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Nilgai (*Boselaphus tragocamelus*) Habitat Evaluation in Asola-Bhatti Wildlife Sanctuary, Delhi Using Multi-Criteria Analysis

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ABSTRACT

This study aims to assess Nilgai (*Boselaphus tragocamelus* Pallas) habitat in Asola-Bhatti Wildlife Sanctuary (WLS), Delhi, using Multi-Criteria Analysis (MCA). Nilgai is endemic to the Peninsular Indian and Indus divisions of the Indian sub-region in the Asian Indo-Malayan Region. It is a species of least conservation concern in its native range. The study was carried out in the Asola-Bhatti WLS, Delhi, located in the south-eastern part of the southern ridge, the south-east boundary spreading up to the Delhi-Haryana border. The Sanctuary covers an area of about 32.71 km^2. The vegetation is described as semi-arid thorny scrub, while it is designated as Northern Tropical Desert Thorn Forest (6BC$_1$) and scrub as *Ziziphus* scrub (6BDS$_1$). Nilgai habitat suitability in the study area was evaluated using MCA and a linear additive model using Cartosat-1, IRS P6 LISS-IV, and GoogleEarth data. MCA of Nilgai habitat was done using Analytical Hierarchy Process (AHP) through empirical judgement of preferences and an acceptable result was obtained, *i.e.,* 0.019, less than 0.1 which is considered as a standard consistency ratio. A model was processed on the reclassified thematic layers by assigning them weightage according to the preferred habitat of nilgai. Thus, 53% (17.28 km^2) area of the entire Sanctuary was demonstrated as highly suitable followed by 27% (8.98 km^2) as suitable, 8% (2.50 km^2) as moderately suitable, and 12% (3.95 km^2) as least suitable area for nilgai. From the results of the study, it can be concluded that all the predictor variables derived from satellite imagery demonstrated the usefulness of geospatial technology for habitat modelling.

Key words: Antelope, Habitat suitability, Geospatial Technology, Analytical Hierarchy Process, Conservation, Management, Aravalli.

INTRODUCTION

A good understanding of wildlife-habitat relationships is imperative to develop wildlife habitat management strategies and predicting population behaviour (Williamson et al. 2021). Habitat suitability assessment provides acumen on the spatial distribution of habitat for wildlife species. Wilderness areas and wildlife habitats are shrinking throughout the world (Kushwaha and Roy 2002, Nandy et al. 2019). Globalization along with the unprecedented growth of human population and resultant commercial exploitation of land has been a prime cause of the decline of wildlife in India (Alfred et al. 2001). Encroachments of natural habitats, poaching, and grazing are major issues, which threaten the wildlife habitats all over the world (Panwar 1991; Nandy et al. 2020). Habitat evaluation is the crucial first step for effective wildlife conservation. It is the assessment of the suitability of land or water as a habitat for specific wildlife species. The characteristics of the habitat can be evaluated based on key habitat factors using numerical ratings (Kushwaha and Roy 2002). Simultaneously, it has been made a prerequisite for the use of standardized procedures for habitat evaluation, both for cost reasons and for ease of communication of data both between and within organizations and professionals. The quickest, cost-effective, and accurate way for habitat evaluation is through the application of geospatial technology which includes remote sensing (RS), geographic information system (GIS) combined with global positioning system (GPS). Ground methods have been used since time immemorial to evaluate the habitats using various indices derived through intensive ground surveys (Lamprey 1963). Remote sensing and GIS have been widely used in wildlife habitat studies (Roy et al. 1995, Porwal et al. 1996, Kushwaha et al. 2000, Nandy et al. 2007, Nandy et al. 2012, Nandy et al. 2020). Habitat suitability index (HSI) models use binomial multiple logistic regression (Zarri et al.

2008, Nandy et al. 2020), refined logistic regression (Singh and Kushwaha 2011), geo-statistics (Kushwaha et al. 2004, Habib et al. 2010), multi-criteria analysis (MCA) using analytical hierarchy process (AHP) (Nandy et al. 2012) and other data integration techniques to calculate an index of species occurrence (Brown et al. 2000) to provide an effective and low-cost method for evaluating the habitat (Schamberger and Krohn 1982).

This study attempted to use MCA for the evaluation of the Nilgai habitat in Asola-Bhatti Wildlife Sanctuary, Delhi**.** Nilgai is a diurnal creature and is found almost everywhere in tropical forests. It is said to be a habitat generalist but has a tendency to occur in arid areas, dry deciduous forests, and thin bushes with scattered low trees or alterations of scrub and open grassy plains with either level or undulating topography, but often in cultivated areas and very rarely in thick forest (Prater 1980). It eats mainly shrubs and herbs, crops, and grasses. Dietary selection varies seasonally (Khan 1994, Prajapati and Singh 1994, Sankar and Vijayan 1992, Sharma 1981, Shukla and Khare 1998, Solanki and Naik 1998).

Nilgai (meaning blue cow), the largest antelope in Asia, is endemic to peninsular India and the Indus region of the Indian subcontinent in the Asian Indo-Malayan Region (Corbet and Hill 1992). The native range of nilgai in Asia includes the foothills of the Himalaya in Nepal (Dinerstein 1980), northeastern Pakistan (Mirza and Khan 1975), and almost all of India-stretching from the base of the Himalaya in the north to Karnataka in the south (Blanford 1888, Ellerman and Morrison-Scott 1966, Prater 1980). They live on a variety of land types from hillsides to level ground with scattered grasslands, woodlands, and scrub (Corbet and Hill 1992). It is a species of least conservation concern in its native range (IUCN 2006). The total number of this species in India is about 100,000 but have always been low in lowland Nepal (Adams 1858, Dinerstein 1979); and rare in Pakistan (Mirza and Khan 1975) and extinct in Bangladesh (Rahmani 2001, Mallon 2003). An ever-expanding human population and their enterprises are the main threat to Nilgai because humans destruct the habitat of this species. Nilgai is conserved in numerous National Parks and other Protected Areas (PAs) across India although most of the population occurs outside PAs (Rahmani 2001) as of now.

The animal is considered sacred by Hindus because of its resemblance to the cow and hence, rarely persecuted. Both the nilgai population and its preferred habitats have significantly shrunk over time.

STUDY AREA

Asola-Bhatti WLS, covering an area of 32.71 km^2 in the eastern part of the southern ridge of Delhi, is located between 28°24´52´´ to 28°29´45´´N and 77°11´32´´ to 77°16´13´´E (Fig. 1). Biogeographically, the entire Sanctuary represents oldest mountain system, *i.e., Aravalli*. The study area lies within 230-320 m amsl. Sangam Vihar is situated along the northern boundary. The Sanctuary area is surrounded by five villages- Satbari, Sahurpur, Maidangarhi in the west, Deoli village in the north-west, Tuglakabad in the north-east, Anangpur and Surajkund in the south. The Sanctuary is divided into two parts - Asola on the northern side and Bhatti, on the southern side. The Asola and Bhatti areas were declared as WLS by the Government of Delhi under Section-18 of the Wildlife (Protection) Act, 1972 in the year 1986. The Bhatti area was annexed into the Sanctuary in 1991. By then, the Bhatti area was severely altered by mining. A scheme for reclamation of Bhatti mines by Eco-Task Force (ETF), Territorial Army has been implemented. The entire area of Sanctuary is degraded, dry, and has mine pits (Sati and Khanna 2003).

The soil is thin, skeletal, dry, and sandy with high porosity and low humus content, supporting sparse vegetation of shrubby nature (Sawarkar and Hussain 1997). The extensive weathering of the quartzite rocks yields high-quality silica sand, locally known as *Badarpur Bajri*. The climate is semi-arid and the temperature rises to 45°C in summer and dips to 4-5°C in winter. The annual precipitation is about 711 mm falling mainly during monsoon months (July - September). Maheswari (1963) described the vegetation as semi-arid thorny scrub while Champion and Seth (1968) designated it as *Northern Tropical Desert Thorn Forest* ($6BC_1$) and scrub as *Zizyphus* scrub ($6BDS_1$). There are about 150 plant species in the Sanctuary (Sawarkar and Hussain, 1997). The total growing stock of the Sanctuary was estimated to be 20,772.95 m^3 while the total biomass stock

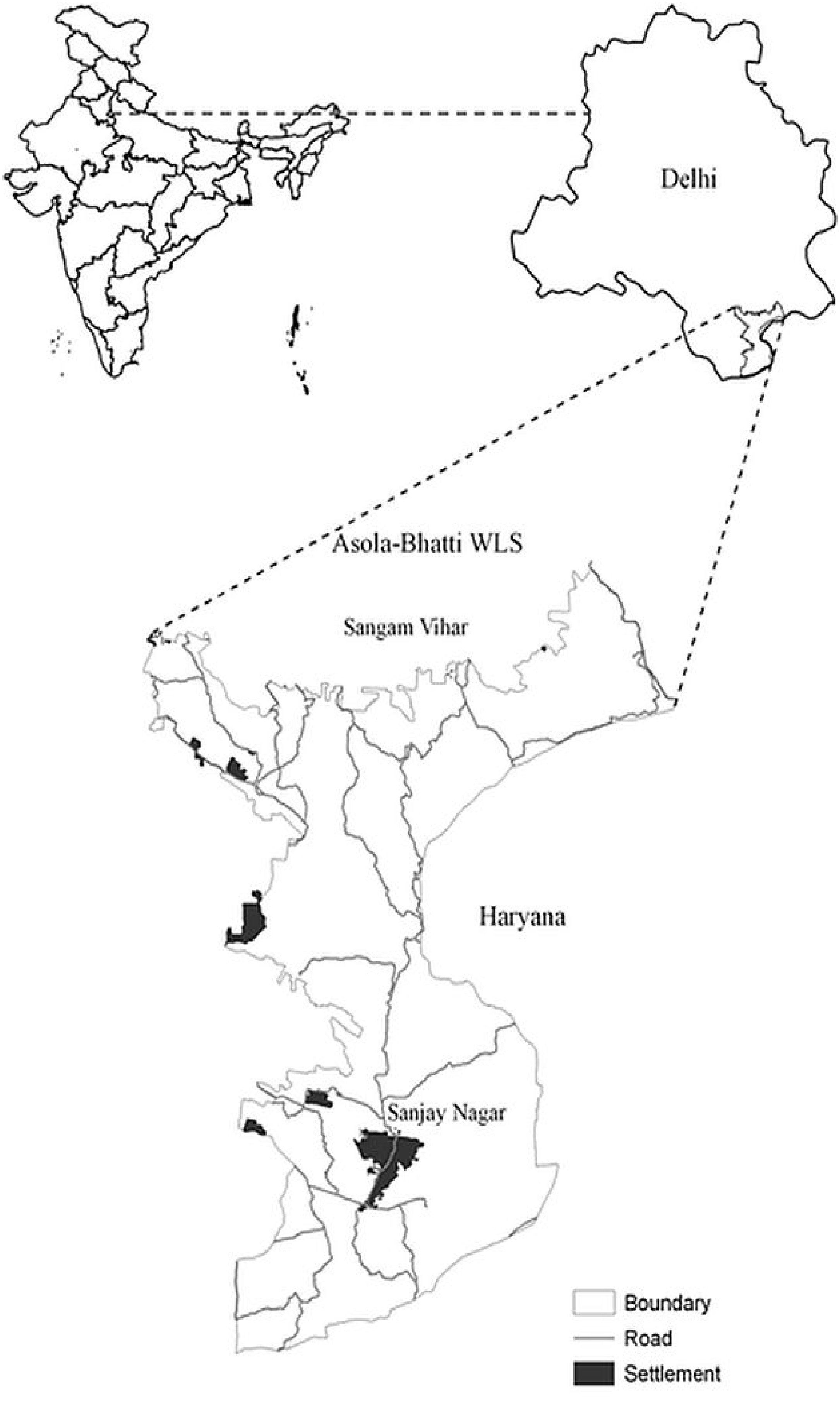

Figure 1. Location of the study area

worked out to be 19,366.83 tonnes (Kushwaha et al. 2014). The Sanctuary is home to a large number of animals ranging from invertebrates to amphibians, reptiles, birds, and mammals (Khanna and Sati 2003). The Sanctuary is surrounded by human habitations on all sides. Hence, the wilderness area and wildlife area within the Sanctuary is shrinking due to the biotic pressure. Latter is increasing with time due to encroachment, livestock grazing, farming along the fringes, dumping of degradable and non-degradable garbage, fuel wood collection, and collection of non-wood forest products and fodder. The boundary of the Sanctuary at some places is under dispute with the residents of adjoining areas.

MATERIALS AND METHODS

The detailed methodology followed for the study is presented in Figure 2. The false color composite (FCC) of IRS-P6 LISS-IV data, with spatial resolution of 5.8 m (Fig. 3a) and high-resolution Cartosat-1 data, with spatial resolution of 2.5 m, were used for the present study. Ancillary data like topographic maps were also used. The radiometric correction was carried out to minimise the topographic and atmospheric effects by the dark pixel subtraction technique (Lillesand et al. 2015). The LISS-IV image was geometrically corrected using Landsat TM orthorectified image and then Cartosat-

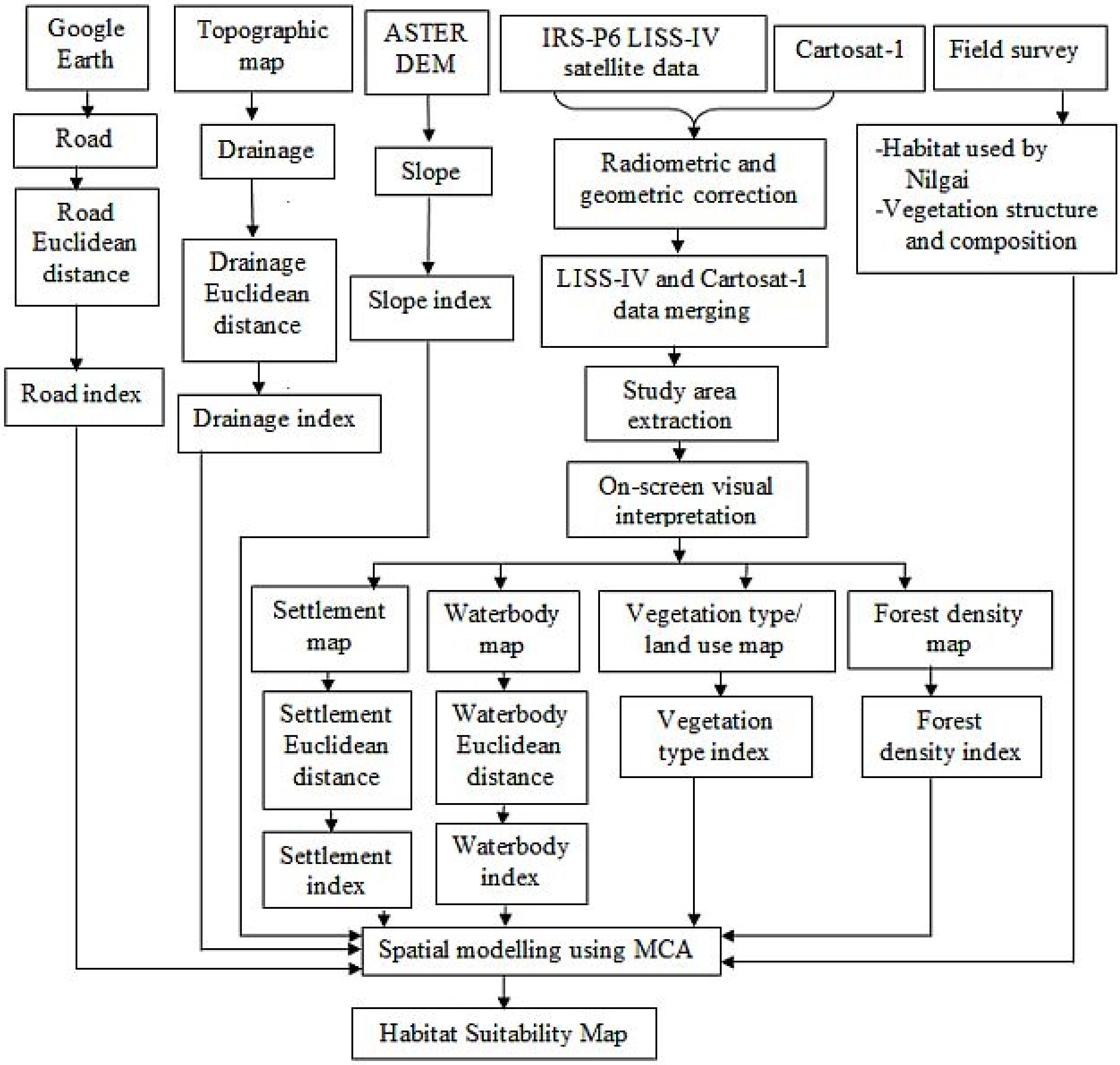

Figure 2. Paradigm of the study

1 was georeferenced with the LISS-IV image. Both the data sets were merged to get a merged LISS-IV and Cartosat-1 data, with the end resolution of 2.5 m. The area of interest (AOI) layer was extracted using Sanctuary boundary provided by the Deputy Conservator of Forests, Asola-Bhatti WLS. The boundary (boundary wall) of the Sanctuary was modified by delineating partly from the merged LISS-IV and Cartosat-1 data and partly from *GoogleEarth*.

The FCC was taken to the study area to relate the image characteristics with actual ground features to generate a vegetation type/land use and forest density maps of the study area. Presence points (direct sighting and indirect evidences) of *Nilgai* were noted using a handheld Trimble Juno-SD GPS. Habitat features of that location were also noted for data analysis and further interpretation. The image features on the satellite data were interpreted for vegetation type/land use types as well as forest density classes using various image elements, *viz*., tone, texture, pattern, shape, size, shadow, location, and association. Various land cover categories were classified, correlated, and interpreted using on-screen visual interpretation. Maps were prepared on a 1:12,500 scale using Universal Transverse Mercator (UTM) projection and WGS 84 datum. The area under different vegetation types/land uses and forest densiy categories are shown in Table 1 and 2, respectively. The digital database of the study area included various vector layers such as vegetation type/land use types, forest canopy density, drainage, settlement, road, water body/waterholes, etc. were prepared in the GIS environment. All thematic layers, which represent the integration of food and cover (vegetation cover, forest density and water body), physical landscape (slope and elevation), and human activities (road, and settlement) were reclassified into habitat values by assigning numerical ranks based on their suitability on a scale of 1 to 4 in decreasing order of suitability like value 1 was assigned to highly suitable and 4 to least suitable habitat. Habitat Quality Rating (HQR) assessment was done based on the status of the animal in the field (and the literature reviewed) during the entire study. Euclidean distance maps were prepared for waterbody, drainage, road, and settlement and HQR was assigned to different distances for each class. HQRs for various thematic layers are given in Table 3. Finally, a linear additive model was run to evaluate the habitat suitability for Nilgai. Weights were assigned to different thematic layers during Multi-Criteria Analysis (MCA), using Analytical Hierarchy Process (AHP) – a decision-aiding method developed by Saaty (1980).

In AHP, the pair-wise comparison matrix of seven variables, *viz*., vegetation type/land use, forest density, waterbody, slope, drainage, settlement, and road was generated (Table 4), which was then converted to a synthesized matrix by dividing each element of the matrix by its column total (Table 5). The row averages (Table 5) were used to find out the priority vectors. Following Saaty (1980), the consistency ratio was found to be 0.019 (<0.1), which indicates that the calculation is acceptable. The weights (priority vectors) of the seven variables, obtained from AHP analysis, were used in a linear additive model as:

$$HSI = 0.352 \times FDI + 0.257 \times VTI + 0.162 \times WI + 0.102 \times SLI + 0.063 \times DI + 0.039 \times STI + 0.025 \times RI$$

where, HSI = Habitat suitability index, FDI = Forest density index, VTI = Vegetation type index, WI = Waterbody index, SLI = Slope index, DI = Drainage index, STI = Settlement index, RI = Road index.

RESULTS AND DISCUSSION

The various vegetation type/land use types existing in the study area are shown in Figure 3b. The vegetation type/land use map is divided into 8 classes. *P. juliflora* was found to be the dominant vegetation covering an area of 23.43 km^2 (71.62%) followed by scrub with an area of 3.94 km^2 (12.04%), *Anogeissus pendula,* which was found as sparsely distributed in various locations within the entire Sanctuary, having an area of 0.09 km^2 (0.29%) (Table 1). Forest plantations, non-forest, rock outcrops, waterbody, and settlements covered the rest of the area of Sanctuary. Forest plantations covered 4.01% area.

Forest density was divided into three classes, *i.e.*, 10-40% as low density, 40-70% as moderate density, and more than 70% as high density (Fig. 3c). Of the 32.71 km^2 of Sanctuary, only 7.70% (2.51 km^2) was found to have high forest density. Moderate density

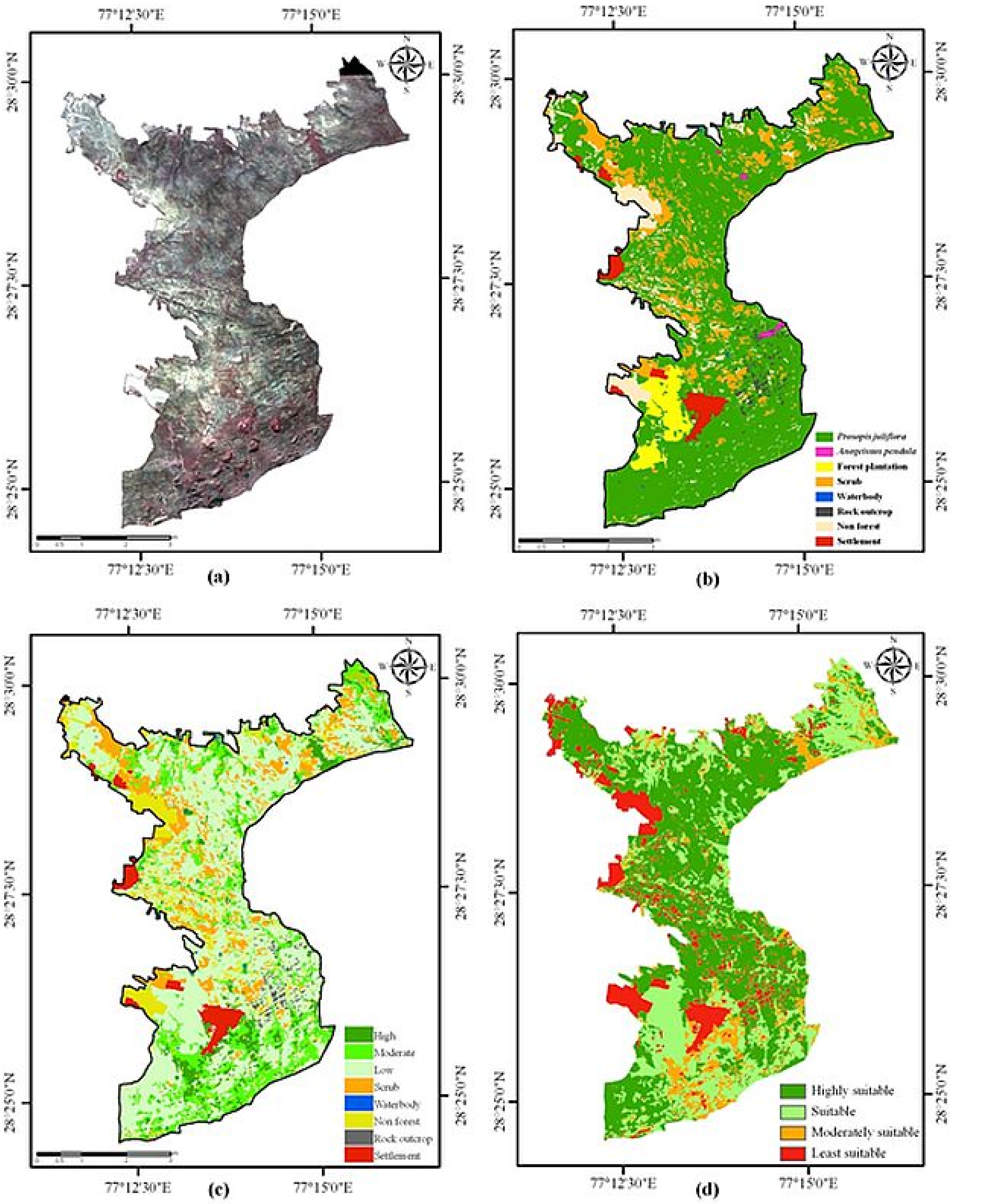

Figure 3. (a) False colour composite of Cartosat-1 and IRS-P6 LISS-IV merged data, (b) Vegetation type/ land use map, (c) Forest density map, and (d) Habitat suitability map

Table 1. Area under different vegetation type/land use types

Vegetation type/land use	Area (km^2)	Area (%)
Prosopis juliflora	23.43	71.62
Anogeissus pendula	0.09	0.29
Forest plantation	1.31	4.01
Scrub	3.94	12.04
Non-forest	2.59	7.93
Rock outcrop	0.34	1.03
Waterbody	0.05	0.16
Settlement	0.96	2.92
Total	**32.71**	**100.00**

Table 2. Area under different forest density classes

Forest density classes/ land use	Area (km^2)	Area (%)
High	2.52	7.70
Moderate	5.31	16.22
Low	17.01	52.00
Scrub	3.94	12.04
Rock outcrop	0.34	1.03
Waterbody	0.05	0.16
Non-forest	2.59	7.93
Settlement	0.96	2.92
Total	**32.71**	**100.00**

Table 3. Habitat quality rating (HQR) for forest density, vegetation type/land use, and distances to waterbody, drainage, slope, settlement, and road

Forest density		**HQR**
1.	High density (>70%)	3
2.	Moderate density (40-70%)	2
3.	Low density (10-40%)	1
4.	Scrub	1
5.	Water body	4
6.	Rock outcrop	4
7.	Non-forest	4
8.	Settlement	4
Vegetation type/land use		
1.	Scrub	1
2.	*Prosopis juliflora*	2
3.	*Anogeissus pendula*	3
4.	Forest plantation	3
5.	Waterbody	4
6.	Rock outcrop	4
7.	Non-forest	4
8.	Settlement	4
Distance to water body		
1.	< 500m	1
2.	500-1000m	2
3.	1000-1500m	3
4.	> 1500m	4

Distance to drainage		**HQR**
1.	< 500 m	1
2.	500-1000 m	2
3.	1000-1500 m	3
4.	> 1500 m	4
Degree for slope		
1.	< 5º	1
2.	5-10º	2
3.	10-15º	3
4.	>15º	4
Distance to settlement		
1.	> 750m	1
2.	500-750m	2
3.	250-500m	3
4.	< 250m	4
Distance to road		
1.	> 750m	1
2.	500-750m	2
3.	250-500m	3
4.	< 250m	4

(1 - Highly suitable, 2 - Suitable, 3 - Moderately suitable, 4 - Least suitable)

vegetation covered 16.22% (5.30 km^2) area, while 52% (17.01 km^2) of the Sanctuary had low density forest vegetation (Table 2). Thus, the result indicates that low density forest and scrub majorly occupy the Sanctuary area. Low density forest is the result of the anthropogenic pressure which, if not prevented, may lead to the total forest loss in the WLS.

The habitat suitability map (Fig. 3d), generated from the above analysis, indicated 52.82% (17.28 km^2) area to be highly suitable, 27.44% (8.98 km^2)

Table 4. Pair-wise comparison matrix

Category	Forest density	Vegetation type	Waterbody	Slope	Drainage	Settlement	Road
Forest density	1	2	3	4	5	7	9
Vegetation type	1/2	1	2	3	5	7	9
Waterbody	1/3	1/2	1	2	3	5	7
Slope	1/4	1/3	1/2	1	2	3	5
Drainage	1/5	1/5	1/3	1/2	1	2	3
Settlement	1/7	1/7	1/5	1/3	1/2	1	2
Road	1/9	1/9	1/7	1/5	1/3	1/2	1
	2.54	4.29	7.18	11.03	16.83	25.50	36.00

Table 5. The synthesized matrix

Category	Forest density	Vegetation type	Waterbody	Slope	Drainage	Settlement	Road	Priority vector
Forest density	0.394	0.466	0.418	0.363	0.297	0.275	0.250	0.352
Vegetation type	0.197	0.233	0.279	0.272	0.297	0.275	0.250	0.257
Waterbody	0.131	0.117	0.139	0.181	0.178	0.196	0.194	0.162
Slope	0.099	0.078	0.070	0.091	0.119	0.118	0.139	0.102
Drainage	0.079	0.047	0.046	0.0454	0.059	0.078	0.083	0.063
Settlement	0.056	0.033	0.028	0.030	0.030	0.039	0.056	0.039
Road	0.044	0.026	0.020	0.018	0.020	0.020	0.028	0.025
								1.000

Table 6. Area under different habitat suitability classes

S. No.	Class	Area (km^2)	Area (%)
1.	Highly suitable	17.28	52.82
2.	Suitable	8.98	27.44
3.	Moderately suitable	2.50	7.65
4.	Least suitable	3.95	12.08
	Total	**32.71**	**100.00**

as suitable, 7.65% (2.50 km^2) as moderately suitable and 12.08% (3.95 km^2) as least suitable (Table 6). The fact that 52.82% area of the Sanctuary is highly suitable for Nilgai indicates that Asola-Bhatti makes one of the most potential habitats for Nilgai. The validation of the habitat suitability map was carried out in the field during subsequent visits at 24 locations spread all over the Sanctuary area. The result indicated that the habitat suitability map generated was 88.88% accurate. Anthropogenic disturbances like fuelwood and fodder collection are leading to habitat loss for Nilgai. The competitive superiority of stray cattle against the Nilgai, may lead them to migrate elsewhere or exterminate instead of anticipated recovery of the site. Thus, cattle grazing also affects the habitat of Nilgai. Nilgai is found in either flat or undulating terrain but not on steep slopes like in Bhatti mines. Hence, the Bhatti mines area was placed under the least suitable category.

The current investigation underscores the application of geospatial technology for the swift assessment of wildlife habitats. It emphasizes the significance of MCA in habitat evaluation, with AHP being a commonly utilized tool for managing diverse criteria and decision-making in habitat suitability analysis. Previous studies, such as Nandy et al. (2012) on swamp deer in Jhilmil Jheel Conservation Reserve, Uttarakhand, India, and Imam and Tesfamichael (2013) on tiger habitats in the Motichur range of Rajaji National Park, India, support the efficacy of AHP in habitat identification. These studies advocate the collective potential of RS, GIS, and AHP in wildlife habitat evaluation, emphasizing their effectiveness. A similar methodology was employed by Kumar et al. (2023) to map the suitability of Asian elephant habitats in Alur Taluk, Central Western Ghats, with a notable emphasis on its usefulness for conservation efforts.

Habitat suitability of Blue bull (*Boselaphus tragocamelus*) was mapped by Dhami et al. (2023) across Nepal. They explored the influence of environmental variables on the distribution of Blue bulls in Nepal and identified potential conflict zones. Employing ensemble modeling, the study conducted a habitat suitability analysis for Blue bulls, selecting 15 ecologically significant environmental variables and employing ten species distribution modeling algorithms. The findings indicate that 15.26% of Nepal's area is suitable for the Blue bull, with key environmental contributors including slope, precipitation seasonality, and distance to roads. Furthermore, 45% of the predicted suitable habitats coincide with agricultural land, highlighting the potential for conflicts between humans and Blue bulls. Hence, geospatial technology along with HSI model can provide an efficient, quick, cost-effective and accurate method of wildlife habitat evaluation. The habitat suitability maps and models serve as important tools for wildlife habitat conservation and management.

CONCLUSIONS

Overall results of the study indicated the habitat suitability status of Nilgai in Asola-Bhatti WLS, Delhi. It was found that most of the Sanctuary area is under low forest density. Hence, measures must be taken to improve the forest density. The anthropogenic pressure and cattle grazing must be reduced to improve the habitat quality for nilgai. From the results of the study, it can be concluded that all the predictor variables derived from satellite imagery demonstrated the usefulness of geospatial technology for habitat modelling. This study can be used as a baseline to carry out further research work in the Sanctuary as it was the first study for evaluation of the nilgai habitat in this Sanctuary. This study can also be an important input in the preparation of the management plan for the Sanctuary.

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