Land-use dynamics in Corbett National Park, Uttarakhand, India using CA-Markov and agent-based LULC-SaarS model

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Corbett National Park (CNP), Uttarakhand, India is currently facing pressure of encroachments from human settlements around the buffer zone leading to increasing human and animal conflicts. In the present study, we have analysed the extent of land-use/land-cover (LULC) changes between 1976 and 2011 using medium-spatial-resolution satellite data in and around CNP. Future projections have also been generated using CA-Markov and agent-based SaarS model. The study highlights that unlike in the past decades, the projected LULC may undergo restricted growth in built-up area agriculture.

Keywords: Agent-based modelling, buffer zone, land-use dynamics, National Park.

THE protected areas (PAs) in Southeast Asia carry large resources which are facing habitat degradation due to intensive agriculture and other land uses[1]. The growing popularity of wildlife tourism is also subjecting national parks to various ecological threats and ecotourism-based luxuries by expansion of commercial activities of human settlements in the vicinity of the PAs[2]. The national parks, particularly in India, are under tremendous pressure due to large populations living around them as well as impacts of increased tourism in PAs[3]. Corbett National Park (CNP), Uttarakhand, one of the first tiger reserves of India[4], is a popular ecotourism centre in North India. The overwhelming popularity of CNP is indeed its biggest threat. Excessive tourist influx and increasing local population, mainly the Gurjars around the boundary of park in this area have an adverse impact on its ecosystem[5]. The key factor behind the rapid biodiversity degradation around CNP is human-induced land use land cover (LULC) changes, which include agricultural expansion, development of human settlements, increased resource dependency on forest resources, and indiscriminate poaching and hunting activities. This study presents an analysis and modelling of vegetation cover and land-use dynamics in and around CNP, for 35 years, i.e. from 1976 to 2011, using remote sensing data – satellite images of medium spatial resolution (Landsat Multi Spectral Scanner, Thematic Mapper and Linear Imaging Self Scanner-III), various drivers and modelling approaches like CA-Markov and SaarS model.

CNP is situated in the foothills of the Himalaya, in the districts of Nainital and Pauri Garhwal, Uttarakhand (Figure 1). The present area of the reserve is 1618.54 sq. km, which includes 520 sq. km of dense core area, 797.72 sq. km of buffer zone and 301.18 sq. km of the Sonanadi Wildlife Sanctuary. CNP is located between the lesser Himalaya and the Shiwalik Mountains. The southern boundary of CNP flanks the ecologically important Terai–Bhabar region, a strip of land skirting the southern part of the Shiwaliks. The elevation of the CNP region is between 385 and 1100 m amsl. The park area features ridges, small plateaus, minor streams and ravines. The villages around CNP are mostly agrarian. The population density of Nainital district is 225 per sq. km, where most of the area of CNP lies[6]. Majority of the people living in these villages depend on buffer-zone forests of CNP for fuelwood, fodder and for grazing livestock.

The LULC maps of different time periods – 1976, 1985, 1995 and 2011 – were generated based on visual interpretation of two season's (pre-monsoon and post-monsoon) satellite images of medium spatial resolution – Landsat Multispectral Scanner (1976 and 1985), Linear Imaging Self Scanner III (2005) and Landsat Thematic Mapper (2011). A mixed LULC classification scheme was used along with national LULC mapping manual, biodiversity characterization at landscape level (national assessment)[7] and Anderson's LULC classification system[8] (Supplementary Table 1). A total of 13 classes were identified in the LULC maps (Table 1). Figure 2 presents a brief outline of the methodology used. The results obtained from the LULC maps were validated through field work in CNP.

In the present study, the CA-Markov model was applied for future LULC predictions based on LULC maps of different years (1976, 1985, 1990, 2005 and 2011). The spatial dynamics in the model is controlled by local rules through cellular automata (CA) mechanism considering either neighbour configuration or transition probabilities using Markov cellular automation[9,10]. Initially, the model was applied over a period of 14 years from 1976 to 1990 and a prediction for 2005 was made, which was compared with the LULC map of that year prepared through visual interpretation for accuracy assessment. The overall kappa score obtained based on this validation was 0.9884. On the basis of these LULC change maps for the period of 35 years (1976–2011), LULC map for the year 2046 was projected.

SaarS model uses transitional Markovian probability in association with defined decision rules in image composition for the geography of land-use classes as dictated by the drivers of change. This is an open-ended model where the drivers can be defined based on the local/regional specific characteristics. Multiple regression methods were

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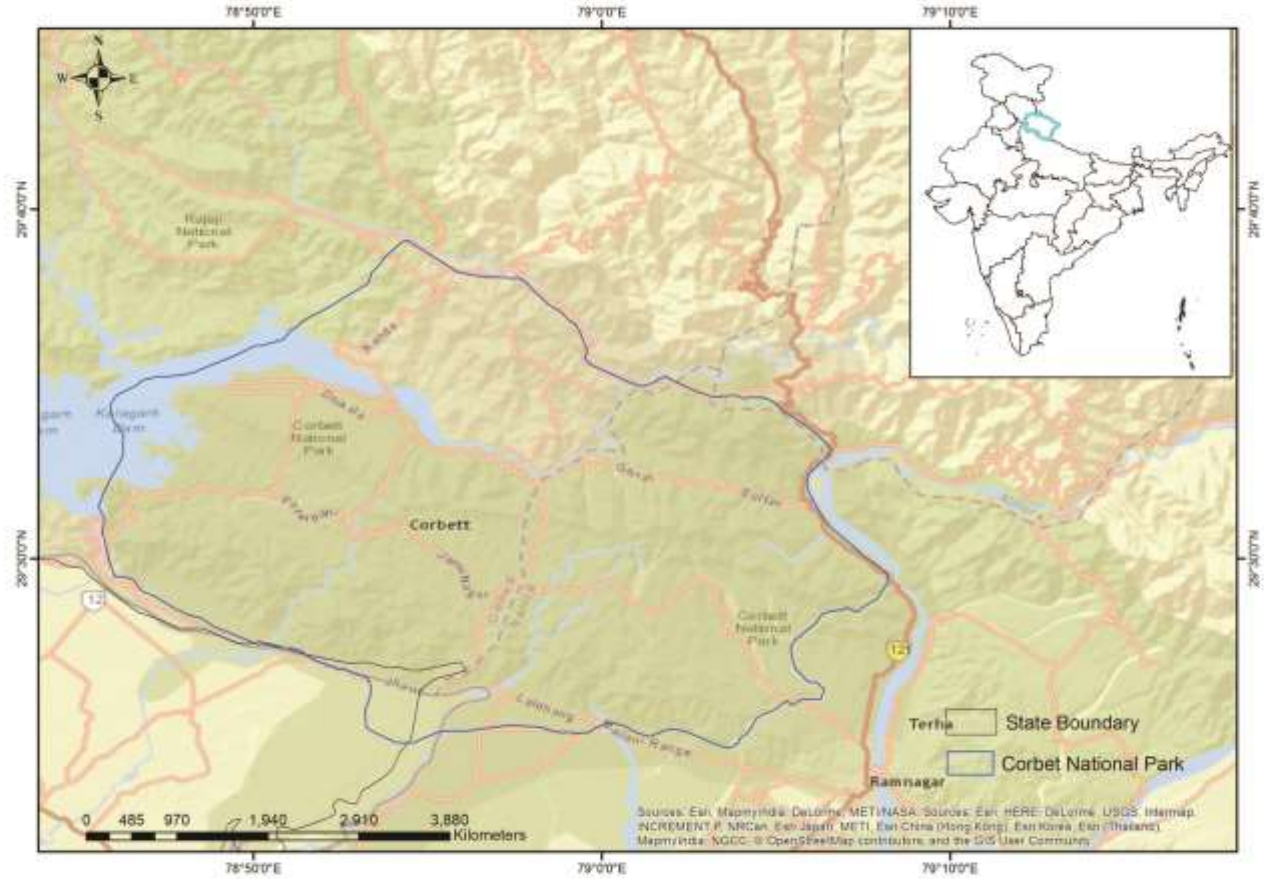

Figure 1. Study area.

Table 1. LULC statistics in and around Corbett National Park from 1976 to 2011

LULC code	LULC class	CNP		CNP buffer	
		1976 (%)	2011 (%)	1976 (%)	2011 (%)
1	Agricultural land – crop	9.80	9.80	16.16	19.54
2	Built-up – residences	0.16	0.16	0.17	0.80
3	Built-up – touristic	0.00	0.00	0.00	0.05
4	Built-up – dam structure	0.02	0.02	0.03	0.02
5	Forest – dense/closed	21.53	21.53	6.49	6.51
6	Forest – moist deciduous	38.90	38.90	38.34	35.31
7	Forest – dry deciduous	6.84	6.84	4.32	4.31
8	Forest – plantation	9.40	9.40	15.67	16.26
9	Forest – scrub	0.89	0.89	3.47	1.35
10	Natural grassland	0.94	0.94	0.61	0.23
11	Open scrub	0.87	0.87	1.01	0.75
12	Water bodies – reservoir	5.34	5.34	9.04	8.79
13	Water bodies – river/stream	5.29	5.29	4.72	6.09

used to assess the impact of drivers which were calibrated and fed into the model.

In 1976, the majority of the area in CNP consisted of dense and moist forests (21% and 38% respectively; Table 1), followed by agriculture and forest plantation (9.8% and 9.4% respectively; Table 1). The share of built-up areas was relatively less in 1976 (0.16% built-up-residences; Table 1). In the buffer zone of CNP, moist deciduous forest (38.34%), agriculture (16.16%) and forest plantation (15.67%) formed the top three classes in terms of area (Table 1).

However, in 2011, agriculture and built-up area increased in the study region (Figure 3 *a*), which might be associated with economic reforms such as increased

Table 2. Projected percentage gain/loss statistics in CNP from 2011 to 2046

LULC code	LULC class	Gain/loss (%)
1	Agricultural land – crop	–0.87
2	Built-up – residences	3.61
3	Built-up – touristic	–15.38
4	Built-up – dam structure	0.00
5	Forest – dense/closed	–0.02
6	Forest – moist deciduous	0.08
7	Forest – dry deciduous	0.07
8	Forest – plantation	–0.20
9	Forest – scrub	2.34
10	Natural grassland	60.81
11	Open scrub	–5.18
12	Water bodies – reservoir	–0.55
13	Water bodies – river/stream	–2.23

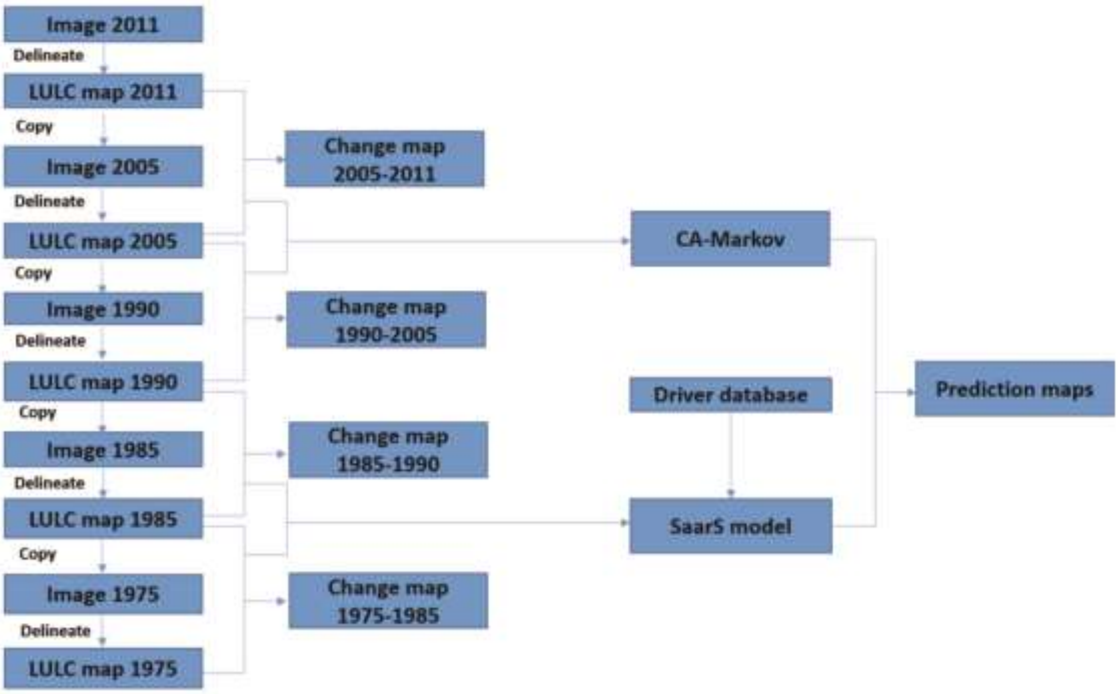

Figure 2. Flowchart of the methodology.

network of rail/road, hydroelectric projects and increased population[11]. The change matrix analysis suggests that agricultural land expansion has benefitted majorly by conversion of moist deciduous forests to croplands in the northern parts of CNP and reclaimed river/stream areas to agriculture (Figure 4). Small portions of land in the Banali river near Hidyatpur were converted into agricultural land (Figure 4). With 32% and 384% increase, built up-residences and built-up – touristic areas demonstrate maximum changes in the buffer zone of CNP (Figure 4). The change map (Figure 5) shows the conversion of agricultural land into built-up-residential areas mainly around Afzalgarh and Ramnagar in the southwestern parts of the study area.

Grasslands, forest scrub and forest land have consistently reduced in the study area (Figure 4). The biggest losses in CNP, however, were observed in grassland (52.9%) and forest scrub (14.17%). With increasing pressure on natural areas for food and urban development, a high percentage of available land such as grasslands and scrublands which are highly elastic in terms of conversion, is being converted into agricultural land[12].

The LULC of CNP was projected using two different models, i.e. CA-Markov and SaarS for the years 2046 and 2020 respectively (Figure 6). The present analysis shows that there may be a slight decrease in agricultural area. This may be a probable scenario due to more career options like tourism than just agriculture in future. An

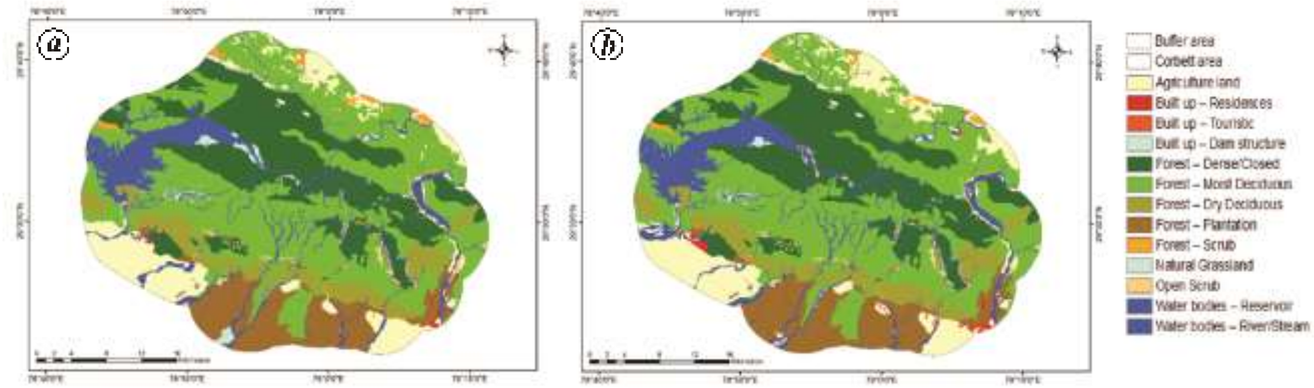

Figure 3. LULC dynamics in and around Corbett National Park, Uttarakhand during (***a***) 1976 and (***b***) 2005.

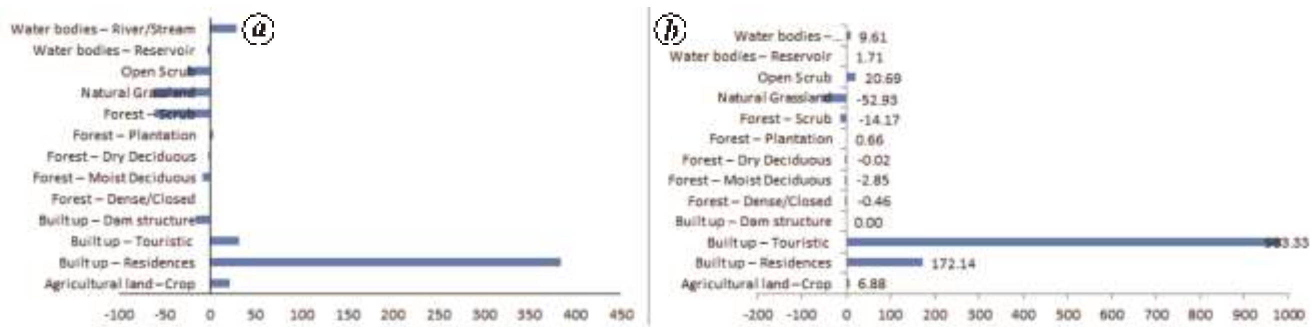

Figure 4. Percentage loss/gain statistics of LULC classes for 1975–2011 in (***a***) CNP and (***b***) buffer areas.

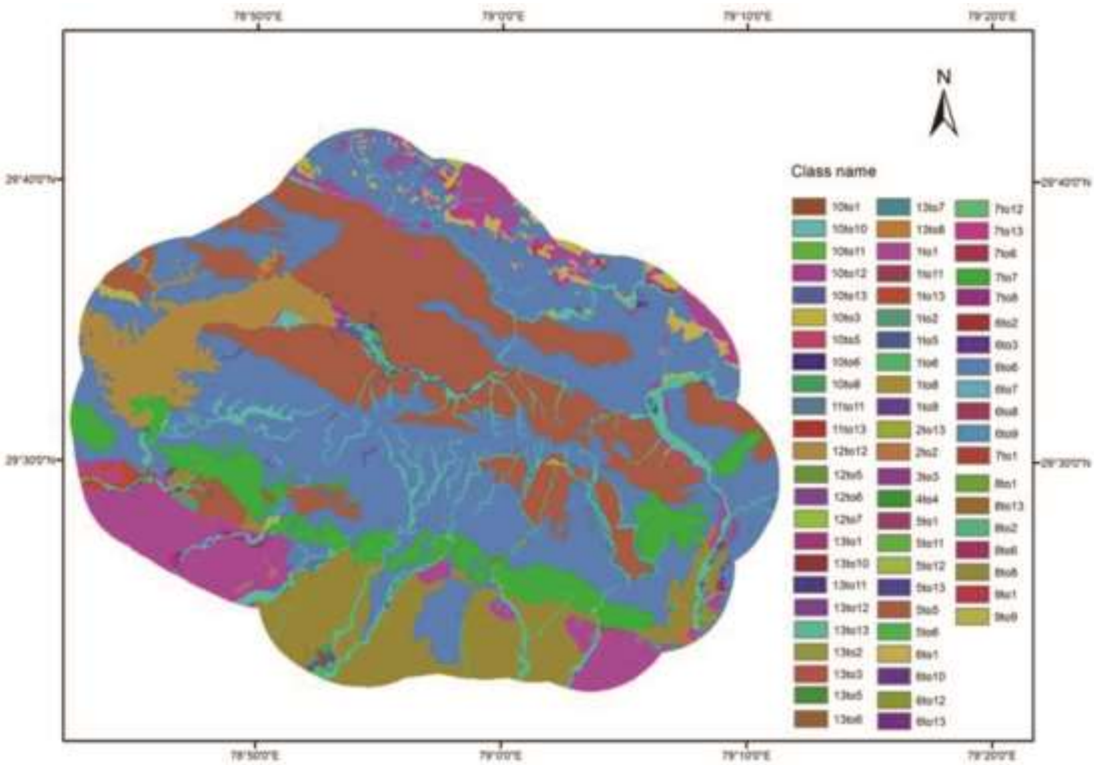

Figure 5. LULC change map of CNP from 1976 to 2011.

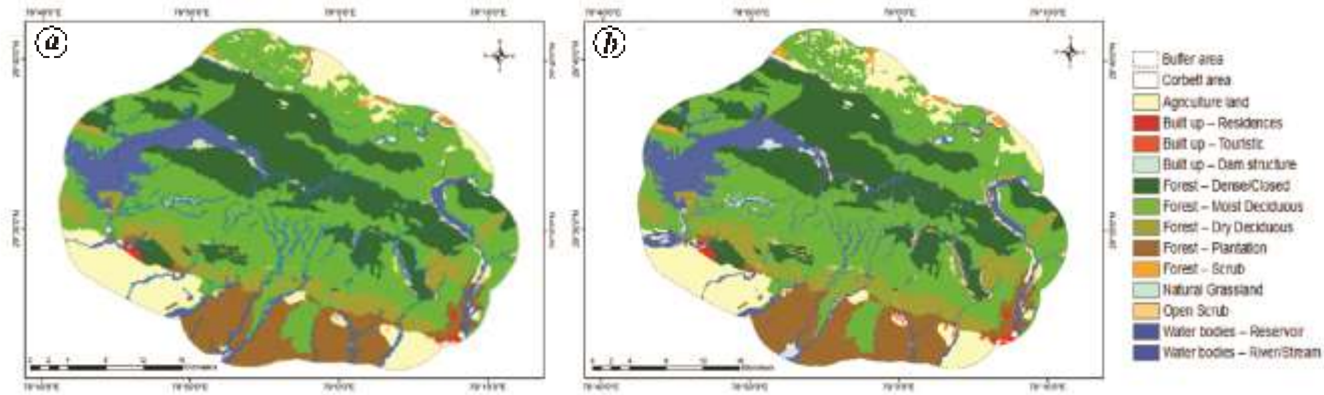

Figure 6. Projected LULC dynamics in and around CNP during (***a***) 2020 using SaarS model and (***b***) 2046 using CA-Markov model.

increase in built-up residential areas (3.61%) was also observed in the future maps generated by CA-Markov model (Table 2), which is consistent with the low-probability growth forecasted in the Himalayan region[13]. However, there may be a decline in the areas under forest plantation (1.0%), forest scrub (13.9%) and open scrub (39.1%) in 2020, as predicted by the SaarS model. The trend is expected to continue in 2046, according to the results obtained by CA-Markov model (Table 2).

This study described the current trends in land-cover change and simulates possible future scenarios in CNP. Agriculture, forests and open scrubs are vulnerable to land-use changes in CNP. The trends are consistent throughout the study period. The study has also revealed that the northern area around CNP is facing higher rates of LULC change, which pose higher risks to the park as a reserve for wildlife. However, the future LULC trends in the wake of wider employment opportunities, and more stringent conservation and environment protection policies may lead to limited expansion to urban and agricultural areas in CNP.

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