Habitat suitability analysis for blackbuck (*Antilope cervicapra*) in Nahar Wildlife Sanctuary, Haryana, India

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Remote sensing and GIS play an important role in wildlife species conservation through their applicability to study spatial distribution, landscape pattern and also factors that affect the distribution, density and movement of wild fauna. The present study deals with the distribution of blackbuck (*Antilope cervicapra*) in Nahargarh Wildlife Sanctuary, Haryana, India, and to determine their habitat suitability which is shrinking due to the spread of settlements (urban and rural). For habitat suitability analysis of blackbuck, data from WorldClim, 19 bioclimatic variable layers such as temperature, humidity, precipitation, etc. were utilized to calculate the maximum entropy using MaxEnt version 3.2. Satellite data from Landsat 8 were used to generate land use and land cover for analysing habitat suitability. An area of 330.71 ha was found to be suitable for blackbuck habitat within the 10 km buffer area, against the present area of 28.32 ha. The growth of *Prosopis juliflora* which causes damage to the skin of blackbuck during movement was found to be another factor responsible for confining its niche within the Sanctuary. The present study will help in the effective safeguarding of blackbuck species by the Wildlife Wing of the Haryana Forest Department.

Keywords: Bioclimatic variables, blackbuck, habitat suitability, remote sensing, spatial distribution.

CONSERVATION of forest and wildlife habitat has gained importance with changes in land use and land cover (LULC), climatic variables, and decrease in the number of species. Continuously changing forest areas have affected biodiversity and threatened the ecological balance. It has more relevance for a developing country like India, which is under going fast changes in urban and rural expansion, industrial pattern and agriculture. The unprecedented changes in forest ecology are caused by anthropogenic factors and hence, forests need to be protected to maintain the ecological balance[1]. Environmental conditions within the geographic range currently occupied by a species only approximately reflect its physiological tolerances[2–5]. Geographic ranges potentially can be affected by other factors such as dispersal[6], biotic interactions[7,8], stochastic factors[9], macro-evolutionary history[10], etc.

The conservation strategies devised in 1989 by the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, included positive steps to be taken to convert protected forests (PFs) and Reserved Forests (RFs) into eco-sensitive zones, to minimize the effects of anthropogenic activities into the core area. The role of geospatial techniques in analysing the habitat of wildlife species is becoming more important because of many advantages deciphered. This can provide an insight into factors (temperature, precipitation, land use, etc.) and their influence on wildlife density, movement and distribution in an area[11–13]. Conservation of forest and wildlife demands delineation of characteristics of space and habitat of a particular species and can be achieved using the existing GIS models or any new model. The distribution of Kashmir musk deer was studied by Singh *et al.*[14] using maximum entropy model by compiling the occurrence record of the species which was validated genetically. The distribution of this species was found limited to central Nepal on the east and northeast Afghanistan on the west, primarily determined by temperature and precipitation of the dry and wet quarter[14]. Another study using the MaxEnt model was used to predict habitat and distribution of Nilgiri wood pigeon in the Western Ghats, India, and proved to be a successful to find a high degree of suitability[15]. The unsuitability of *Passer domesticus* (house sparrow) in the future (2050–70) was predicted in the Guntur region, Andhra Pradesh, India, using maximum entropy model and studying the future climatic scenario[11]. A study to establish the current and future distribution of Himalayan musk deer (*Moschus chrysogaster*) was also carried out using MaxEnt and global climate models (GCMs) in Nepal and adjoining Himalaya ranges[16]. The deep learning modelling approach utilizing MaxEnt was employed by the authors in this study to establish the habitat distribution of blackbuck.

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A study of habitat suitability analysis for blackbuck was considered at the Nahar Wildlife Sanctuary, Haryana, India, as blackbuck has been reintroduced in this Sanctuary. Also, restoration work of the habitat is underway since 2014. Considering the advancement in geospatial technology in terms of spatial and radiometric resolution, this study explores the applicability of GIS techniques. The importance of the study lies in the fact that blackbuck is the state animal of Haryana and is under the 'endangered' category of the IUCN list.

The blackbuck favours open areas or grasslands, bushland, scrubland and is found in the piedmont region of Shivalik, western Indian and east Pakistan[17,18]. Once powerful Indian blackbuck *Antilope cervicapra* (state animal of Haryana) family is shrinking in population currently and is listed as an endangered species in Schedule 1 of the Indian Wildlife Act, 1972 along with tigers and Rhinos. The blackbuck population is shrinking at an alarming rate in Punjab and the Rajasthan plains[19]. The natural habitat for blackbuck comprises arid and semi-arid regions of the world and its distribution is being affected by the reduction in grasslands[20].

Importance of the present study

This study was conducted to find the reasons for the shrinking population of blackbuck. The suitability of habitat for any species varies from one place to another due to different climatic conditions. Thus, it is difficult to determine the perfect habitat suitability[21]. Different GIS techniques with remote sensing data can suggest suitable areas of habitat of different species based on the bioclimatic conditions of an area. A deep neural network or maximum entropy (MaxEnt) approach has been applied to the data to predict suitable areas of habitat[22–25]. In the present study, we evaluate the habitat of blackbuck (*A. cervicapra*) in the Nahar Wildlife Sanctuary using geospatial techniques to delineate suitable areas for their conservation. The project was conducted as a pilot study for the Haryana Forest Department (HFD) to identify suitable habitats of the state animal (blackbuck) and suggest areas for its niche expansion. It is expected to extend this study to the entire state, for restoration of habitat of this endangered species.

Study area

Nahar Wildlife Sanctuary is situated in the Kosli subdivision of Rewari district, Haryana, located between 28°24′10″–28°25′00″N lat. and 76°24′00″–76°25′50″E long.[19]. It covers an area of about 522.25 ha. The study area comprises of 10 km buffer created around Nahar Wildlife Sanctuary, including the total area (40,131.68 ha) of the Sanctuary.

The Sanctuary is divided into three unequal parts, i.e. two parts by the State Highway blocking the natural wildlife corridor into 331 and 93 acres and another part of 98 acres north of this area (http://haryanaforest.gov.in/en-us/Wild-Life/Protected-Area/Nahar-Wildlife-Sanctuary-District-Rewari) (Figure 1). The area was managed as RF before its declaration as a Sanctuary in 1987. Extreme temperatures are recorded in the summer and winter months. The highest temperature is recorded in June before the onset of monsoon (46°C), and the lowest temperature is recorded in January (0°–2°C).

Materials and methods

In the present study, the Landsat 8 (OLI) datasets for 2021 (March) have been utilized for suitability analysis. ArcGIS 10.8 and MaxEnt were used to analyse habitat suitability. Twenty-five presence points (.csv) for blackbuck were located where the species was present in the study area. Figure 2 is a flow chart depecting the methodology applied for assessment and analysis of the blackbuck habitat in the study area. Figure 3 is a photograph depecting the ground survey for locating the blackbuck in the study area.

Nineteen bioclimatic factors such as temperature of the warmest month and the coldest month, annual precipitation, humidity, etc. were extracted at a spatial resolution of 818 m (30 sec) and converted into ASCII format along with the LULC layer. The spatial extent and distribution are required in ASCII format as input by MaxEnt. All the layers were brought to the same projection system GCS (WGS 1984), with the same extent and similar pixel size of 818 m. Jack-knife regularized training to gain and random test percentage (25%) were used with the linear, quadratic, product and hinge features for habitat suitability. This shows the importance of different variables that are given as input to MaxEnt in graphical form. The MaxEnt highlights the contribution of individual variables (maximum, average, minimum) and their combination in analysing the habitat suitability.

The generative MaxEnt model which uses response variables for presence-only data was used in this study. The response variable, C was modelled not directly as a response to explanatory variables Z_j (EVs), but to a set X of m derived variables, X_k (DVs) obtained from Z_j by transformation. The general relationship between X_k and Z_j is given by transformation and back-transformation functions h and h^{-1} respectively, as follows

$$X_k = h_k(Z) \leftrightarrow Z_j = h_j^{-1}(X).$$

The utility of deep learning in model building is based on two major components, i.e. entropy and constraints. The model was calibrated for the presence of species locations (entropy) and these locations were constrained by the environment variables prevalent in the study area. The probability densities of the presence locations and background

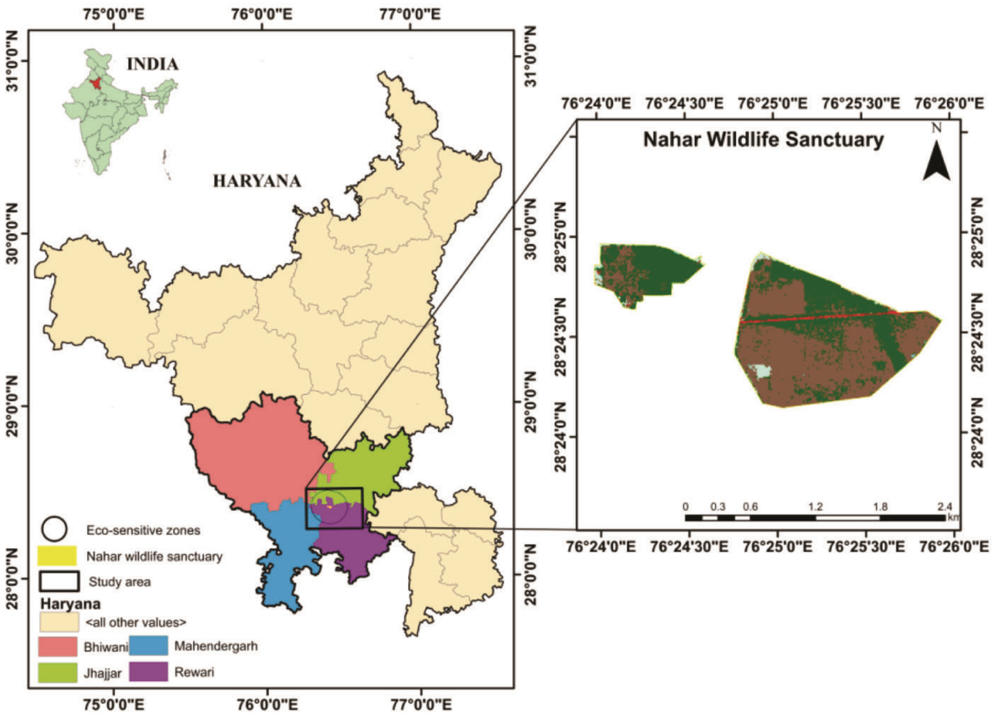

Figure 1. Location of Nahar Wildlife Sanctuary, Haryana, India.

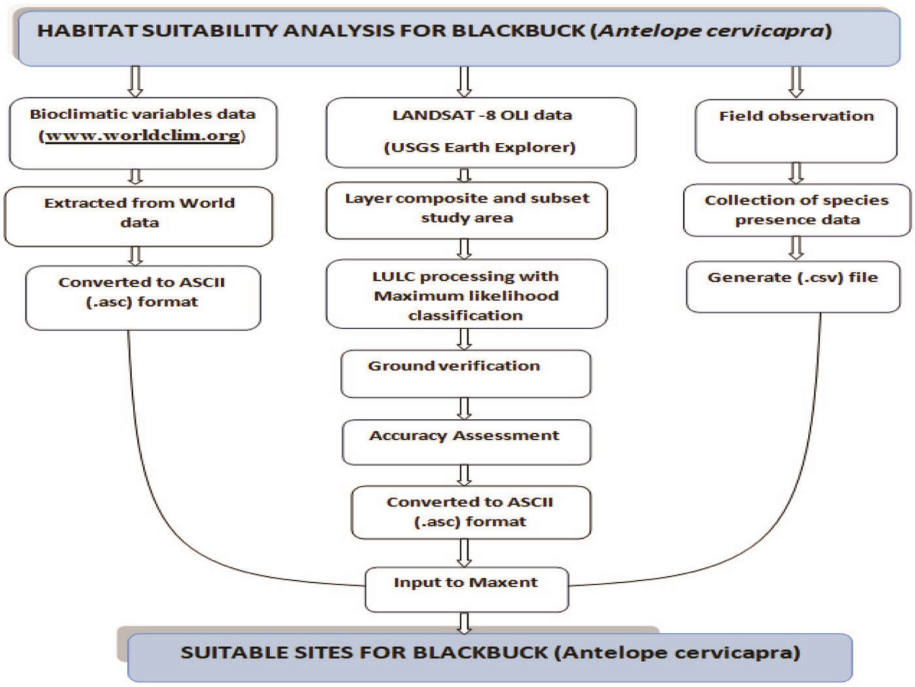

Figure 2. Methodology flow chart.

densities were compared using MaxEnt to estimate the presence probability for blackbuck in each pixel of the map.

To reduce the biases in the result, the random test percentage was set to 25% so that it not only considered the presence data (specified ground data), but other areas as well for suitability analysis. The presence of blackbuck in the Sanctuary was confirmed by taking ground surveys and the GPS coordinates were collected (GARMIN 72H GPS). The sub-sampling technique of random sampling

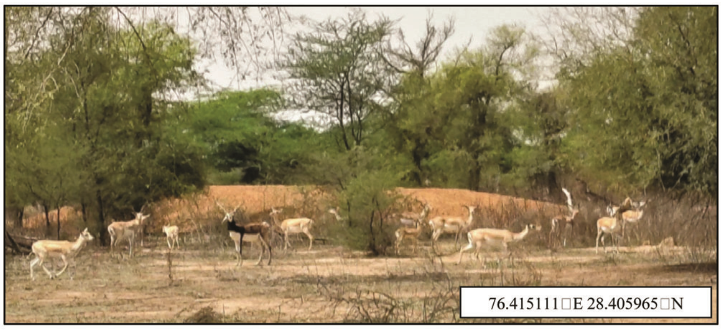

Figure 3. Presence point of blackbuck, *Antilope cervicapra* within the study area.

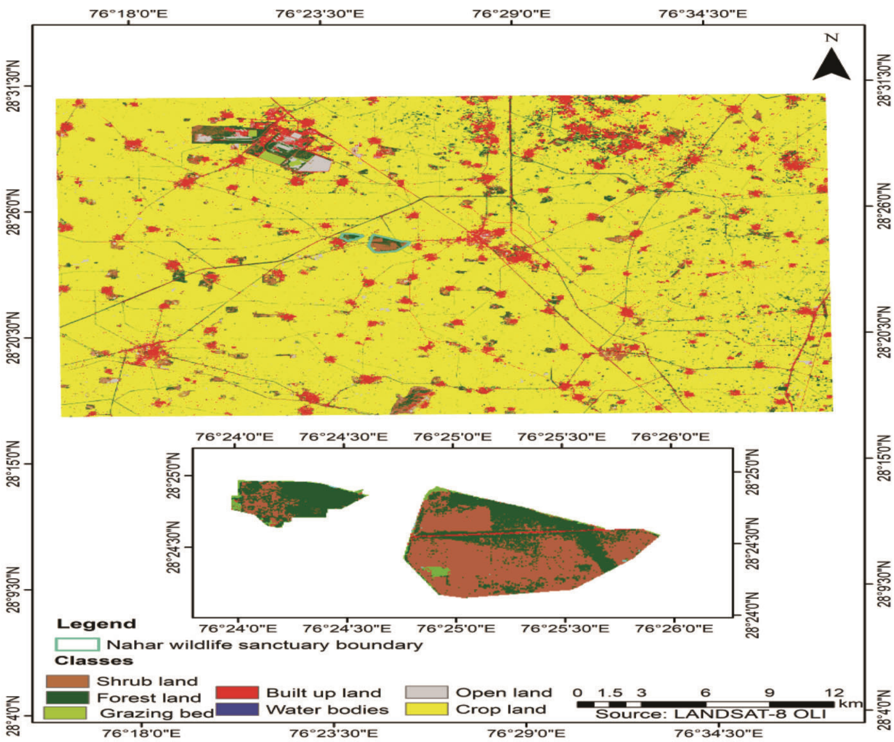

Figure 4. Land-use/land-cover map of the study area.

with a set of 15 replications to quantify the variability in the model output was used in the study. The vegetation of the area was also studied to aid in determining the habitat suitability of blackbuck.

Results and discussion

Land-use/land-cover classification

The analysis of OLI satellite datasets for LULC in the study area within the eco-sensitive zone (ESZ) has revealed that the area is dominate by croplands (76,350.5 ha) followed by built-up land (4555.15 ha), shrublands (6299.73 ha) and open lands (600.76 ha) and forest land (4410.93 ha). As shrublands and open areas are favourable for the blackbuck habitat, the LULC layer can help in identifying the most suitable area for the habitat of species. Figure 4 shows that shrublands are favourable for blackbuck habitat in the Nahargarh Sanctuary.

The LULC map prepared using the satellite datasets of 2021 indicate that considerable area under shrublands within the notified Wildlife Sanctuary is dominated by *Prosopis juliflora* sp., restricting blackbuck to the areas devoid of this species.

Weightage parameters

Based upon the jack-knife test, it was observed that in the study area the temperature parameter which shows warm and arid conditions is a favourable habitat for blackbuck.

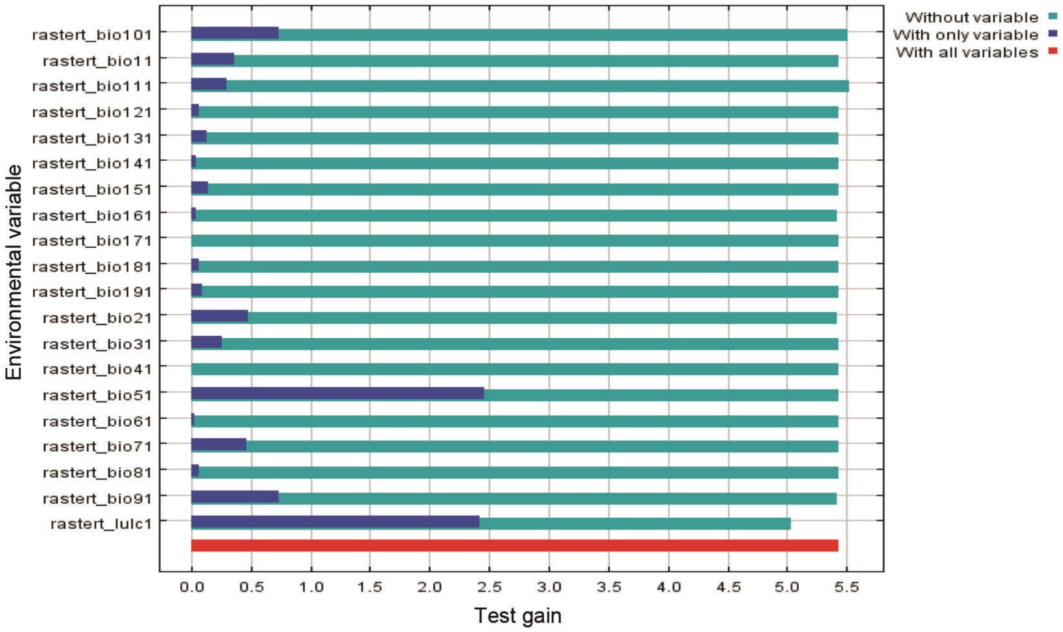

Figure 5. Jackknife test gain of variables for *A. cervicapra.* BIO1, Annual mean temperature; BIO2, Mean diurnal temperature range (mean of monthly (maximum temperature – minimum temperature)); BIO3, Isothermality (BIO2/BIO7 × 100); BIO4, Temperature seasonality (standard deviation × 100); BIO5, Maximum temperature of warmest month; BIO6, Minimum temperature of coldest month; BIO7, Temperature annual range (BIO5–BIO6); BIO8, Mean temperature of wettest quarter; BIO9, Mean temperature of driest quarter; BIO10, Mean temperature of warmest quarter; BIO11, Mean temperature of coldest quarter; BIO12, Annual precipitation; BIO13, Precipitation of wettest month; BIO14, Precipitation of driest month; BIO15, Precipitation seasonality (coefficient of variation); BIO16, Precipitation of wettest quarter; BIO17, Precipitation of driest quarter; BIO18, Precipitation of warmest quarter; BIO19, Precipitation of coldest quarter.

A total of six parameters with weightage were identified by the results obtained from MaxEnt (Figure 5). The weighted parameters by the jackknife test are discussed below:

Mean annual temperature: Statistical analysis of the bioclimatic data showed that the annual mean temperature was above 24.75°–25.0°C in the entire study area, showing a variation of 0.25°C (Figure 6 *a*). The maximum annual average temperature was recorded in the northwest direction and the minimum annual average temperature was recorded in the southwest direction. The total percentage contribution of this variable was 1 and the proportion of allowances for profit was 23.4%. This is the most essential variable among the bioclimatic factors based on its percentage increase.

Mean diurnal temperature range: The typical diurnal temperature range was between 14.8°C and 14.05°C (Figure 6 *b*). The mean diurnal temperature varied from maximum to minimum on the same day. The percentage contribution from the mean diurnal temperature range was 1.3, with a 1.4% gain. In the subtropical region, the diurnal temperature and annual temperature range are high due to the continental effect.

Maximum temperature of the warmest quarter: The case of the maximum temperature of the warmest month was recorded in June because the angle of the sun is above the Tropic of Cancer during this month. Figure 6 *c* shows the temperature during June which varies between 41.5°C and 41.2°C. Since the study area is in the semi-arid zone, it is hot and dry before monsoon. The dark colour in Figure 6 *c* depicts the highest temperature (41.5°C) while the light colour depicts the lowest temperature (41.2°C), showing a difference of 0.3°C over the study area. This parameter favours the blackbuck habitat, as a large number of days with good sunshine are required in their habitat.

Annual temperature range: It was observed that the yearly average temperature range varies from a specific year's highest to the lowest temperature. In the study area, both summer and winter conditions are harsh and severe and therefore, it was observed that the difference between highest and lowest temperature is very high. It was observed that the temperature ranged from 35.7°C to 34.9°C (Figure 6 *d*). The temperature in the study area was largely below 35.7°C. The dark brown areas in Figure 6 *d* represent the low temperature range and blue-colour areas represent high annual temperature range.

Mean temperature of the driest quarter: This quarterly indicator estimates the average temperature prevailing in the driest quarter. This quarterly indicator estimates the average temperature prevailing in the driest quarter. The

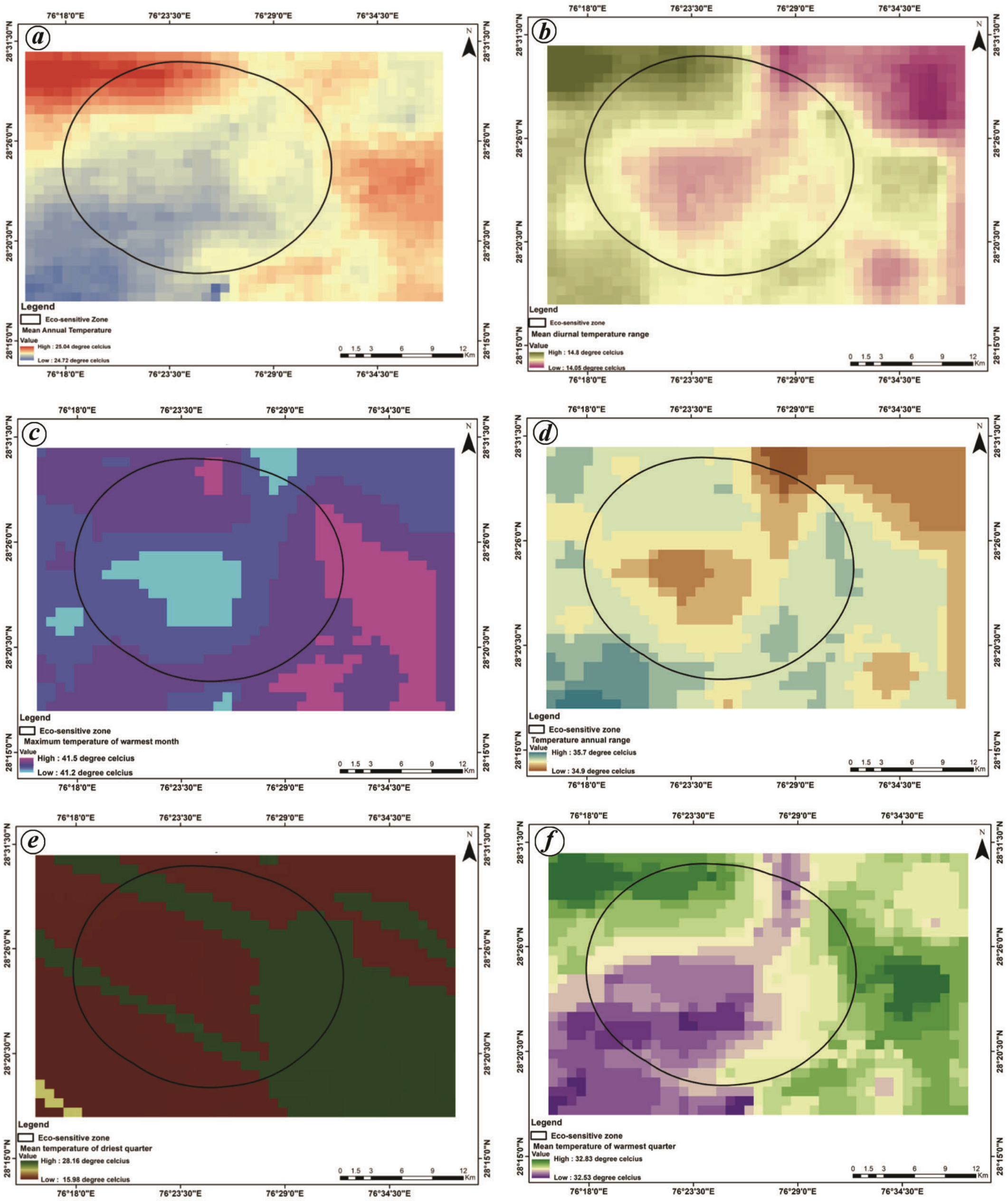

Figure 6. ***a***, Mean annual temperature; ***b***, mean diurnal temperature range; ***c***, maximum temperature of warmest quarter; ***d***, temperature annual range; ***e***, mean temperature of driest quarter; ***f***, mean temperature of warmest quarter.

average temperature and total precipitation during each month were computed. In November when the rainfall is under 0.2 in, the driest month was recorded in the study area.

The driest quarter average temperature ranged between 28.16°C and 15.98°C. The gain of this variable in habitat suitability was 0.8% (Figure 6 *e*).

Mean temperature of the warmest quarter: The annual average temperature was calculated for the hottest quarter, after which the quarter having the highest temperature was estimated. The quarterly index estimates the average temperature of the hottest quarter. The average temperature was between 32.83°C and 32.53°C during the hottest quarter in the study area. The gain in habitat suitability of this variable was 11.4% (Figure 6 *f*).

The peaks in Figure 7 represent higher gain in the variables. The *X*-axis represents the values of variables, while the *Y*-axis denotes the gain/weightage of an individual variable. The integer 1 represents the higher probability of blackbuck habitat, while the integer 0 represents the lowest suitability for blackbuck in the area. For example, the bioclimatic factor (bio10) representing the mean temperature of the warmest quarter in the study area peaks at a

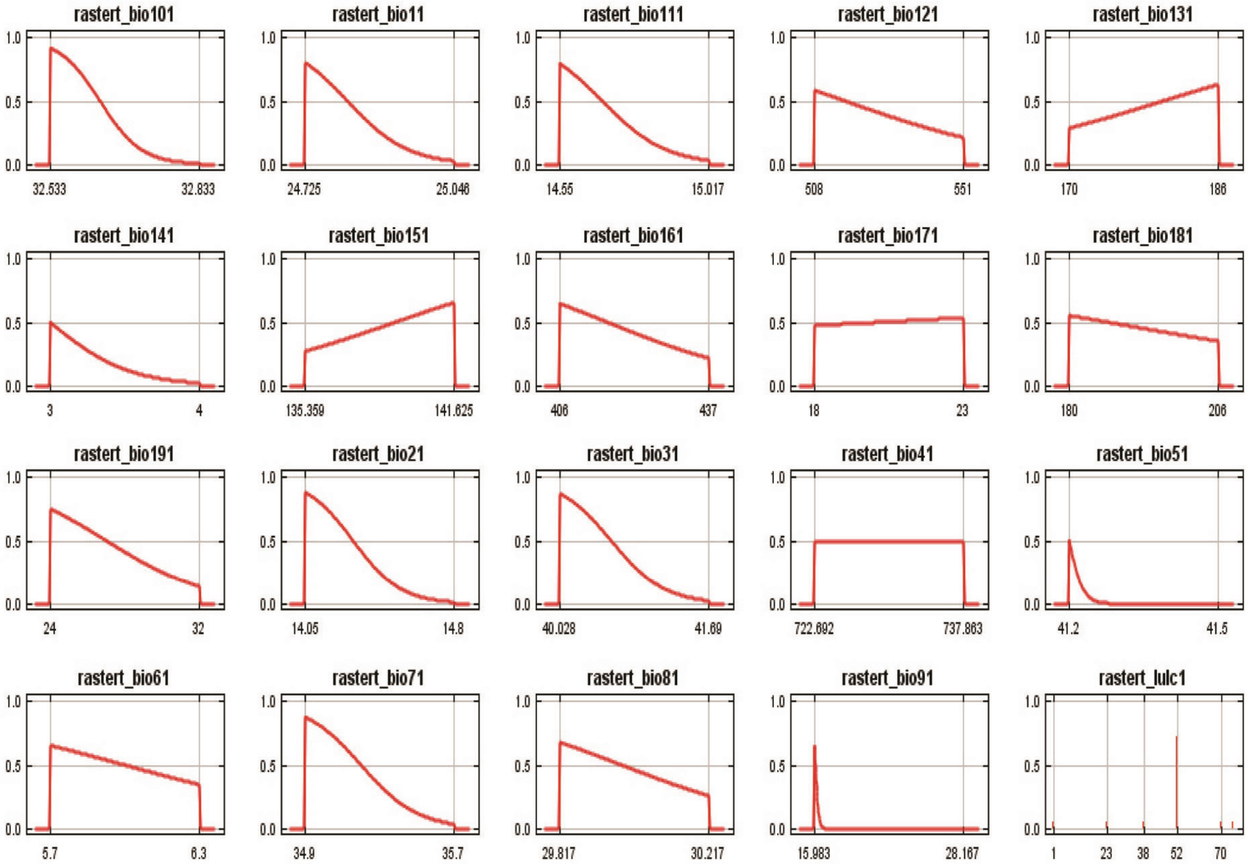

Figure 7. Bioclimatic individual variables and their gain for habitat suitability analysis of blackbuck.

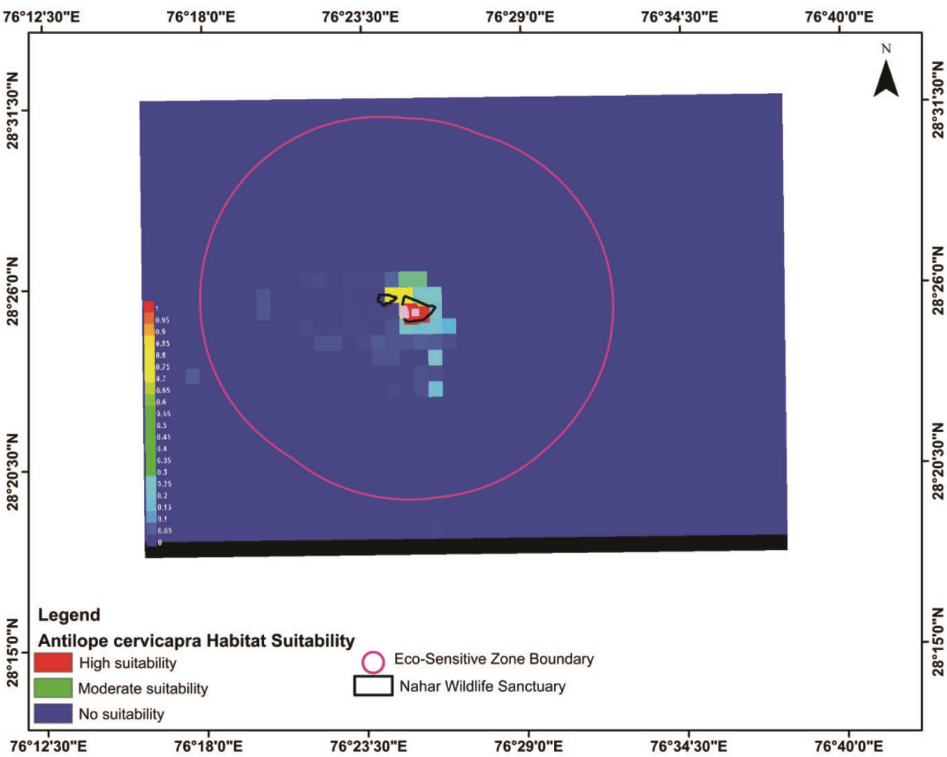

Figure 8. Habitat suitability sites for blackbuck.

Table 1. Suitable and unsuitable areas for blackbuck habitat within eco-sensitive zones

	Area suitability (ha)		
Present habitation area of blackbuck (ha)	High	Moderate	Unsuitable
28.32	156.43	174.28	39,800.97

temperature of 32.53°C, which is highly favourable for blackbuck. In the graph indicated by 'rastert_bio11', bioclimatic variable 1 (bio1) is shown, which represents the mean annual temperature with a peak observed at 24.72°C representing favourable conditions for blackbuck in the study area. LULC variable which is a categorical variable has its peak in shrubland area representing the most suitable LULC. From all the variables shown in Figures 5 and 7, the habitat suitability of blackbuck is analysed and assessed. Figure 8 shows the suitable areas for the blackbuck.

It was observed that the areas suitable for blackbuck habitat were from the shrublands, located far from human settlements. The areas under very high suitability are shown in red colour with a value of 1, while those under very low suitability are shown in blue colour with a value of 0 as shown in Figure 8. Based upon the calculations for the areas suitable for habitat analysis and assessment, the entire area of the notified Wildlife Sanctuary with a buffer of 10 km has been classified into four classes of suitability, namely present habitat of blackbuck species, highly suitable (1–0.95), moderately suitable (0.95–0.5), areas of low suitability (0.5–0.3) and unsuitable areas (0.25–0).

At present, the blackbuck is limited to an area of 28.32 ha. An area of 156.43 ha was identified to be highly suitable for the species, while 17.28 ha of the area was found to be moderately suitable (bringing a total of 330.71 ha as suitable blackbuck habitat), while an area of 39,800.97 ha was found to be unsuitable for the species habitation (Table 1).

Conclusion

The present study on habitat suitability analysis for blackbuck (*A. cervicapra*) was undertaken at Nahar Wildlife Sanctuary for HFD to alter conservation practices in the habitat of the species in the area using geospatial techniques. It was observed that at present, the blackbuck is residing only in an area of 28.32 ha, while an area of 330.71 ha can be made available for its habitation, of which 156.43 ha is under the highly suitable category while the rest of the area of about 174.28 ha is under moderately suitable category. From field observations, it was found that the movement of blackbuck was restricted to a confined area within the Sanctuary due to vehicular movement on the State Highway passing through it and fencing along the highway dividing the Sanctuary into two unequal parts. Another factor restricting the movement of blackbuck within the Sanctuary is the wide distribution of *P. juliflora*, which causes damage to its skin leading to fencing inside the Sanctuary for conservation. The eradication of *P. juliflora* will give chance for increase in the shrubland and thus, the expansion of suitable habitat ranging from moderate to high for Blackbuck in the study area. The findings of this study will help the Wildlife Wing of HFD in the effective management of the blackbuck species.

Conflicts of interest: The authors declare no conflict of interest.

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