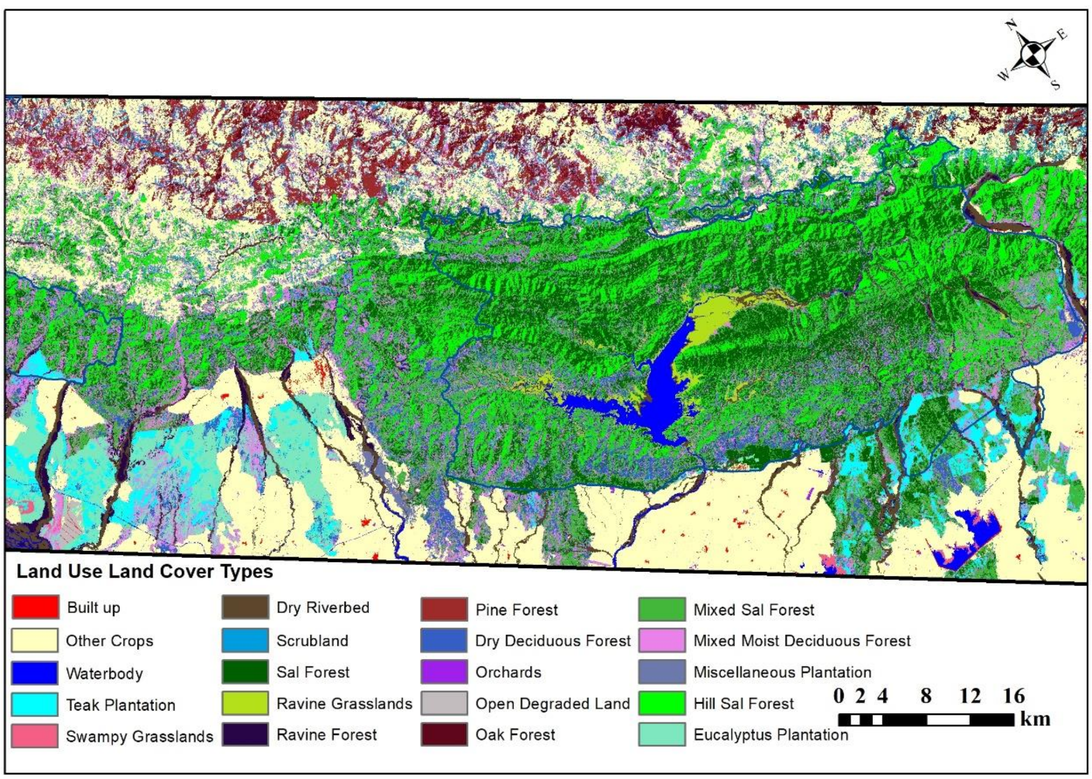
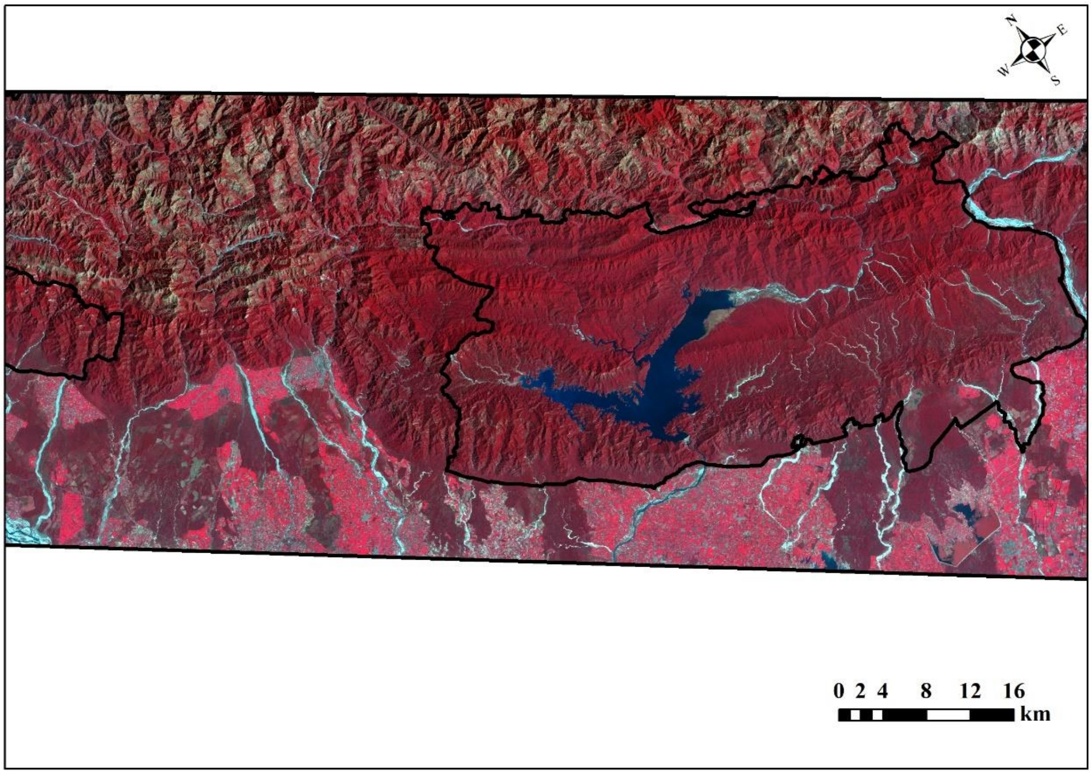


Figure 3. (a) False color composite (FCC) image and (b) LULC map for year 2003



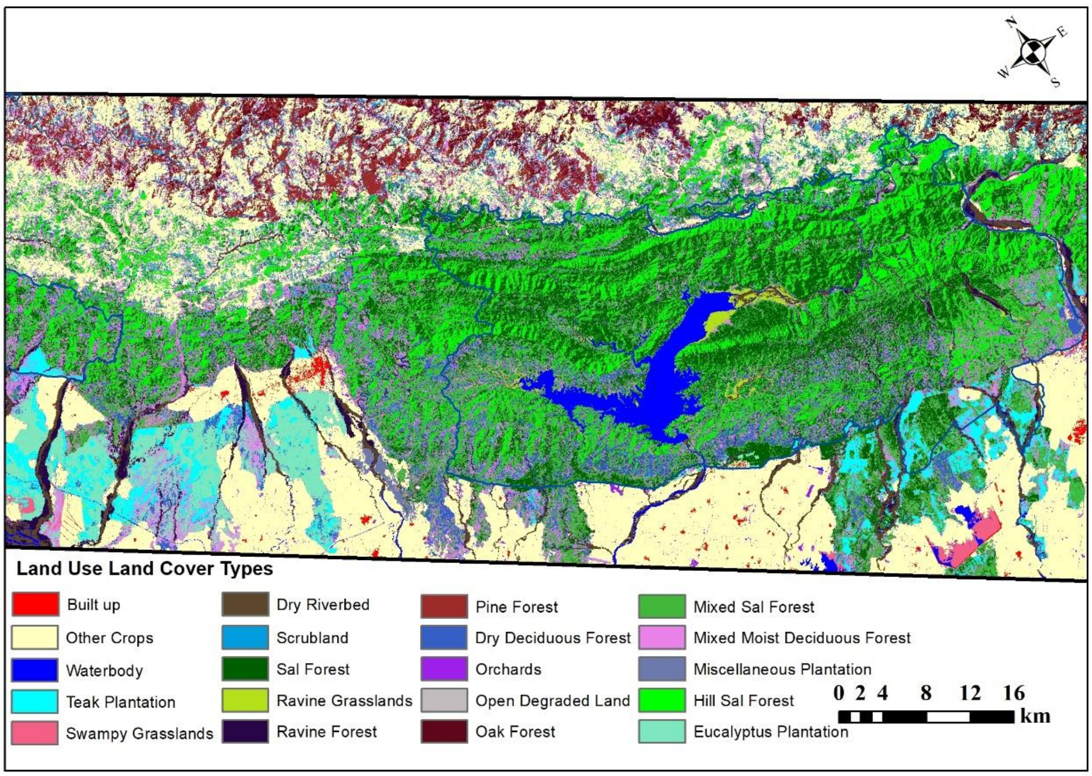


Figure 4. (a) False color composite (FCC) image and (b) LULC map for year 2015

Table 3. Area statistics of LULC maps for years 1991, 2003 and 2015

LULC Type	Abbreviation	Year wise area					
		1991		2003		2015	
		Area	km²	Area	km²	Area	km²
Sal Forest	Sal	647.50	15.07	647.50	15.07	647.50	15.07
Hill Sal Forest	Hill Sal	443.76	10.33	443.76	10.33	443.76	10.33
Sal Mixed Forest	Sal MF	512.02	11.92	512.02	11.92	512.02	11.92
Mixed Moist Deciduous Forest	MMF	465.10	10.83	465.10	10.83	465.10	10.83
Dry Deciduous Forest	DDF	141.13	3.29	141.13	3.29	141.13	3.29
Pine forest	Pine	171.01	3.98	171.01	3.98	171.01	3.98
Oak Forest	Oak	54.33	1.26	54.33	1.26	54.33	1.26
Ravine Grasslands	RG	35.89	0.84	42.01	0.98	17.68	0.41
Ravine Forest	RF	55.52	1.29	54.67	1.27	66.02	1.54
Miscellaneous Forest	Misc. F	8.25	0.19	9.14	0.21	16.44	0.38
Swampy Grasslands	SG	147.40	3.43	147.40	3.43	147.40	3.43
Holoptelea Plantation	HP	118.40	2.76	118.40	2.76	118.13	2.75
Teak Plantation	Teak	142.98	3.33	139.82	3.25	137.61	3.20
Eucalyptus Plantation	Euc.	8.70	0.20	8.70	0.20	8.70	0.20
Orchards	Orchard	3.98	0.09	6.09	0.14	12.77	0.30
Built up	Built up	6.94	0.16	8.82	0.21	17.55	0.41
Open Degraded Land	ODL	1.88	0.04	6.05	0.14	0.84	0.02
Sugarcane	Sugarcane	117.14	2.73	153.18	3.57	193.72	4.51
Other Crops	OC	1005.87	23.41	969.81	22.57	926.19	21.56
Dry Riverbed	DRB	128.93	3.00	125.65	2.92	101.36	2.36
Water Body	WB	79.24	1.84	71.39	1.66	96.73	2.25

Table 4. Change area analysis of LULC maps for periods between 1991-2003, 2003-2015 and 1991-2015

LULC Type	Abbreviation	1991-2003		2003-2015		1991-2015	
		Area					
		km²	%	km²	%	km²	%
Sal Forest	Sal	0.00	0.00	0.00	0.00	0.00	0.00
Hill Sal Forest	Hill Sal	0.00	0.00	0.00	0.00	0.00	0.00
Sal Mixed Forest	Sal MF	0.00	0.00	0.00	0.00	0.00	0.00
Mixed Moist Deciduous Forest	MMF	0.00	0.00	0.00	0.00	0.00	0.00
Dry Deciduous Forest	DDF	0.00	0.00	0.00	0.00	0.00	0.00
Pine forest	Pine	0.00	0.00	0.00	0.00	0.00	0.00
Oak Forest	Oak	0.00	0.00	0.00	0.00	0.00	0.00
Ravine Grasslands	RG	6.11	17.03	-24.33	-57.92	-18.22	-50.75
Ravine Forest	RF	-0.86	-1.54	11.36	20.77	10.50	18.91
Miscellaneous Forest	Misc. F	0.89	10.82	7.29	79.74	8.18	99.18
Swampy Grasslands	SG	0.00	0.00	0.00	0.00	0.00	0.00
Holoptelea Plantation	HP	0.01	0.01	-0.27	-0.23	-0.26	-0.22
Teak Plantation	Teak	-3.16	-2.21	-2.21	-1.58	-5.37	-3.76
Eucayptus Plantation	Euc.	0.00	0.00	0.00	0.00	0.00	0.00
Orchards	Orchard	2.10	52.85	6.68	109.73	8.78	220.56
Built up	Built up	1.88	27.08	8.73	98.89	10.61	152.75
Open Degraded Land	ODL	4.17	221.26	-5.21	-86.05	-1.04	-55.18
Sugarcane	Sugarcane	36.04	30.76	40.54	26.47	76.58	65.37
Other Crops	OC	-36.06	-3.58	-43.62	-4.50	-79.68	-7.92
Dry Riverbed	DRB	-3.28	-2.54	-24.29	-19.33	-27.57	-21.38
Water Body	WB	-7.86	-9.91	25.34	35.49	17.48	22.06

Forest Canopy Density (FCD) Analysis

The accuracy assessment analysis of different time periods FCD maps indicates the overall accuracy ranged between 85% for year 1992 map and 91% for year 2011 FCD map. Among these categories, the user's accuracy for all time periods map was observed highest for VDCF (~93%) and lowest for MCF (78%). Category wise area analysis for years 1992, 2001 and 2011 are shown in **Table 5**. The results indicate the highest area in the landscape was under very dense forest ranged between ~1046 km^2 in 2011 and ~1080 km^2 in 1992. However, lowest area was observed under open canopy forest (~304 km^2 in 2001 to ~378 km^2 in 1992. The change analysis results represented in **Table 6** for periods 1992-2001, 2001-2011 and 1992-2011 have showed that between years 1992 and 2011, the highest increased was noticed for very dense forest (~140 km^2 or ~21%) may be due to rejuvenation of plantation forest in the different part of landscape whereas loss was observed highest in open canopy forest (~70 km^2 or ~19%) due to conversion of plantation forest in the agriculture land, particularly in Haridwar forest division (**Figure 5b, 6b and 7b**).

Table 5. Area analysis of FCD classes for years 1992, 2001 and 2011

FCD Category	**Year wise Area (km²)**		
	1992	**2001**	**2011**
OCD	377.57	303.79	307.17
MCF	516.89	437.51	481.59
HCF	666.91	826.78	806.87
VFCF	1080.41	1073.69	1046.14
OCD =Open canopy forest, MCF= Moderate canopy forest, HCF= High canopy forest, VHCF= Very high canopy forest			

Table 6. Change analysis of FCD classes for years 1992-2001, 2001-2011 and 1992-2011

FCD Category	**1992-2001**		**2001-2011**		**1992-2011**	
	Area					
	km²	**%**	**km²**	**%**	**km²**	**%**
OCD	-73.78	-19.54	3.38	1.11	-70.40	-18.64
MCF	-79.38	-15.36	44.08	10.07	-35.30	-6.83
HCF	159.87	23.97	-19.90	-2.41	139.97	20.99
VDCF	-6.72	-0.62	-27.56	-2.57	-34.27	-3.17
OCD =Open canpoy forest, MCF= Moderate canopy forest, HCF= High Canopy forest, VHCF= Very high canopy forest						

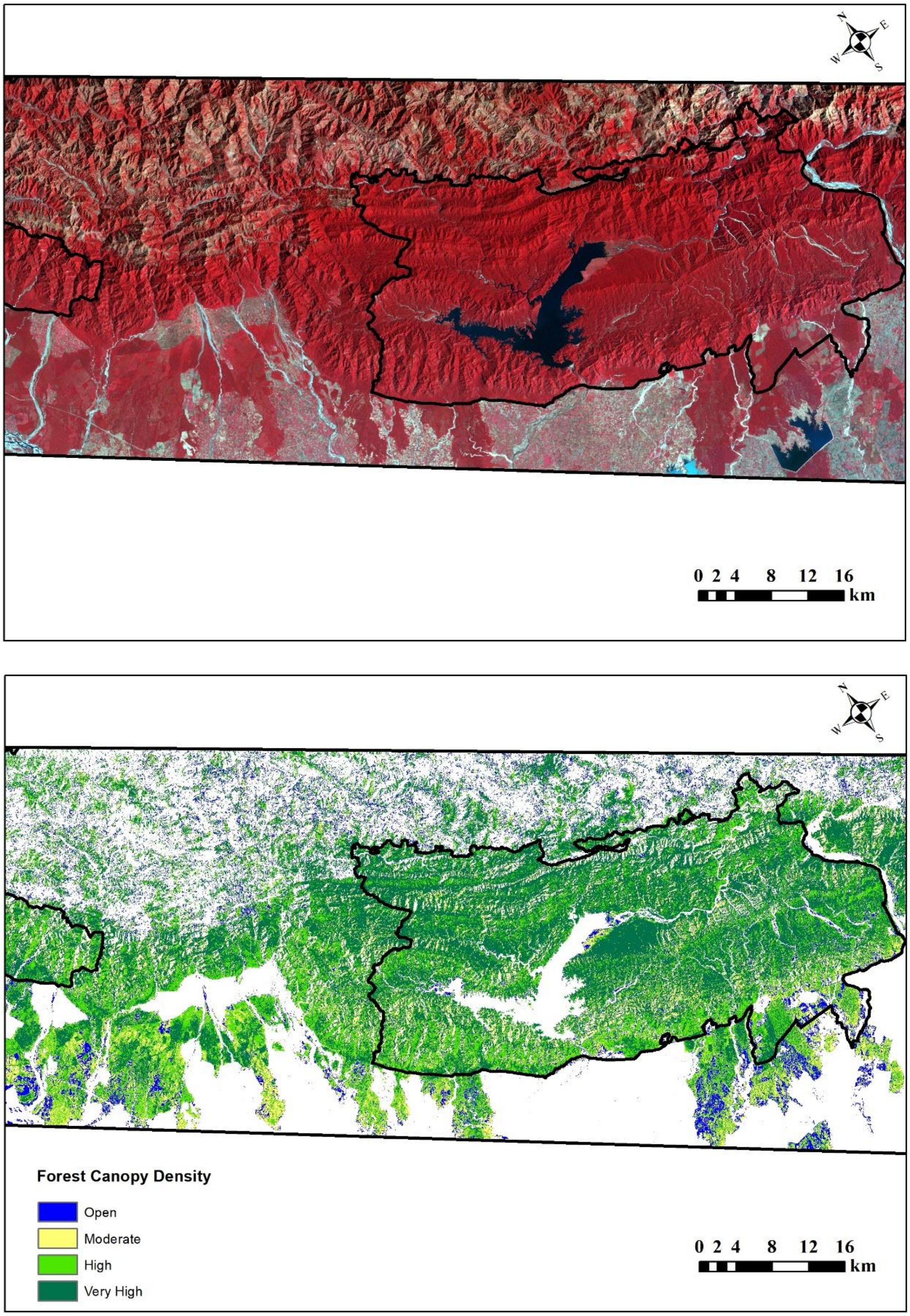


Figure 5. (a) False color composite (FCC) image and (b) FCD map for year 1992

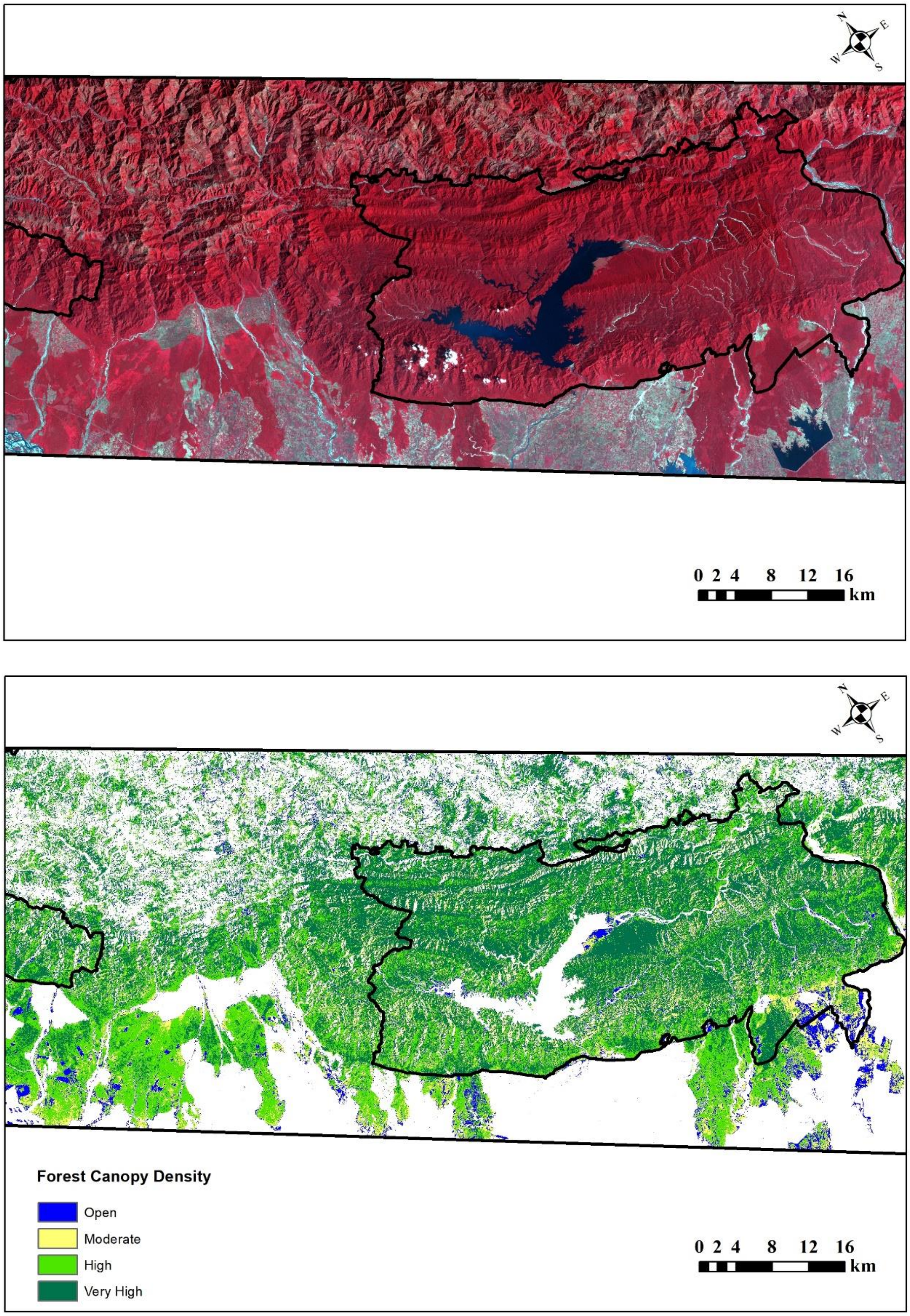
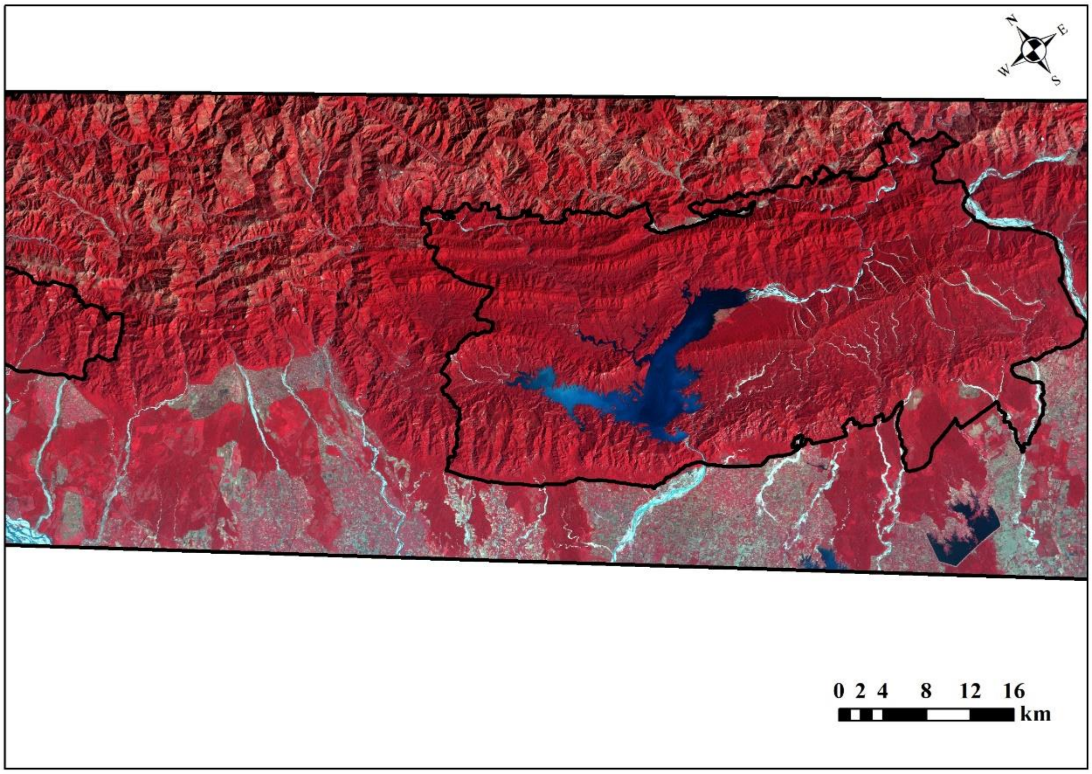


Figure 6. (a) False color composite (FCC) image and (b) FCD map for year 2001



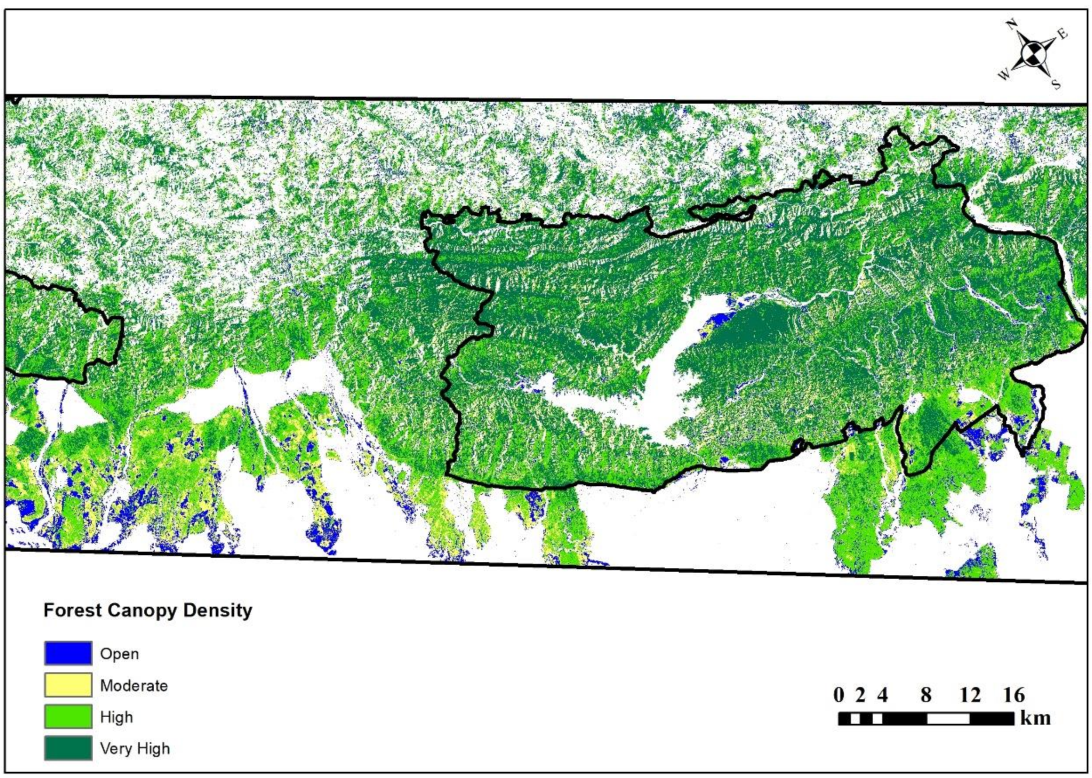


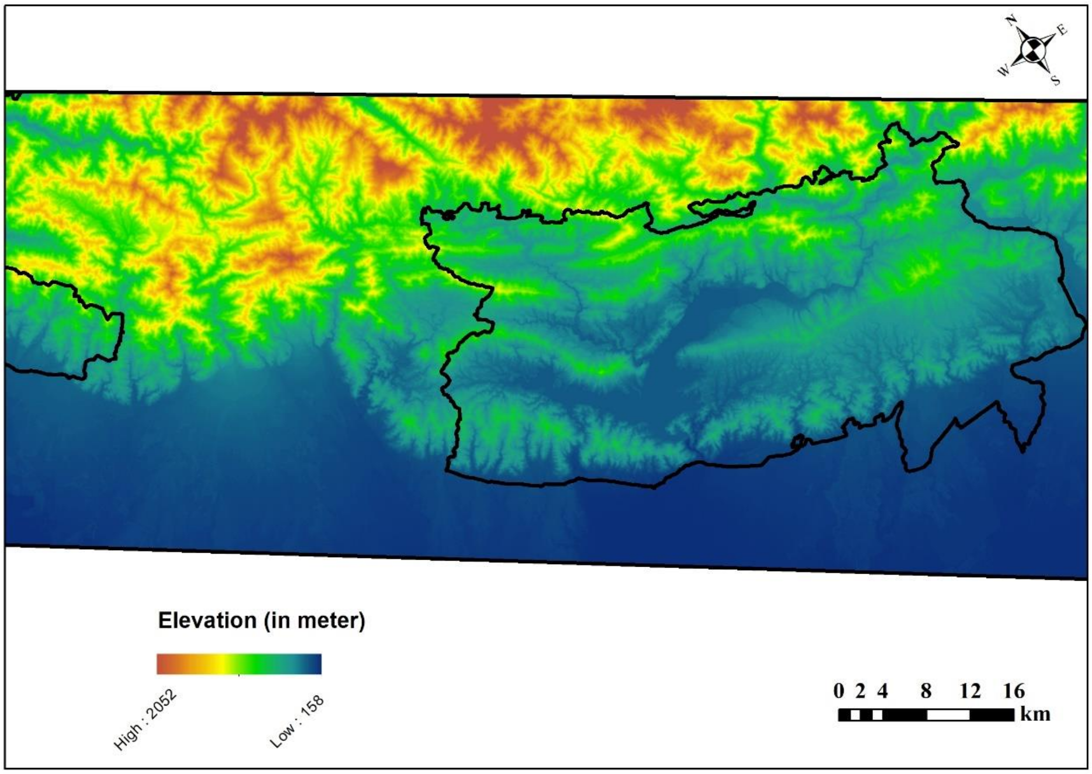
Figure 7. (a) False color composite (FCC) image and (b) LULC map for year 2011

Habitat Use/ Suitability Analysis of Elephant

At landscape level, the habitat suitability analysis of elephant was carried out using different ecologically important environment layers such as DEM, slope, aspect, water, settlements, etc. (**Figure 8-12**) through multi-criteria decision analysis. For this, each layer was given relative weightage form low to high (0 to 1) based on its importance. After assigning the weightage, the value was multiplied with corresponding layer to generate the habitat suitability map of elephants. The results of elephant habitat suitability analysis **(Table 7)** have indicated that only 13 per cent area in the landscape was very high suitable whereas 27 per cent was highly suitable for elephants. The areas of very high suitable were mainly comprised mixed vegetation and Sal mixed forest categories dominated by *Mallotus* plant species (most palatable species). However, 925 km^2 or 22% of the landscape area was noticed unsuitable for elephants. It may be due to this area was mainly dominated by the agriculture land and built up on the high altitudes (**Figure 13**).

Table 7. Habitat suitability of elephant in the landscape

Suitability	**Area**	
	(km^2)	**%**
Very High	574.24	13.37
High	1139.03	26.52
Moderate	487.05	11.34
Least	1169.09	27.22
No	925.57	21.55



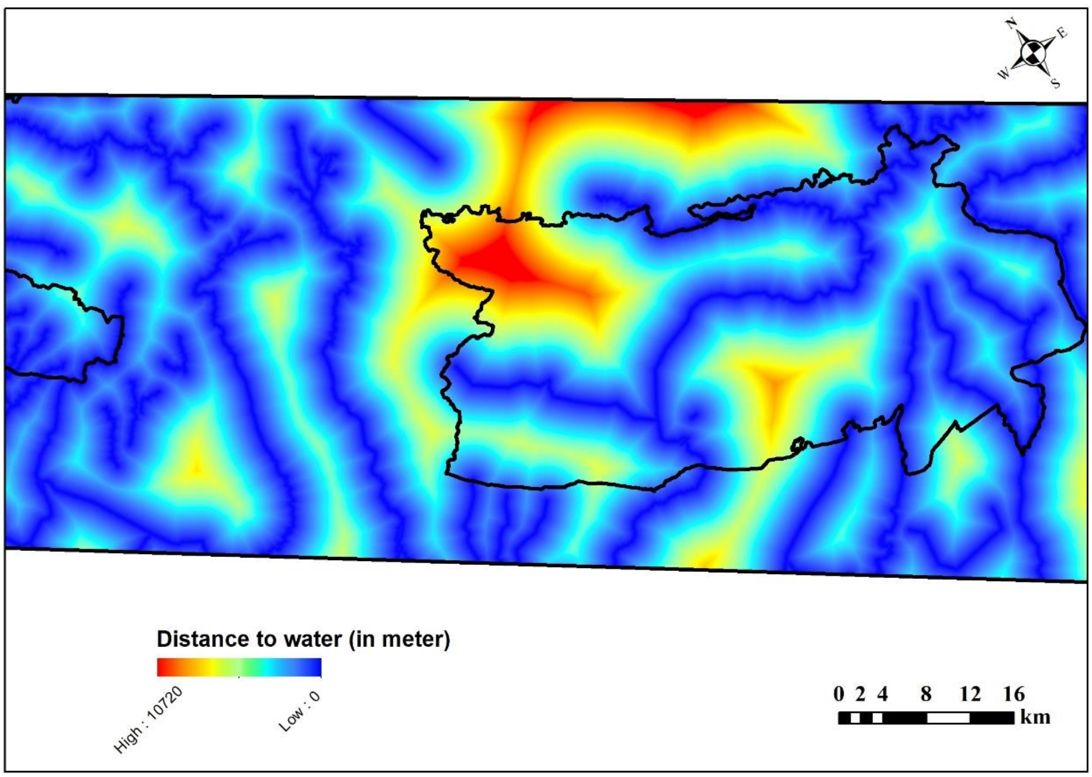
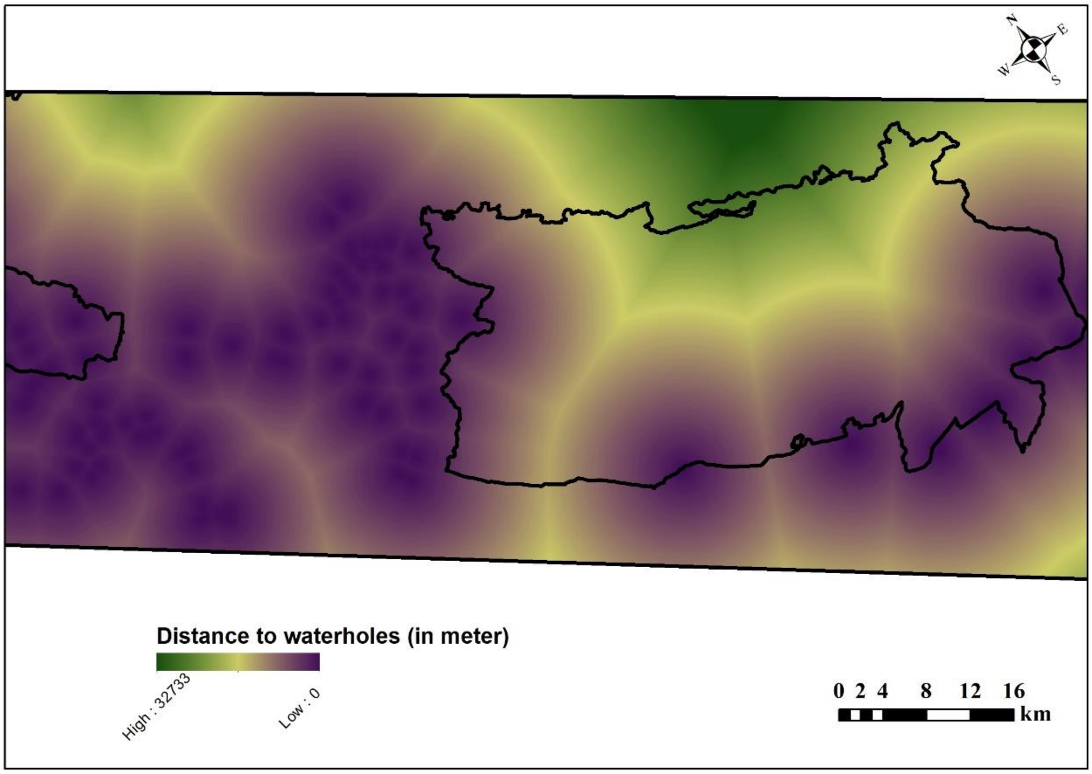


Figure: (8) DEM (elevation) and, **(9)** Euclidean distance maps of drainage system of the study area



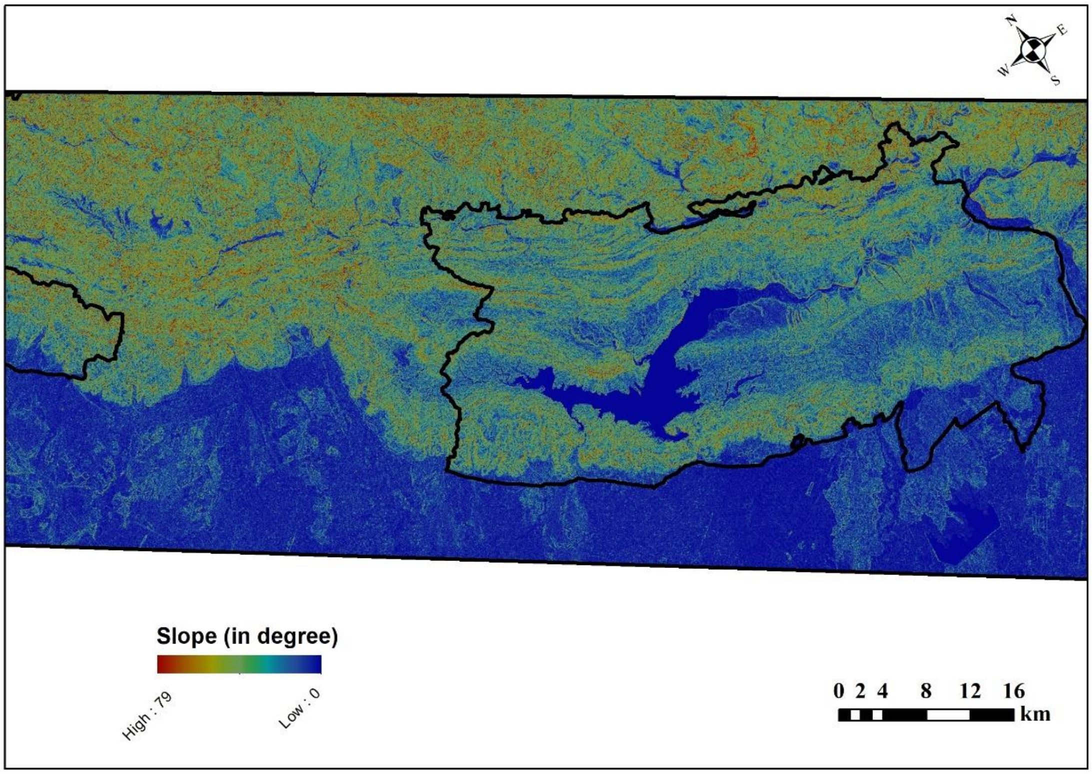
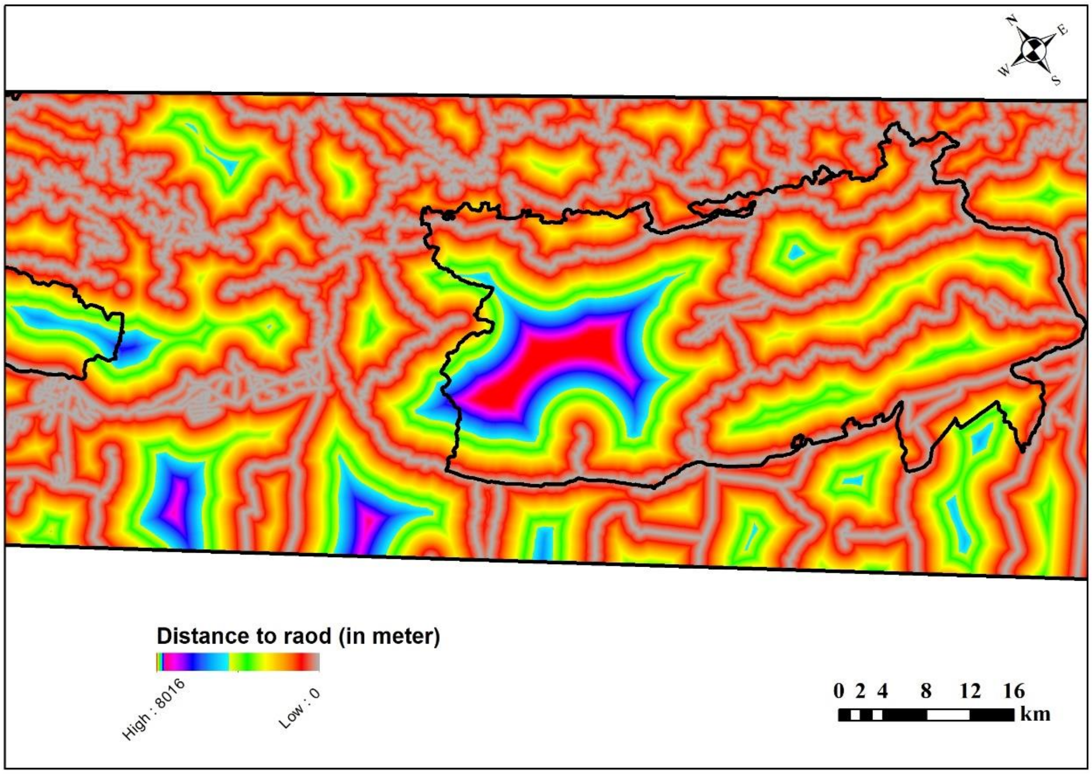


Figure: Euclidean distance map of **(10)** waterholes and, **(11)** slope of the study area



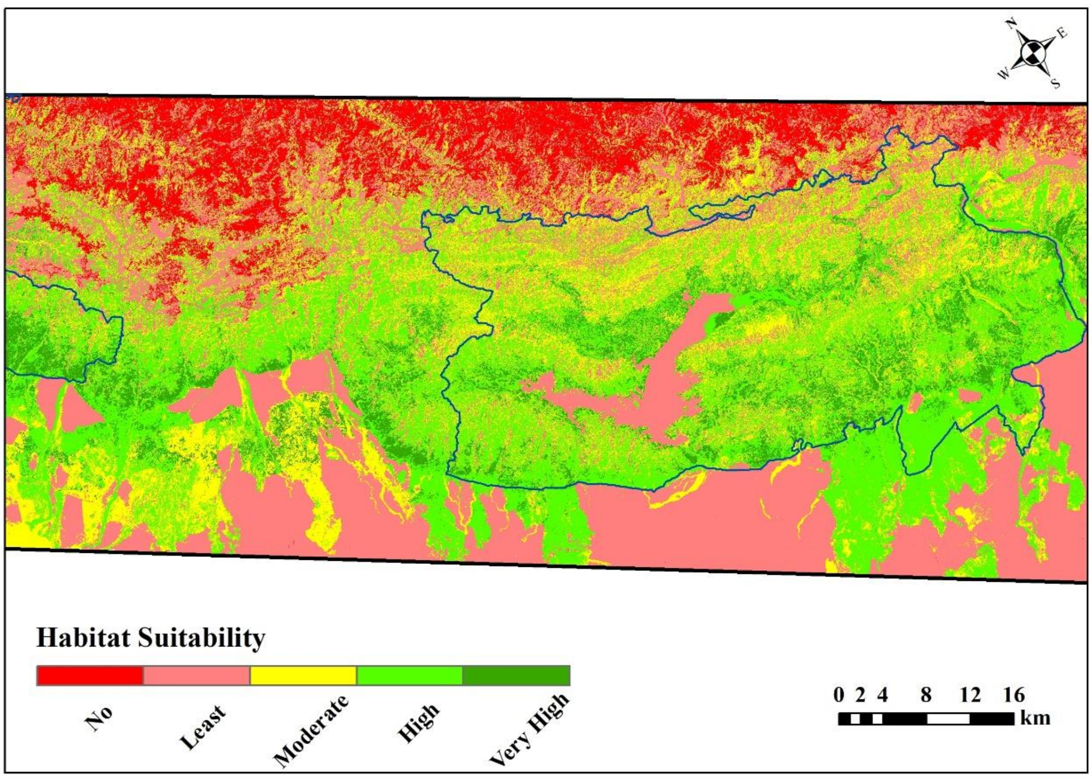


Figure: (12) Euclidean distance map of roads and, **(13)** Habitat suitability map of elephant

Human-Elephant Conflict Analysis

Out of total nine eco-geographical variables, contribution in the prediction of conflicts area was noticed highest for distance to forest boundary (0.98) and habitat suitability layers (**Figure 14**). The villages situated nearby forest boundary especially up to 6 km and adjacent to low suitable habitats have had high conflict incidences (**Figure 15**). Conflict prediction map also shows that villages situated in the areas landlocked by forests indicated high conflicts. These villages were mainly Laldhang, Sajanpur Pili, Shyampur, Missarpur, Katarpur, etc. Also, the temporal analysis based on human-elephant conflict data collected from the forest department and interviews taken from villagers during field survey have indicated high conflicts in winters followed by summers and monsoon. The reasons might be due to ripening of sugarcane and wheat crops and the low visibility due to fog in winters, the elephants are attracted towards agriculture fields. Hence, the conflict frequency between human and elephant due to increase in crop depredation and human mortality incidences are elevated.

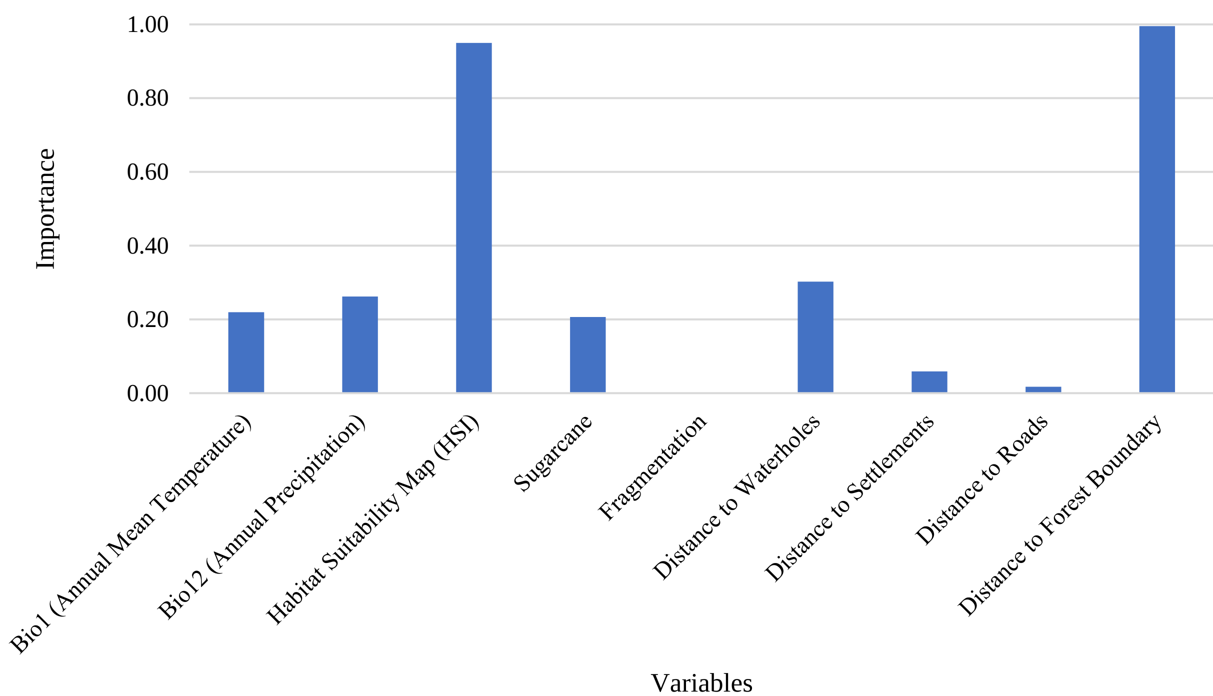


Figure 14. variable wise contribution in human-elephant conflict prediction

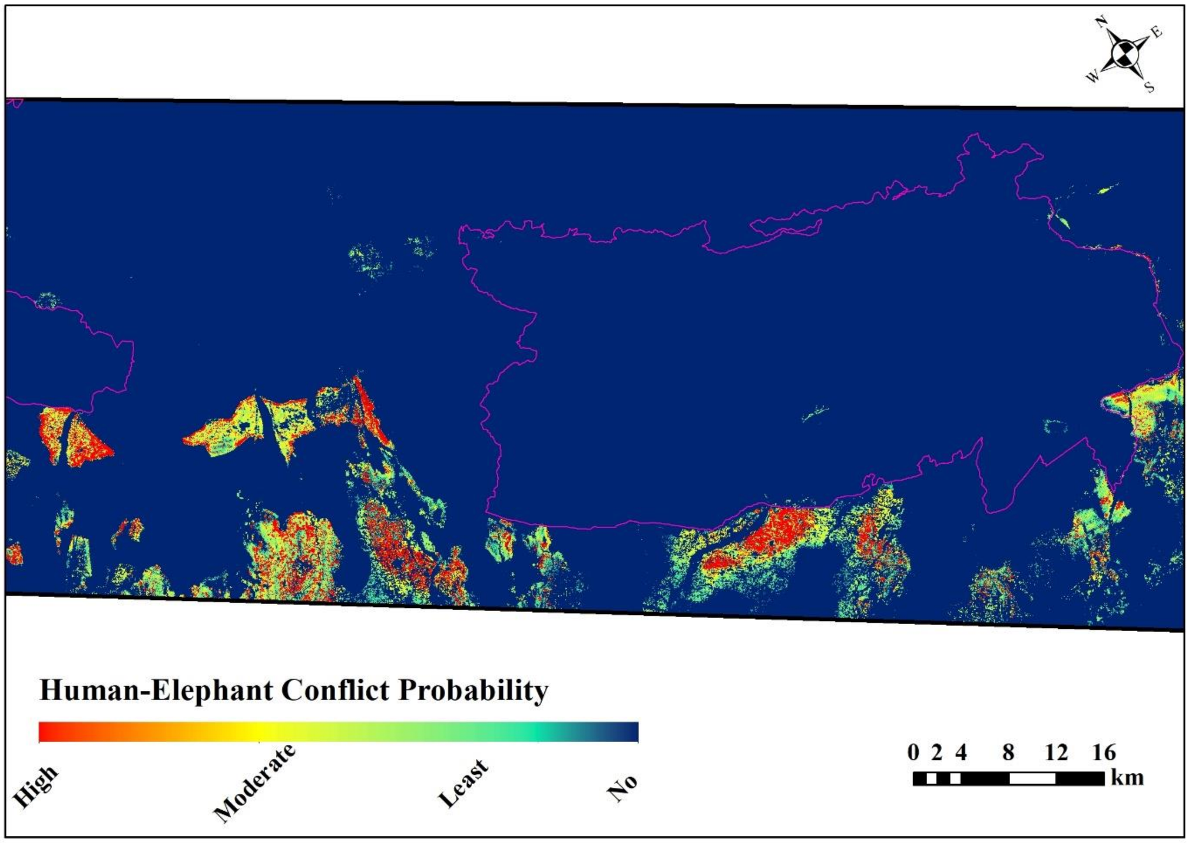


Figure 15. Prediction map of the human-elephant conflicts in the Study area

REFERRENCES

Sivakumar, K., Sathyakumar, S., & Rawat, G. S. (2010). A Preliminary Review on Conservation Status of Shivalik Landscape in Northwest India. *Indian Forester*, 136(10), 1376–1382.

Goswami, V. R., Vasudev, D., & Oli, M. K. (2014). The Importance of Conflict-Induced Mortality for Conservation Planning in Areas of Human-Elephant Co-Occurrence. *Biological Conservation*, 176, 191–198.

Venkataraman, A. (2005). What is an Asian Elephant (Elephas maximus) Corridor. *Right of Passage: Elephant Corridors of India. Wildlife Trust of India, New Delhi*, 24–33 Pages.

Singh, A. P., & Sharma, R. C. (2001). Conflicts Between Linear Developments and Asian Elephants in Sub-Himalayan Zone of Uttranchal (India). *In Proceedings of International Conference on Ecology and Transportation (ICOET 2001)*. 423-432 Pages.

Joshi, R., & Singh, R. (2008). Feeding Behaviour of Wild Asian Elephants (Elephas maximus) in the Rajaji National Park. *The Journal of American Science*, 4(2), 34–48.

Appendix 1. Elephants crossing the road which pass through Ramnagar forest division.

Appendix 2. Elephant feeding on one of its palatable species in Lansdowne forest division.

Appendix 3. Ground truth data collection for validating LULC and FCD maps.

Appendix 4. Boundary wall damaged by elephants in the Ramnagar forest division.

Appendix 5. Interview taken from the villagers about the human-elephant conflicts.

Appendix 6. Wheat crop field depredated by elephants in village situated on the southern fringe of Corbett national park.