Habitat suitability analysis of *Nemorhaedus goral* – A remote sensing and geographic information system approach

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With the decreasing size of habitat and increasing fragmentation, it has become essential to develop species-specific habitat suitability maps. Such an approach for endangered species is a priority task for India's conservation programme. The mountain goat (goral) is an endangered species. The viable population of goral (*Nemorhaedus goral*) on Siwalik mountain is now confined to only Rajaji National Park, Uttar Pradesh. The goral habitat is restricted to specific land attributes, viz. landcover, slope, water availability and human habitation. Human settlements, biotic pressure (grazing and lopping) and erosional subsidence on hills have threatened goral habitat. The study is an attempt to model habitat suitability using spatial landscape patterns (interspersion and juxtaposition) and specific habitat requirements (restrictive factors). The approach has been tested in the part of Rajaji National Park for goral.

HABITAT is a place occupied by a specific population within a community of populations[1]. Habitat selection is an important part of an organism's life history patterns. The worldwide destruction of the natural environment is reducing the number of species and the amount of genetic variation within individual species. Major threats to biodiversity include habitat alterations, overharvesting, pollution, climate change, introduced species and human population increase. Of these, habitat alterations due to overuse, deforestation and consequent habitat loss, fragmentation and degradation are the primary factors[2]. There is a need to identify priority areas for conserving wildlife habitat. India's conservation effort is evolved around the UNESCO protected area concept by creating biosphere reserves, national parks, and sanctuaries. About 3.4% of India's geographical area is under protection for '*in situ*' biodiversity conservation. The approach takes into account endangered species and habitats. However, with mounting pressure on the protected areas and species, the approach is under review.

It is now considered imperative to analyse baseline data on the physical set-up, vegetation and socioeconomic environment to ensure the effectiveness of the conservation effort.

Unfortunately, the study area (Rajaji National Park, Uttar Pradesh, India) has suffered from habitat loss, near fragmentation and degradation. The area around Rajaji National Park has had a twofold increase in human population from 1951. The increase in the human population has accentuated the biotic pressure on the forest[3].

The most characteristic Himalayan mammal of this park is the goral, a mountain goat. Johnsingh[3] has described the animal and its habitat requirements. The goral (*Nemorhaedus goral*) is a stocky goat antelope, 65–70 cm at the shoulder and 25–30 kg in weight. Both sexes have horns and a conspicuous white throat patch.

Goral habitat

Three species of goral inhabit the Himalaya, northeast part of India, Burma, China and Thailand[4]. The Himalayan goral (*Nemorhaedus goral*) is found from 200 msl in the Siwalik Hills to 4000 msl in the main Himalayan range[5]. The Siwalik forest landscapes of the Himalayas are exposed to various degradational processes due to their fragile geomorphology and heavy human dependency. Rajaji National Park is an attempt to protect the representative biogeographic unit (Gangetic plain). Goral habitat has been extensively studied and it is established that goral has a very specific habitat requirement[3,6–10]. The habitat size has been shrinking due to fast degradation caused by the lopping of trees, grazing and cutting of grass, and erosional subsidence of slopes. This has threatened the survival of goral.

The habitat parameters required for goral were summarized based on the field observations and literature:

– Goral is not seen near human habitation.

– Goral is a grazer. It selects vegetation with good grass cover.

– It avoids lesser slope angle categories and prefers areas with higher slope.

– Escape terrain is either a cliff, steep slope or 'nalah'/gully followed by broken/rocky terrain. But cliffs are one of the most important escape terrains; forest cover seems to be the next highly used escape routes[8].

– Goral avoids areas with extensive shrub cover. This was related to forage availability as well as its anti-predatory strategy.

In spite of the species being endangered, no attempts have so far been made to analyse spatial habitat suitability and the available habitat size.

Habitat evaluation approach

The colonization pattern of the animals is related to the following parameters: cover, physical set-up and land use. The habitat suitability analysis based on these parameters is considered essential to protect the species. Since long time, ground methods have been used to evaluate the habitat using habitat suitability index based on ground observations[11,12]. However, these methods do not provide any spatial information. Aerospace remote sensing has been used effectively to characterize the habitat[13–15]. Subsequent attempts have also been made in India to evaluate wildlife habitats and related parameters using remote sensing data[16–18]. These studies, however are subjective and do not take into account spatial patterns and diversity of landscape. Researchers have used Geographic Information System (GIS) to handle multi-layered data and analyse spatial patterns statistically[19]. The model can be driven for different combinations of the controlling factors identified from a GIS database to predict suitability[20].

This study presents an approach to identify goral (*Nemorhaedus goral*) habitat based on analysis of spatial patterns of landscape. A remote-sensing-derived vegetation map, water sources, human settlement, road infrastructure and digital terrain model are the basic inputs for the study. The habitat suitability has been derived based on spatial patterns of landscape and the specific habitat requirements of goral.

Study area

The study area is located in Dhaulkhand range of the Rajaji National Párk (77°55′35″E to 78°4′42″E longitude and 29°59′45″N to 30°8′48″N latitude) covering an area of 149.6 km[2] (Figure 1). The topography of the area varies with altitude, ranging from 320 m above msl in submontane area to above 800 m in the Siwalik ranges. The climate is subtropical. Rainy season commences from
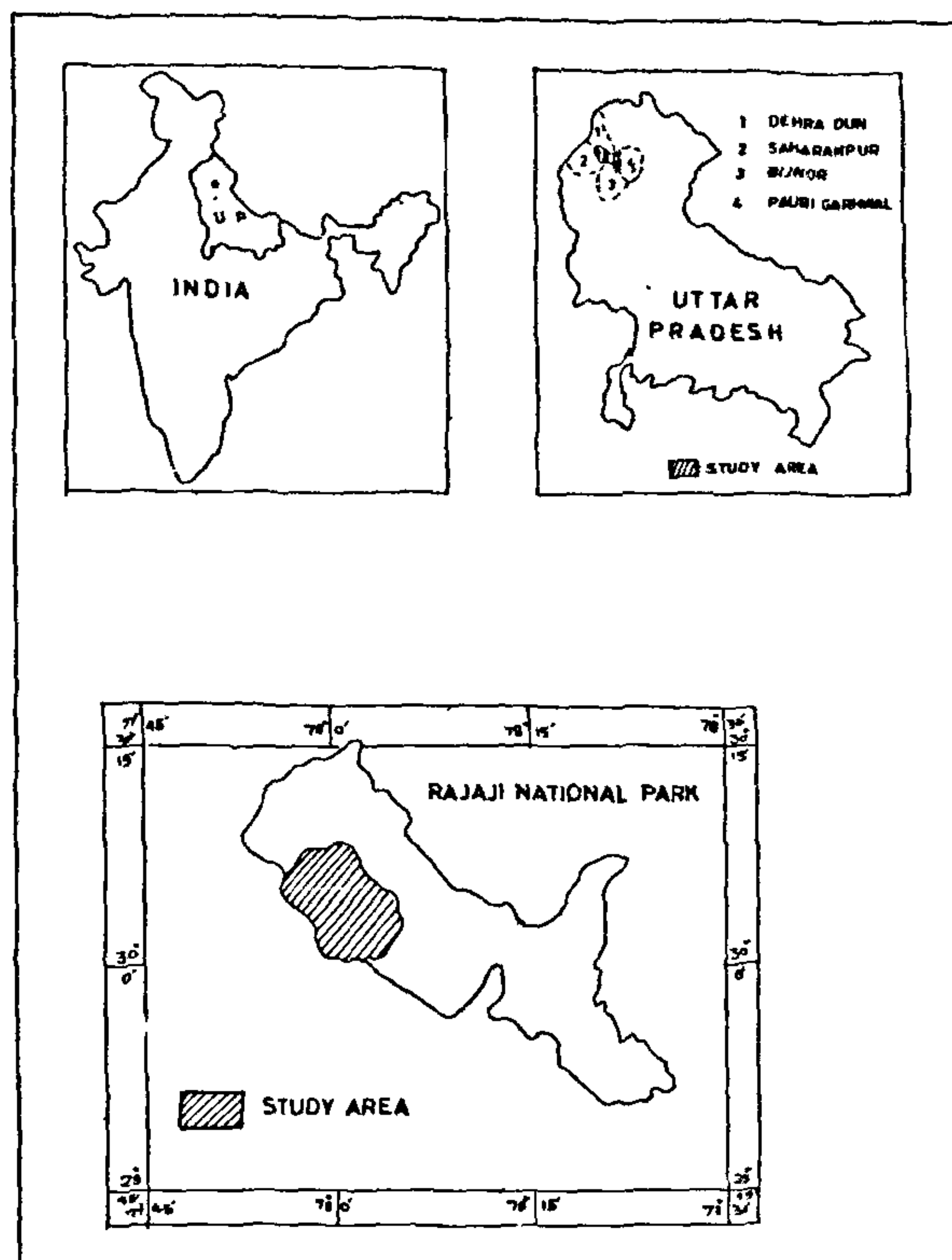

Figure 1. Location map of the study area

late June and continues up to the middle of September with the heaviest rainfall recorded in August (range 1200–1500 mm). The average annual rainfall is about 1270 mm. The temperature varies from 13.1°C (in January) to 38.9°C (in June). The vegetation mainly belongs to the northern tropical dry deciduous forest and subtropical forest[21]. Among fauna, herbivorous game animals of the deer family, cheetal (*Axis axis*), hog deer (*Axis pornicus*) are common. Large mammals like elephants are abundant.

Materials and methods

Input data

Indian Remote Sensing Satellite-1B Linear Imaging Self Scanning Sensors (IRS–1B LISS II) (with ground resolution of 36.25 m) false colour composite (FCC) of bands 4, 3 and 2 have been used to prepare the vegetation map on a 1:50,000 scale. The vegetation types and associated land use details interpreted are sal (*Shorea robusta*) (S), sal mix (SM), miscellaneous (M), miscellaneous with grass (MG), chir (*Pinus roxburghii*) (C), chir with grass (CG), scrub (Sc), riverine (r), plantation
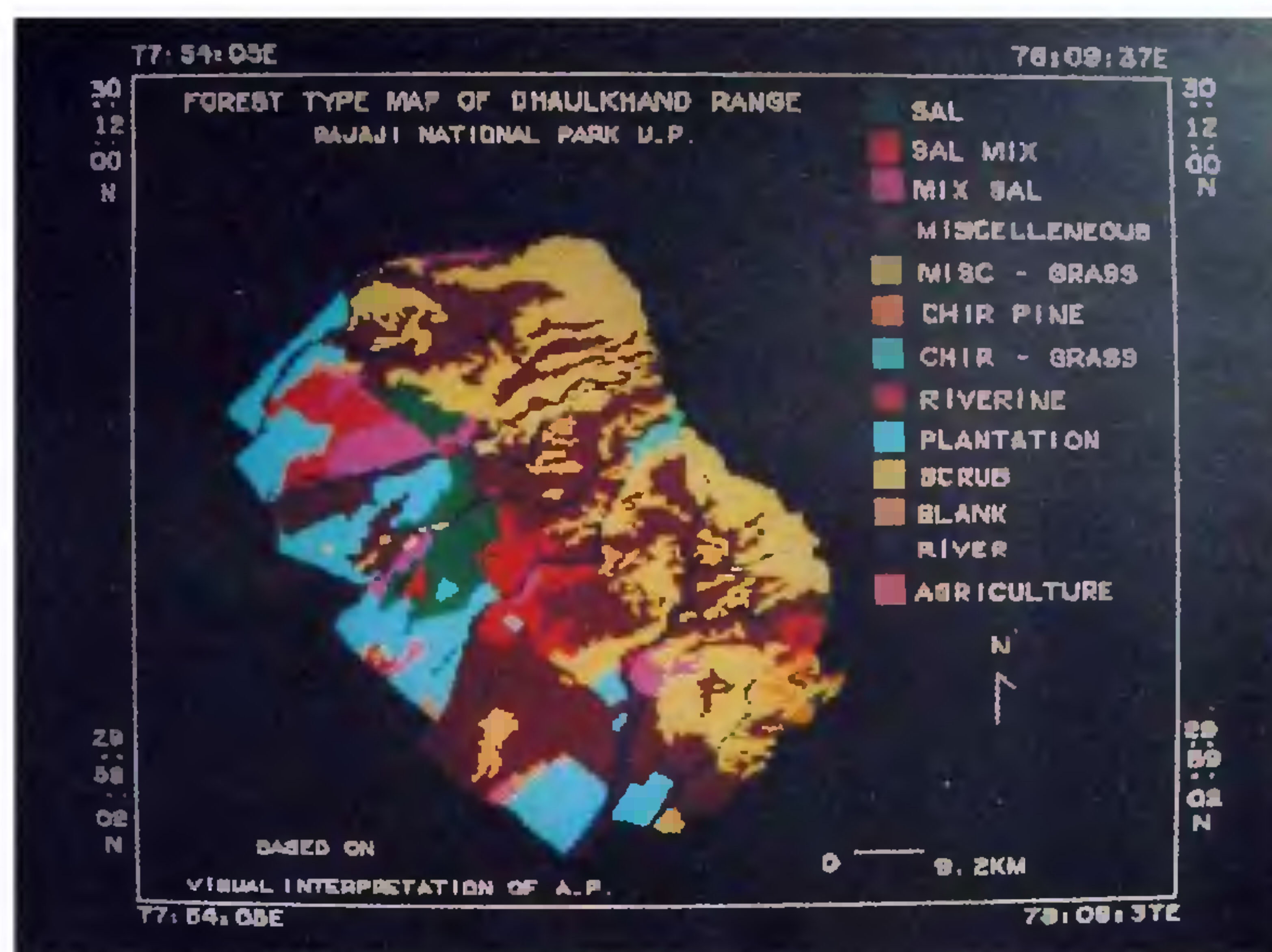
Figure 2. Forest type map of Dhaulkhand Forest Range, Rajaji National Park, UP.

Table 1. Locations where gorals were sighted either feeding/resting

Location	Habitat parameters			
	Slope (degrees)	Forest type	Water	Habitation
Dhaulkhand ridge near Sayyawala point	35–60	Misc with grass, Misc.	Within 1 km	Nil
Dhaulkhand ridge about 200 m NW from point 1	35–60	Misc with grass, Misc.	Within 1 km.	Nil
Ridge between Gularia and Tangsot towards Tangsot	>70	Misc. with grass	Within 100 m	Nil
Gulari ridge	>60	Misc.	Within 100 m	Nil
Ridge between Gulari and Tangsot point towards Dhaulkhand road	>50	Misc with grass	Within 100 m	Nil

(Pt), agriculture (Ag), drainage and water bodies (Figure 2). The terrain features like contours and roads were obtained from Survery of India toposheets. The known habitat parameters for goral (from field and literature) were used along with the spatial information in GIS.

GIS approach

PAMAP GIS configured on PC-based platform has been used in the present study. The maps showing vegetation/land use, contours, water and human habitation were digitized. The contours were interpolated to calculate digital terrain model (DTM) and the slope map was

derived. Finally, the spatial information along with restrictive factors (Table 1) were modelled using overlay and neighbourhood techniques. The study approach is presented in Figure 3.

Results

Spatial pattern analysis

The vegetation landscape is analysed to determine habitat interspersion and juxtaposition. The interspersion (Is) is a measure of the spatial intermixing of habitats/land use and is calculated in a nonspecies-specific
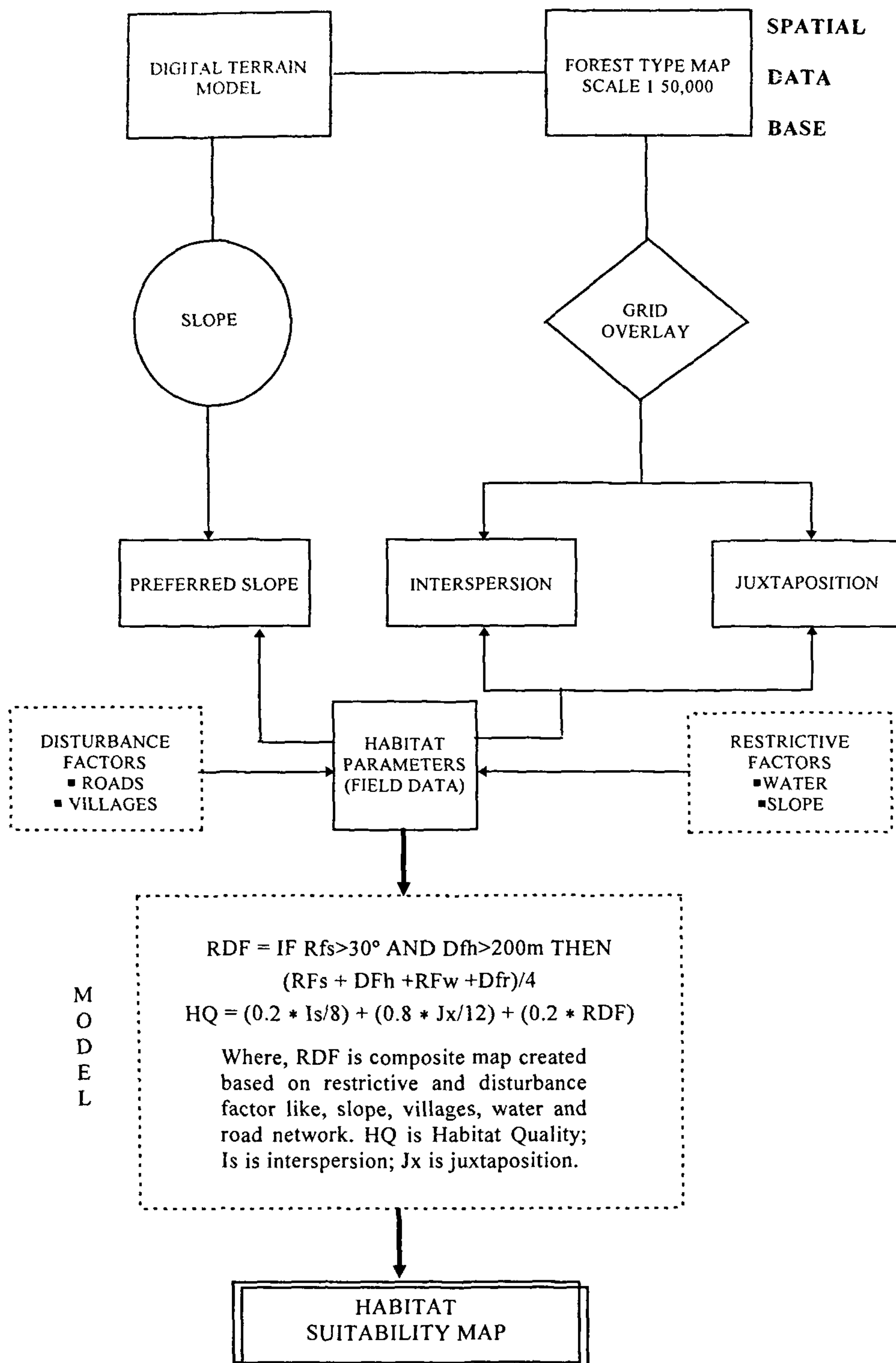
Figure 3 Approach for habitat suitability analysis

manner[12,22]. The juxtaposition (Jx) is a measure of the proximity of habitat types and relative importance of adjacency[12,23]. Thus, Jx is a measure species-specific to goral. This was accomplished by defining a grid which was placed on a forest type map. Based on the field observation on the habitat size, grids of 20 s × 20 s were used for the present study. Grid sizes can be changed as per the required level of details. Gridwise interspersion and juxtaposition were calculated using a software developed in database management system (dBase III+) interfaced with PAMAP GIS. The weightage factors were assigned to different edges based on the order of preference by goral.

Measure of interspersion

A window of size 3 × 3 grids panned over vegetation map and an interspersion value was assigned to the central grid to prepare the interspersion map. Interspersion of central cells is calculated as the number of surrounding grid cells that differ from the central cell. The interspersion of a given window is 6. The maximum limit of interspersion is 8.

$$
\begin{array}{ccc}
MG & MG & M \\
S & MG & M \\
S & Sc & S
\end{array}
$$

Measure of juxtaposition

The juxtaposition of the central grid cell is calculated by comparing the class of the central cell with an adjacent cell as per the weighted preference of the species on use of the habitat. The length of the edge (diagonal or horizontal/vertical) is also provided as a weightage. The habitat preference and weightage criteria are given as follows.

Goral habitat preference of vegetation cover in descending order is:
Miscellaneous forest with grasses on slopes (MG) – Chir-Pine with grasses on slopes (CG) – Miscellaneous (M) – Chir-Pine (C) – Miscellaneous sal (MS) – Sal miscellaneous (SM) – Scrub (Sc) – Blanks (B) – Riverine (R) – Sal (S) – Plantation (Pt) – Agriculture (Ag). The weightages assigned to different edges are given in Table 2. Calculation

Table 2. Weightage assigned to different edges of vegetation types

Vegetation type factor	Association	Weightage
Miscellaneous forest with grasses on slopes	Any cover	0 9
Chir-pine with grasses on slopes	Any cover	0 9
Miscellaneous forest	Chir-pine with grasses, miscellaneous, scrub and blanks	0 9
Miscellaneous forest	Any other cover	0.6
Miscellaneous sal	Any cover	0 6
All other combinations		0 2

Table 3. Measure of juxtaposition

Edge combination	Weightage factor (specific to goral)	Quantity	Juxtaposition (Jx)
M/Sc	0 6	3	1 8
MG/Sc	0 9	3	2 7
C/Sc	0 2	2	0 4
R/Sc	0 2	1	0 2
Sc/Pt	0 2	2	0 4
Sc/Ag	0 2	1	0 2

Note Diagonal count as 1, while vertical or horizontal count as 2

of juxtaposition for the central grid of the given window is given in Table 3 and is equal to 5.7.

$$
\begin{array}{ccc}
M & M & MG \\
S & Sc & C \\
Ag & Pt & R
\end{array}
$$

The juxtaposition in the study area ranges from 2.4 to 10.8. The maximum limit of juxtaposition is 12.

Restrictive (RF) and disturbance (DF) factors

The factors that are essential for wildlife species are called restrictive factors. The presence of this factor is indicated by value one and has no impact on habitat suitability index; otherwise the factor is zero and, consequently, habitat suitability index becomes zero. Intermediate values can also be assigned based on field conditions and habitat requirements of wildlife. Based on habitat use by goral, four restrictive factors were determined.

Water availability (RFw). The availability of water within 1 km is the most important requirement of goral habitat. This was accomplished by generating the map showing a distance buffer around water sources and assigning ratings (0 to 1) based on the proximity.

Slope (RFs). Ratings (0 to 1) were given for slope classes. The rating values are 0, 0.8 and 1 for slope classes <30°, 30°–50° and >50°/cliffs, respectively.

Remoteness from human habitation (DFh). The human habitation is considered a disturbance factor. The presence of villages may alter the suitability of the grid. This was accomplished by generating the map showing a distance buffer around village locations and assigning ratings (0 to 1) based on proximity.

Remoteness from roads (DFr). The roads, although do not have significant impact on habitat, are considered a potential habitat disturbance factor. This was also accomplished by generating the map showing a distance buffer around roads and assigning ratings (0 to 1) based on proximity.

The cost surface developed using these four factors is called restrictive and disturbance factor map (RDF). This map was generated using the logic given below:

CREAT RDF IF RFs >30° and IF DFh > 200 m THEN (RFs + DFh + RFw + DFr)/4

Figure 4 displays the quality of habitat based on slope and proximity to water, road and human habitation. This map was used along with interspersion and juxtaposition maps to determine the final habitat suitability map.

Habitat suitability index

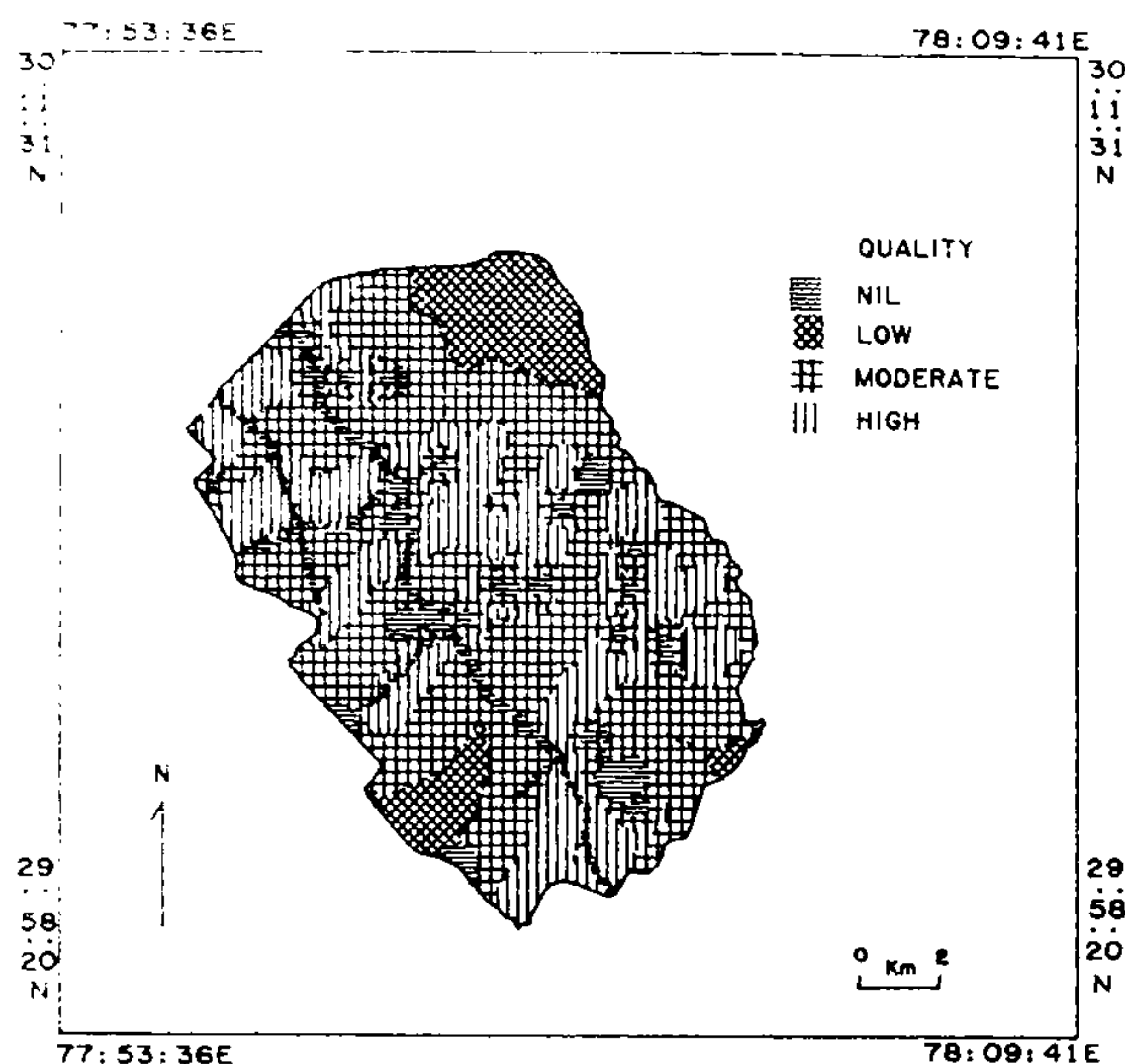The habitat suitability is a function of interspersion, juxtaposition and restrictive factors. It is determined

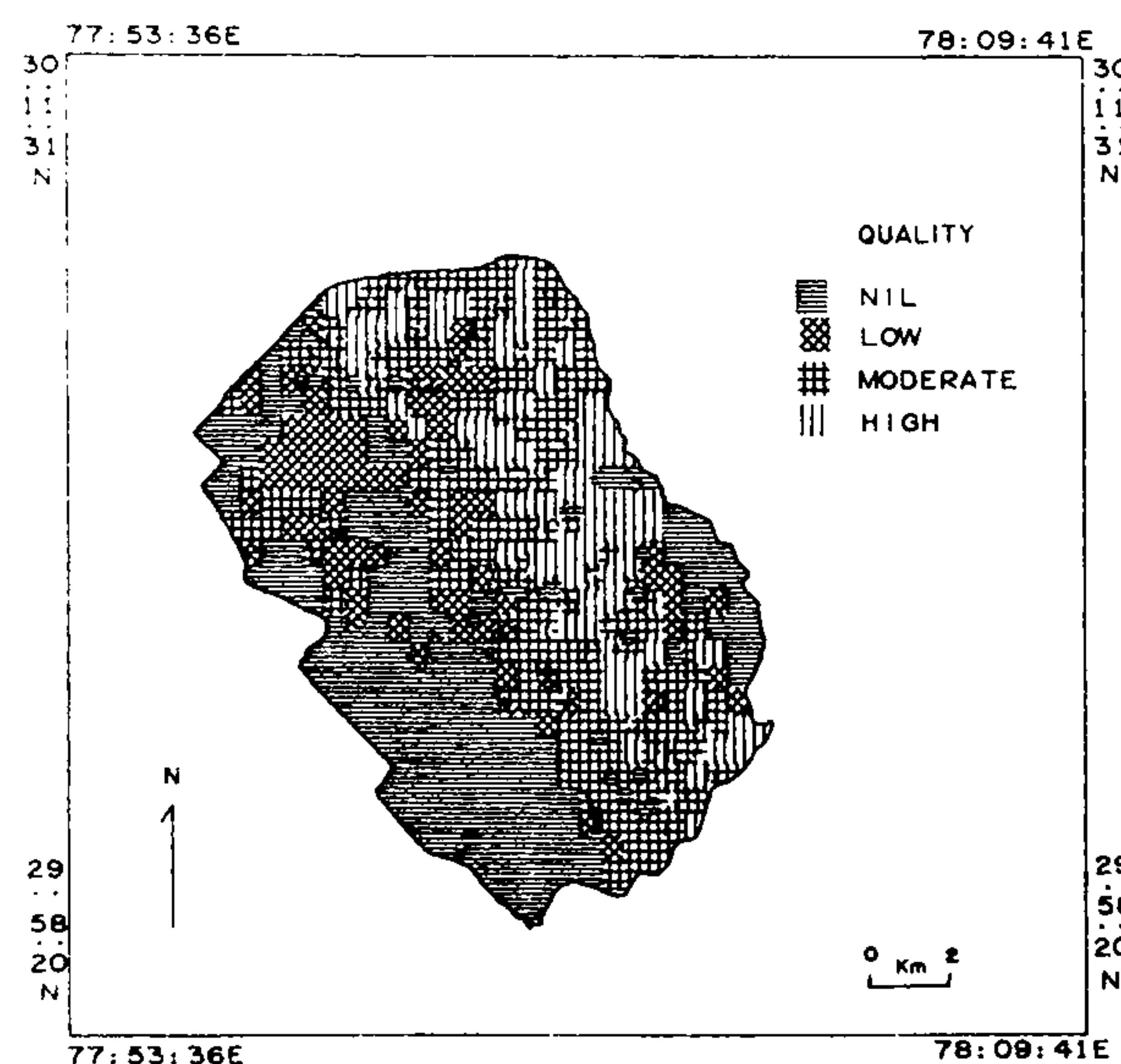Figure 4. Cost surface created using restrictive and disturbance factors.

Figure 5 Habitat suitability map for goral in Dhaulkhand range, Rajaji National Park, UP

based on different weightages assigned to each parameter. The equation used for calculating the habitat suitability index is given below.

habitat index = (0.2*Is/8) + (0.6*Jx/12) + (0.2*RDF).

Thus, each cell was assigned a habitat suitability index ranging from 0 to 1. Histogram equalization was followed to cluster showing different habitat quality zones, viz. highly suitable, moderately suitable, less suitable and not suitable (Figure 5).

Model comparison with field data

The suitable locations for goral noted down during the field work were superimposed on the habitat suitability map. Out of 10 locations, 5 are in most suitable areas, 3 in moderately suitable areas, 2 in less suitable areas and none in unsuitable areas.

The area under each category in percentage is as follows:

Habitat quality	Percentage area
Most suitable	35.22
Moderately suitable	15.15
Low suitable	29.47
Not suitable	20.16.

Discussion

With decreasing habitat and increasing fragmentation, it has become essential to develop species-specific habitat suitability maps. Such an approach for endangered species is a priority task for India's conservation programme. The mountain goat is an endangered species. The viable population of goral on Siwalik mountain is now confined only to Rajaji National Park. In the recent years, increasing human impact within the national park has threatened the very existence of goral in Siwalik. The present study is an attempt to develop an approach for habitat suitability mapping using spatial landscape patterns and specific habitat requirements. The model uses goral habitat parameters reported by Green[8] and Johnsingh[3].

The habitat studies indicate that homogeneity/heterogeneity of landscape, vegetation types, their association and edges characteristics are important parameters. Abundance of these species may be considered a consequence of edges where types of food and cover come together. The edge effect may be defined as the tendency for an increase in variety and density of an organism at a community junction. The present study tries to model it through measurement of interspersion and juxtaposition. The weightages of these two are based on species habitat preference. The conceptual framework on the use of these parameters has been discussed by Mead et al.[22] and Lyon[23]. Since the animal is shy to human presence, human habitation and road

proximity are also used in the model as parameters. The topographical habitat features and the availability of water have also been used as restrictive factors in the present model. The present study attempts to implement habitat suitability approach for the mountain goat.

Conclusion

India has large biodiversity. However, recent population growth trends have put tremendous pressure on the habitats. The situation calls for urgent need to develop comprehensive database of the protected areas, which are temples of *in situ* conservational efforts. It is necessary to evaluate the available habitat size, quality and socioeconomic constraints. The present approach can provide information about the suitability of endangered species having very specific habitat requirements. There is need to implement such an approach for the species which are dwindling and becoming endangered due to shrinking habitat size.

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RESEARCH COMMUNICATIONS

Carbon and oxygen isotopic records of planktonic and benthic foraminifera from a new deep-sea core of the northeast Indian Ocean

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Stable carbon and oxygen isotopic records of the planktonic foraminifera (*Globigerinoides ruber*), covering the past ~100,000 years, have been obtained from a new deep-sea core of the Bay of Bengal. High glacial-to-interglacial $\delta^{18}O$ amplitude (2.0‰) in the surface waters of this region provide evidence for the increased salinity (by ~2‰) in the glacial surface waters of this region[1,2]. In contrast, the surface water $\delta^{13}C_{TIC}$ did not change significantly during the glacial-to-interglacial transition.

Examination of the isotopic record of benthic foraminifera (*Cibicidoides* and *Uvigerina*) shows higher (1.7‰) glacial-to-interglacial $\delta^{18}O$ amplitude. This is attributed to the decrease in deep-water temperature arising from changes in source characteristics during the LGM. The glacial-to-interglacial shift in $\delta^{13}C_{TIC}$ (~0.3‰) in the deep Bay of Bengal is close to the global