Sustainable Management of Bannerghatta National Park, India, with the Insights in Land Cover Dynamics

FIIB Business Review
8(2) 118–131, 2019

DOI: 10.1177/2319714519828462
journals.sagepub.com/home/fib

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Abstract

The ecosystem of health and natural resource management is influenced by the social, political, economic system and institutional framework in a region. Rapid economic growth in Bangalore and its environs in recent decades has resulted in environmental changes in Bannerghatta National Park (BNP) and its buffer (of 5 km). Land use land cover (LULC) change analysis with a modelling technique such as cellular automata (CA)-Markov was used for quantitatively exploring forest cover transitions. The analysis of LULC dynamics has revealed loss of vegetation cover from 85.78 per cent to 66.37 per cent (1973–2015) and severe environmental stress. The region has lost moist deciduous cover, from 26.1 per cent to 13.8 per cent, and witnessed an increase in horticulture, from 8.5 per cent to 11 per cent (1973–2015). The visualization of likely land use in 2027 indicates the loss of forest cover from 41.38 per cent to 35.59 per cent with an increase in urban area from 4.49 per cent to 9.62 per cent (with new residential and commercial layouts in the buffer zone of BNP in violation of the eco-sensitive zone norms as per Section 5(1) of Environment Protection Act 1986). The study provides insights for developing an appropriate planning framework towards conservation and the sustainable management of ecologically sensitive national parks.

Keywords

Urbanization, Bannerghatta National Park, ecosystem services, CA-Markov, modelling and visualization

Introduction

Land use land cover (LULC) dynamics analyses help in understanding the impact of anthropogenic pressures on Earth system processes (Lambin, Geist, & Lepers, 2003; Ramachandra, Setturu, & Bharath, 2012). Forest ecosystems constitute a key component of the global carbon cycle that accounts for over two-thirds of net primary production on land through photosynthesis, converting solar energy into biomass. Forests support local livelihoods through the provision of non-timber forest products (NTFPs), fuel, wood, water and so on. Unplanned developmental activities such as illegal logging, mining, the unsustainable exploitation of resources and so on have been posing serious threats to the sustenance of water resources. This is also evident from the escalation of human-animal conflicts, water scarcity and so on. Deforestation, one of the prime movers of global warming, and consequent changes in the climate are prevalent throughout the globe. Irrational land cover changes resulted in the loss of more than one-thirds of global forest cover in the post-industrialization and globalization era (Schneider, Friedl, & Potere, 2009; Sexton et al., 2013). LULC changes are highly interlinked processes such as the intensification of agriculture, tropical deforestation, pasture expansion, urbanization and so on; they have a wide range of impacts on livelihood, net primary production, biogeochemical cycles, ecosystem stability and biodiversity through land surface processes (Akber & Shrestha, 2015; Haase & Nuissl, 2010). Human-induced LULC changes are the major drivers of the landscape dynamics at local levels. LULC changes alter the homogeneous landscape into a heterogeneous mosaic of patches. This leads to the division of habitat into smaller and more isolated patches known as fragmentation (Liu, Feng, Zhao, Zhang, & Su, 2016; Ramachandra, Setturu, & Chandran, 2016). Fragmented

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forests are likely to suffer from being smaller and more isolated with greater edges which alters the structure of the landscape, affecting ecosystem functional abilities, which is evident from the decline of biodiversity, hydrology and so on (García-Llorente, Martín-López, Nunes, Castro, & Montes, 2012; Kang, Zhu, Zhu, Sun, & Ou, 2014; Vinay, Bharath, Bharath, & Ramachandra, 2013). This induces change in the local climate (Bharath, Rajan, & Ramachandra, 2013; Ramachandra, Bharath, & Sreejith, 2015) as well as in the global climate (Chase, Pielke Sr, Kittel, Nemani, & Running, 2000; Foley et al., 2005). LULC changes have thus gained special attention for land management and planning due to their potentially negative consequences, creating trade-offs between ecosystem services (Polasky, Nelson, Pennington, & Johnson, 2011; Schägner, Brander, Maes, & Hartje, 2013).

Inventorying, mapping and the monitoring of biological resources through LULC analysis aid in the conservation of ecologically rich regions through an understanding of spatial patterns in the environment. The advancement of technologies in vegetation mapping and geospatial models has provided for a precise evaluation of spatio-temporal patterns of forest dynamics and environmental consequences. Remote sensing (RS) data with advancements in spectral, spatial, radiometric and temporal resolutions and geographical information system (GIS) techniques have been useful in monitoring land use changes of even inaccessible areas within a short span. Modelling and the visualization of landscape dynamics help in understanding the status of natural resources, considering the environmental and socio-economic processes, which facilitate in prudent resource planning with scientific insights to meet or mitigate potential threats. Rapid advances in the availability of multi-resolution spatial data and geospatial models have made it increasingly possible to design and simulate spatial patterned LULC changes (Bharath, Vinay, & Ramachandra, 2014; Ramachandra, Bharath, & Bharath, 2014; Verburg, Schot, Dijst, & Veldkamp, 2004). The proven modelling techniques such as cellular automata (CA), Markov chains, multivariate statistics, optimization, system dynamics, multi-criteria evaluation (MCE) and the conversion of land use and its effects model (CLUE) aid in visualizing complex patterns and predictions. The Markov model is based on a stochastic theory of random process systems and the optimal control theory (Pielke Sr et al., 2011; Rands et al., 2010). The traditional Markov model alone is difficult to predict the spatial pattern of land use changes. The CA model has a strong space conception, which is strongly capable of space-time dynamic evolution with complex space systems.

The integrated CA-Markov is a robust and effective modelling approach to analyse the spatio-temporal patterns of LULC changes (Bharath, Rajan, & Ramachandra, 2016; Jiang, Zhang, & Kong, 2009; Kamusoko, Aniya, Adi, & Manjoro, 2009). The spatial simulation modelling technique such as CA-Markov is an efficient tool for quantitatively exploring forest cover change (Ramachandra, Bharath, & Gupta, 2018). The spatial modelling technique such as CA-Markov focuses mainly on local interactions of cells with distinct spatio-temporal features suitable for dynamic simulation and display (Wu, Ge, & Dai, 2017). CA-Markov modelling comprises observations and a structural concept of various forces and functions at various scales in a specific forested landscape (Vázquez-Quintero et al., 2016). CA-Markov incorporates rules based on the consideration of biophysical and socio-economic data to define initial conditions, parameterize the CA-Markov model and calculate transition probabilities and the neighbourhood rules with transition potential maps. The transition rules of CA models help in accounting the temporal and spatial complexities of forest systems. Bannerghatta National Park (BNP) is located in close proximity to Bangalore (20 km to the BNP core area and 1.8 km from the Bruhat Bengaluru Mahanagara Palike (BBMP) boundary), capital city of Karnataka. The peri-urban region of BBMP growth centres and growth poles play a key role in initiating the process of industrialization and urbanization. The growing uncontrolled economic activities in and around the BBMP region threaten local well-being, agricultural regions and the forests of BNP. The objectives of current study are:

1. assessment of the status of forests in and around ecologically sensitive regions, BNP with a 5-km buffer from 1973 to 2027;
2. understanding the transitions in LULC with the causal factors from 1973 to 2015;
3. assessment of the spatial patterns of forest changes from 1973 to 2015; and
4. the suggestion of prudent management options (the restoration of degraded forest patches and sustainable management) to mitigate forest loss.

Method

Study Area

BNP encompasses an area of 260 sq.km, comprising of 13 reserve forests spread over the districts of Bangalore urban, Bangalore rural and Ramanagara districts; it was declared as a national park in 1974 (Figure 1). BNP is located in the south-east tip of Western Ghats with biological, social, hydrological and ecological significance and forms a vital conduit of the animal movement path. Forests in BNP have been aiding Bangalore's climate and necessities through carbon sequestration, the mitigation of human-animal conflicts, the repository of diverse flora and fauna, recreation and pollination services as well as micro-climate moderation. BNP is one of the oldest prime habitats of Asian elephants, supporting a population of 100–150 and a migratory population of a large number, about 200–300, from the adjoining Tali Reserve Forest and Cauvery Wildlife Sanctuary; it acts as a terminal point for Eastern Ghats and Western Ghats. BNP, being part of the Western Ghats (one among 35 global biodiversity hotspots), is known for high species diversity, structural organization, spatial heterogeneity and adaptation to dry climate, moisture stress and irregular rainfall. The average temperature ranges from 22°C to 35°C and the annual monsoon rainfall varies from 625 mm to 1,607 mm, from June to mid-November, from south-west and north-east monsoons. The terrain represents undulating land with broken chains of bolder, strewn hillocks and hills of rocky outcrop and water courses. The forest types cover moist deciduous forests, dry deciduous forests, thorny scrub and grasslands with rich flora and fauna. The cropping pattern of BNP and its environs (5 km) is very much a modern system of agriculture due to its proximity with Bangalore. The farmers grow commercial crops such as banana, coconut, vegetables, sugarcane, mulberry and various flowers. Streams such as Suvarnamukhi, Hebballa, Suddahalla, Jakkanahalla Muthyalammamadu holé, Rayathmala holé and Anthragange halla are present in the region which support major crops. Floral diversity includes *Cissampelos pareira, Decalepis hamiltonii, Cardiospermum halicacabum, Gloriosa superba, Cassia fistula, Wrightia sp., Holarrhena pubescens, Aegle marmelos, Shorea roxburghii, Phyllanthus emblica* and so on;, they are highly valued medicinal plants, many of them rare or endangered and traded in high volumes. A total of 218 plants belonging to 60 families were recorded during the survey. Among these, trees (81 species) and herbs (88 species) had the highest number of species, followed by shrubs (34 species) and climbers (15 species). About 80 species of birds were recorded during the survey, which include migratory birds of winter such as Golden Oriole, Forest Wagtail, Rosy Starling, Booted Warbler, Greenish Warbler, Ultramarine Flycatcher, Lesser Spotted Eagle, Pallid Harrier and Wire Tailed Swallow and so on. The presence of these bird species highlights rich habitats with supporting niche. The distribution of various faunal species such as elephants, tigers, leopards, spotted deer and sloth bears is shown in Figure 2. However, an increase in anthropogenic activities with the increase in human habitation and the expansion of agricultural and horticultural activities have threatened the survival of these fragile ecosystems. The anthropogenic activities include the unsustainable exploitation of forest resources, the encroachment of forests, stone quarrying, sand mining, domestic livestock grazing and unplanned urbanization; they have become a major threat to the conservation of forests and its resources.

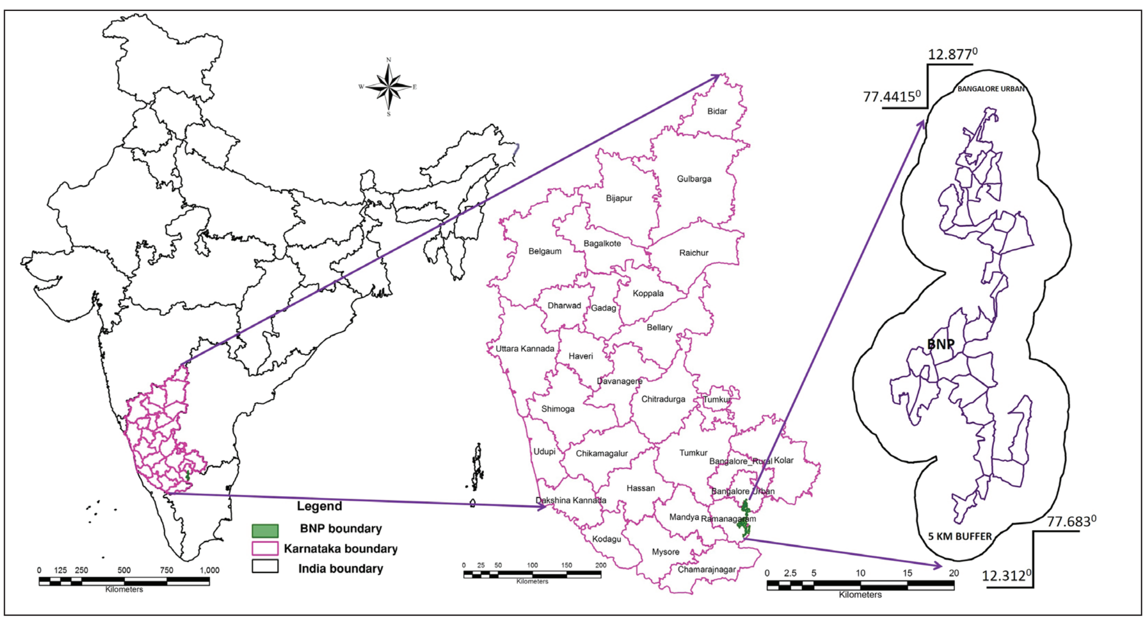

Figure 1. Bannerghatta National Park with 5-km Buffer

Source: The authors.

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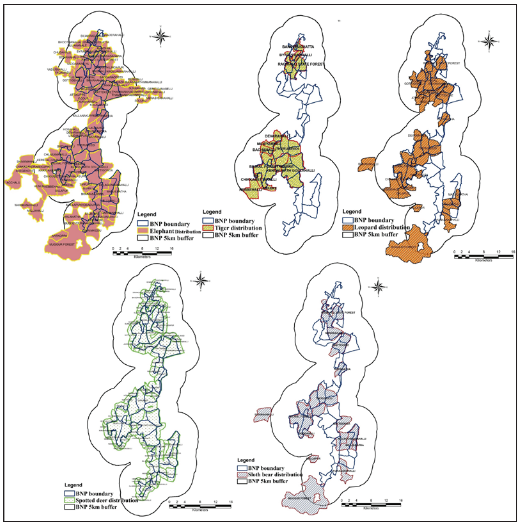

Figure 2. The Distribution of Various Faunal Species in Bannerghatta National Park

Source: The authors.

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Land Use Land Cover Analysis

Landscape dynamics in the BNP region is assessed with the help of temporal spatial data acquired through space-borne sensors (RS data), ancillary data (collateral data compiled from government agencies) and primary data compiled through field investigations (ground control points and training data—polygons of land uses with attribute information). Figure 3 outlines the protocol followed to analyse land uses from the spatial data. RS data used in the study are Landsat MSS (1973), TM (1989, 1999), Landsat ETM + (2009), downloaded from the public domain (http://landsat.org), IRS p6L4X (2015) (http://nrsc.gov.in) and the online Google Earth portal (http://earth.google.com). Ancillary data were used to assist the interpretation of different land use types from RS data. Topographic maps provided ground control points to rectify remotely sensed data and scanned paper maps (topographic maps) and assigned the UTM (zone 43 N) projection system. The Survey of India (SOI) topographic maps (scale: 1:50000 and 1:250000) and vegetation maps of South India (scale: 1:250000) developed by the French Institute (1986) were digitized to identify various forest cover types and for temporal analyses to understand vegetation changes. Field data (ground control points and training data) were collected with the help of pre-calibrated GPS (global positioning system, Garmin GPS unit). Ground control points were used for the geometric rectification of RS data. The training data were used for the classification of RS data (land use analysis) based on supervised classification approaches through the Gaussian maximum likelihood (GML) algorithm. Land cover analysis was conducted to understand the extent of vegetation cover using the normalized difference vegetation index (NDVI) as per Equation (1). NDVI, also known as a greenness index, values ranges between −1 to and +1 and helps in delineating vegetation cover.

$$\text{NDVI} = (\text{NIR} - R) / (\text{NIR} + R) \qquad (1)$$

Land use analyses using remote sensing data involved (a) the generation of false colour composite (FCC) of RS data (bands: green, red and Near Infrared [NIR]). This composite image helped in locating heterogeneous patches in the landscape, (b) the selection of training polygons covering 15 per cent of the study area (polygons are uniformly distributed over the entire study area), (c) loading these training polygon coordinates into the pre-calibrated GPS and (d) the collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, (e) supplementing this information with Google Earth and (f) a total of 60 per cent of the training data were used for classification, while the balance were used for accuracy assessments (Bharath et al., 2013; Congalton, 1991; Jensen, 2005; Ramachandra, Bharath, & Sanna, 2012) by error matrix and kappa statistics (Anderson, Hardy, Roach, & Witmer, 1976; Liu, Frazier, & Kumar, 2007). Land use analysis was conducted using a supervised classification technique based on the GML algorithm with training data (collected from the field using GPS). Gaussian maximum likelihood (GML) is a widely used statistical classification method which assigns a given pixel to a specific class based on conditional probability. The likelihood for a given pixel with a spectral value to be assigned to a class is determined using Bayes' theorem and the decision rule calculated by natural logarithm or 'discriminant function' (Lillesand, Kiefer, & Chipman, 2014). Geographical Resources Analysis Support System (GRASS GIS, http://ces.iisc.ernet.in/grass), a free and open-source software with robust support for processing both vector and raster data, was used to analyse RS data through available multi-temporal 'ground truth' information (http://ces.iisc.ernet.in/grass).

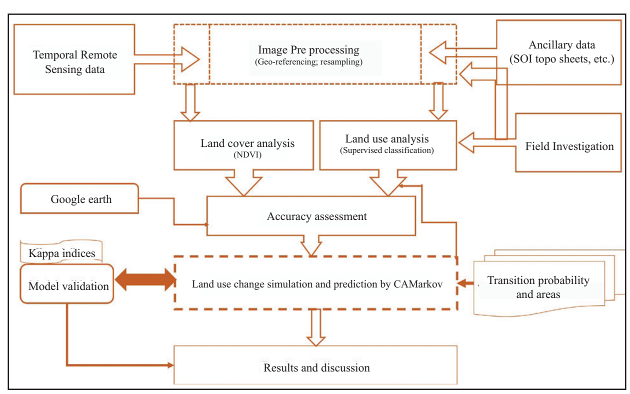

Figure 3. Method Followed in the Analysis

Source: The authors.

Modelling Spatial Patterns of Transitions

Land use analyses provided spatial patterns at the temporal scale and the Markovian process aided to generate the transition probability map and area matrix based on the probability distribution of the current cell state that was assumed to only depend on the current state (Equations [2] and [3]). The land use maps of 1999–2015 were reclassified into five categories for effective visualization as explained in Table 1. The original transition probability matrix (denoted as P) of land use types can be obtained from two former land use maps. Cellular automata was used to obtain a spatial context and distribution map based on Markov's transitional probability and area by combining multi-criteria land allocation to predict land cover change over time. The water category was considered a constraint (assuming that this category continues to exist). The transition rules were made considering the possibility of forests transforming to other land uses, agriculture and built-up transform forests. The rate of transitions was based on past land use changes and current trends, ascertained through field investigations. Also, the city's developmental plans of 2015 (available at http://bbmp.gov.in/revised-master-plan) and 2031 (http://www.bmrda.kar.nic.in/rsp_report.pdf) have been used in the analysis. The proposed housing and industrial layouts were digitized and considered as the future growth poles to simulate the possible land use transitions. The net neighbourhood influences were determined by the 5 × 5 contiguity filter which explains past land use changes and used to simulate future changes. Land use predictions of 2015 were made using CA coupled with Markov chains based on the transitional probability generated for 1999–2009. The validation of predicted land use was done by comparing it with reference land use of 2015 (actual) through the computation of kappa index (for location and quantity). This helped in the visualization of likely land uses in 2027, considering 6-year time intervals.

Table 1. Land Use Classes Considered for the Analysis

Sl. No.	Land Use Categories	Description
1.	Forest	Moist deciduous forests, dry deciduous forests, scrubs/grasslands and forest plantations
2.	Agriculture	Agriculture fields, permanent sown areas, coconut and other commercial plantations
3.	Open fields	Rocks, quarry pits, barren land
4.	Water	Rivers, tanks, lakes, reservoirs, drainages
5.	Built-up	Residential areas, industrial areas, paved surfaces

Source: The authors.

$$P(N) = P(N-1) \times P_{ij} \quad (2)$$

where $P(N)$ is state probability at any time and $P(N-1)$ is preliminary state probability.

Transition area matrix can be obtained by,

$$\text{Transition area Matrix P} = \begin{bmatrix} P_{11} & P_{12} & P_{13} \\ \vdots & \vdots & \vdots \\ P_{N1} & P_{N2} & P_{NN} \end{bmatrix} \quad (3)$$

where P_{ij} is the sum of areas from the ith land use category to the jth category in the years from start point to target simulation periods and n is the number of land use types. The transition area matrix must meet the following conditions (Equations (4) and (5)):

i. $$0 \le P_{\text{ij}} \le 1 \quad (4)$$

ii. $$\sum_{i,j=0}^{n} P_{ij} = 1 \quad (5)$$

Results

Status and Transition of Land Use Land Cover from 1973 to 2015

LULC dynamics is assessed using temporal RS data. The study region (BNP with a 5-km buffer) has witnessed large-scale land cover transformation from 1973 to 2015, due to unplanned developmental activities with large-scale anthropogenic activities. The fast economic and social transformation in the Bangalore metropolitan region has large-scale impacts on BNP and its environs. Temporal variations in NDVI values helped to quantify spectrally distinct vegetation and non-vegetation regions, which highlighted the loss of vegetation cover from 85.78 per cent (1973) to 66.37 per cent (2015) in the study region (Table 2, Figure 4). Land use analyses from 1973 to 2015 reflect the impact of urban expansion and the status of forests in the peripheries of BNP. The buffer region aids in biodiversity conservation, supports wildlife migration and acts as a refugee and a grazing ground for livestock. The western and eastern part of the study region (BNP with the buffer) consist of human habitations with agricultural activities. Figure 5 and Table 3 reflect changes in the forest cover of the BNP buffer region from 1973 to 2015. The large tracts of deciduous cover in the Kanakapura Taluk and Anekal Taluk have disappeared due to the unauthorized expansion of horticulture and agricultural activities in recent years. The region has lost moist deciduous cover, from 26.1 per cent to 13.8 per cent (1973–2015), and horticulture has increased, from 8.5 to 11 per cent. Large-scale land use changes with an increase in built-up areas from 0.4 per cent to 4.5 per cent in the periphery are due to illegal activities such as stone quarrying, granite and sand mining and medium-scale industries. The overall accuracy of land use maps for 1973, 1989, 1999, 2009 and 2015 was 87.86 per cent, 88.4 per cent, 88.8 per cent, 87.85 per cent and 91.66 per cent, respectively. Accordingly, the kappa coefficients were 0.84, 0.86, 0.86, 0.85 and 0.89, respectively.

Bangalore's unrealistic metropolitan growth has intrinsic relations with vegetation loss in the peri-urban landscape of BNP. The increase in the population of Kanakapura Taluk and Maralwadi Town resulted in more transition of forests to other land uses. Encroachments in Kanakapura forests, revenue lands and *gomala* regions (grazing lands) have resulted in deforestation, and the formation of housing layouts has enhanced the instances of human-animal conflicts and loss of human life and crop. The region has 9,254.21 ha of degraded forest patches, which have to be reforested with native plant species to improve the food and fodder availability for wild fauna.

Table 2. Land Cover Changes from 1973 to 2015

Year / Category	1973		1989		1999		2009		2015	
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
Vegetation	107087.8	**87.98**	104039.5	85.5	99992.2	82.2	94693.3	77.8	89419.0	**73.46**
Non-vegetation	14633.13	12.02	17682.5	14.5	21728.7	17.8	27027.6	22.2	32301.9	**26.54**
Total area					**121720.9**					

Source: The authors.

Note: Highlighted values indicate significant changes.

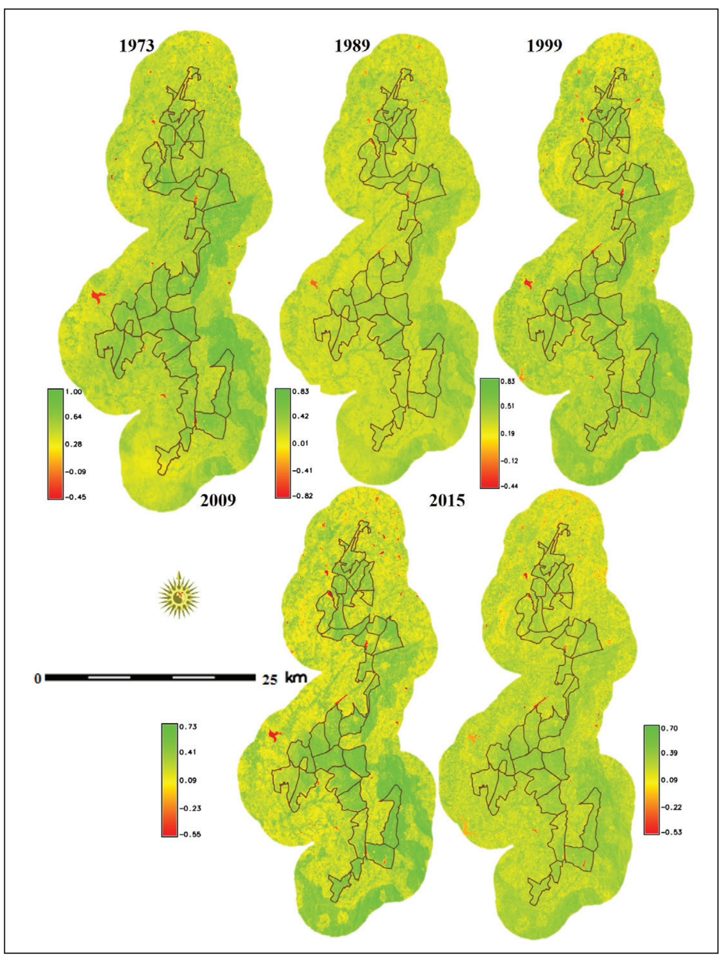

Figure 4. Land Cover from 1973 to 2015 in Bannerghatta National Park with 5-km Buffer

Source: The authors.

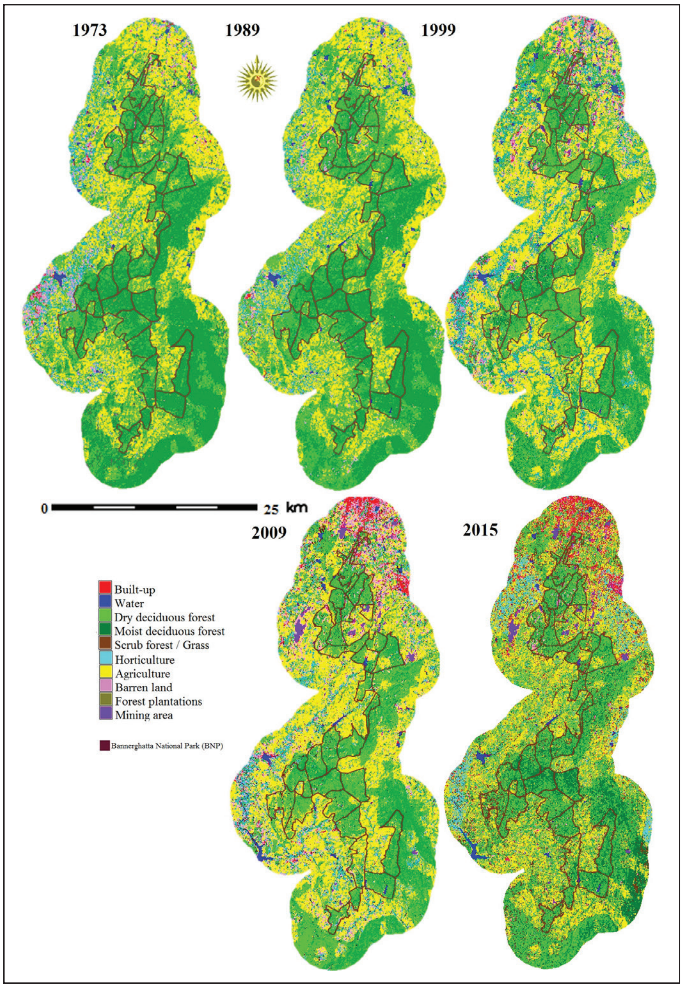

Figure 5. Land Use in BNP with 5-km Buffer (1973–2015)

Source: The authors.

Table 3. Land Use Changes in Bannerghatta National Park with 5-km Buffer from 1973 to 2015

Year Category	1973		1989		1999		2009		2015	
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
Dry deciduous forests	32415.6	**26.6**	31609.3	26.0	26433.6	21.7	24042.3	19.8	22729.9	**18.7**
Moist deciduous forests	31725.9	**26.1**	29694.3	24.4	25941.5	21.3	16916.1	13.9	16822.2	**13.8**
Grass/scrub forests	4876.8	**4.0**	4500.4	3.7	4914.4	4.0	8967.2	7.4	9254.2	**7.6**
Water	377.8	0.3	922.5	0.8	1170.8	1.0	1251.6	1.0	1834.0	1.5
Horticulture	10361.3	8.5	11768.4	9.7	12707.1	10.4	13470.5	11.1	13363.2	11.0
Agriculture	36027.9	**29.6**	37222.3	30.6	40053.5	32.9	44975.1	36.9	45613.8	**37.5**
Urban	490.6	0.4	581.6	0.5	1934.9	1.6	3216.0	2.6	5462.1	**4.5**
Barren land	4461.8	3.7	4251.7	3.5	6833.9	5.6	6114.5	5.0	3536.6	2.9
Forest plantations	921.4	0.8	1060.5	0.9	1011.0	0.8	1533.1	1.3	1566.3	1.3
Mining area	61.8	0.1	109.9	0.1	720.3	0.6	1234.5	1.0	1538.7	1.3
Total area					**1,21,720.9**					

Source: The authors.

Modelling and Visualization of Forest Transitions

The prediction of likely land uses for 2021 and 2017 was done through CA-Markov, incorporating various land use decisions in transition rules (of 1999–2009 and 2009–2015). Land use of 2015 is predicted (Figure 6) considering land use of 1999 (Table 4, with transition details of 1999–2009), which was compared with actual land uses of 2015. This helped in validating the CA-Markov technique for predication, and the results are given in Table 5. A higher kappa value of 0.86 indicates a significant correlation and agreement between the simulated and actual land uses. Kno indicates the overall accuracy of the simulation as compared to the reference map. Klocation evaluates the accuracy of the simulation in specifying a particular location. Kstandard shows the location error with quantification as per reference map. The prediction of land uses for 2021 was done considering base land use data from 2009 to 2015. Similarly, the land use of 2027 was predicted based on land uses of 2015 and 2021 (simulated). The projected land use of 2027 shows an alarming picture of the loss of forest cover, from 41.38 per cent to 35.59 per cent, with an increase in urban area (4.49%–9.62%) due to irresponsible land use changes with housing projects in an ecologically sensitive region (Figure 7). These anthropogenic activities would pose serious threats to the forest ecosystem in BNP, which has been aiding as a carbon sink (in lieu of higher greenhouse gas (GHG) emissions in Bangalore (Ramachandra, Bharath et al., 2015). The forests in southern parts project minimal disturbances (connected to the Tali Reserve Forests and Cauvery Wildlife Sanctuary), whereas northern portions show very disturbing trends of higher rates of transition. The uncontrolled and unplanned growth of Greater Bangalore would certainly spell doom to the survival of fauna and the sustenance of forest cover in BNP. The major growth poles are built-up expansions in the Anekal industrial area, Kalkere, Basavanapura and Weavers Colony, Uttarahalli Manavartha Kaval.

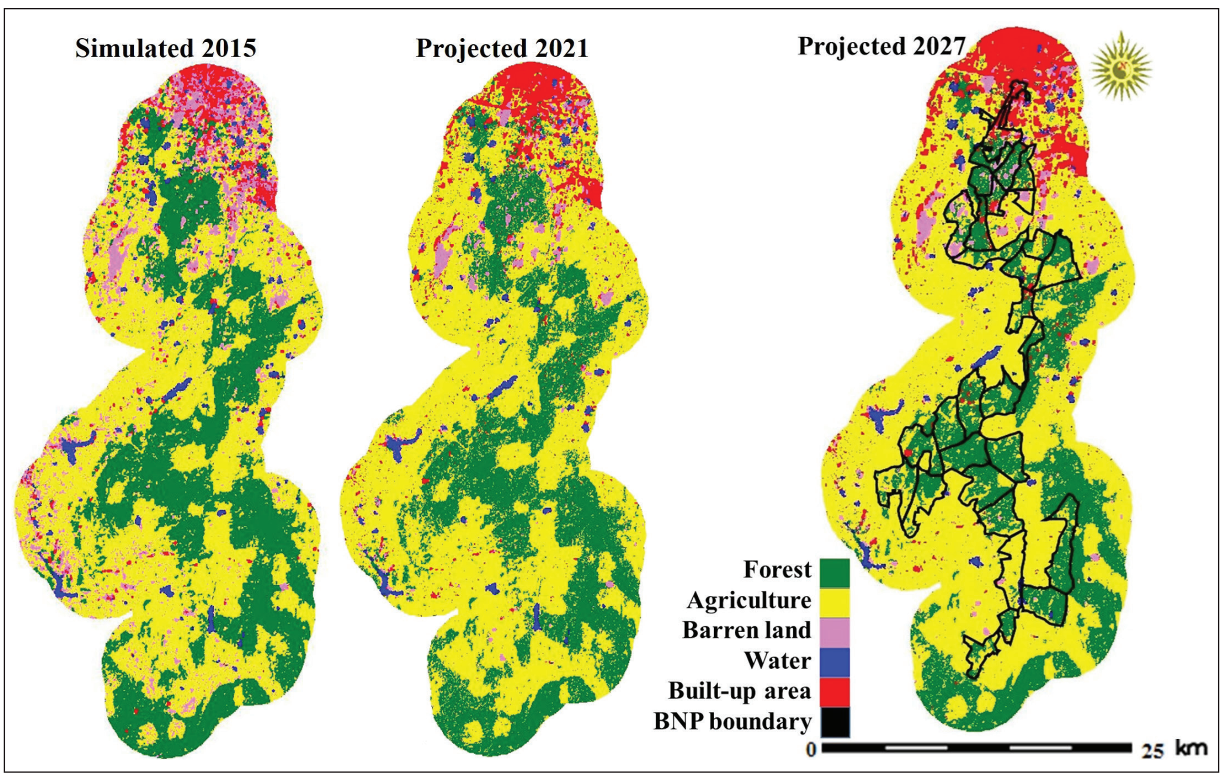

Figure 6. Simulate and Projected Land Use of BNP 2015–2027

Source: The authors.

Table 4. Transition Probability Matrix Based on Land Use from 1999 to 2009

	Probability of Changing to				
Given	**Forest**	**Agriculture**	**Barren Land**	**Water**	**Built-up**
Forest	**0.783**	0.1649	0.0252	0.0022	0.0246
Agriculture	0.025	**0.9**	0.025	0.025	0.025
Barren land	0.1573	0.259	**0.4493**	0.0026	0.1318
Water	0.1055	0.0803	0.0165	**0.7011**	0.0967
Built-up	0.025	0.025	0.025	0.025	**0.9**

Source: The authors.

Table 5. Simulated, Projected Land Use of Bannerghatta National Park from 2015 to 2027 and Accuracy of the Analysis

Year	**Simulated (2015)**		**Projected (2021)**		**Projected (2027)**	
Categories	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
Forest	49444.88	**40.62**	45895.57	37.67	43315.05	**35.59**
Agriculture	58207.18	48.64	60410.02	49.67	60206.03	49.46
Barren land	6668.57	4.66	5030.71	4.13	4460.76	3.66
Water	2011.68	1.65	2033.13	1.67	2031.11	1.67
Urban	5387.75	**4.43**	8350.63	**6.85**	11707.15	**9.62**
Total area	121720.9					
Index	**Validation of Simulated LU 2015**					
K_{no}	0.93					
$K_{location}$	0.86					
$K_{standard}$	0.87					

Source: The authors.

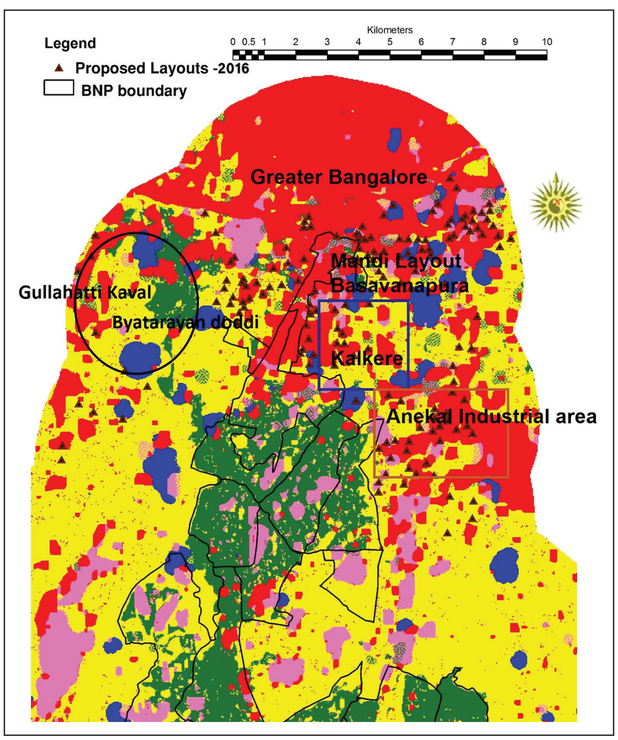

Figure 7. The Regions Likely to Experience Higher Land Use Changes

Source: The authors.

Discussion

The global population growth is projected to increase from 7.2 billion to 9.6 billion from 2013 to 2050 (Wimberly, Sohl, Liu, & Lamsal, 2015), which would escalate anthropogenic pressure on forest resources. Global forest cover destruction has resulted in augmented GHG emissions from 12 per cent to 17 per cent (Van der Werf et al., 2009) due to shunting of the carbon sequestration process. Deforestation in Southeast Asia alone has resulted in ~1.4 ± 0.5 PgC yr−1 net emissions of Carbon (C) between 1990 and 2010 (Houghton et al., 2012). Deforestation and subsequent land use changes will have irretrievable impacts on ecosystem goods and services apart from the decline of carbon sequestration capabilities and an increase in atmospheric GHG emissions. This would also alter the climate and hydrologic regimes that would in turn threaten water and food security. Large-scale LULC changes and loss of forest cover in the study region (BNP with a 5-km buffer) are due to urban sprawl with irresponsible and unplanned urbanization processes in Bangalore. The city witnessed urbanization with the unrealistic increase of paved surfaces by 1,028 per cent from 1973 to 2018 with loss of vegetation (88%) and 79 per cent of water bodies (Halmy & Gessler, 2015; Ramachandra & Bharath, 2016; Ramachandra, Setturu et al., 2012; Ramachandra, Bharath et al., 2012). Uncontrolled and uncoordinated urban growth was noticed subsequent to globalization and the push towards industrialization in recent decades. Drivers of urbanization include political and economic in various proportions. Urban sprawl already has telling impacts evident from resource scarcity and enhanced instances of human-animal conflicts, which necessitate the restoration of the integrity of ecologically sensitive buffer regions with the afforestation of degraded forest patches with native species of flora and immediate eviction of unauthorized occupations of forests and common lands (grazing lands, etc.). Various spatially explicit models have been developed in recent years to simulate transitions in LULC, thereby enabling the advanced visualization of dynamic phenomena such as urban growth. The CA-Markov model adopted for the visualization of LULC changes highlights the likely ecological and environmental implications in the absence of appropriate policy interventions for the conservation of BNP.

Visualization through CA-Markov (Briassoulis, 2000; Keshtkar & Voigt, 2016) was comparable to actual growth (2015). Predicted LU changes for 2021 and 2027 have provided valuable insights into landscape dynamics and likely implications. Non-agent-based (AGB) models however have drawbacks of the non-inclusion of agents and in particular human decision-making (Briassoulis, 2000; Keshtkar & Voigt, 2016; Truong et al., 2015). Compared to this, AGB dynamics are well conceived for conditional decision-making of nonlinear behaviour by rules that distinguish them from mathematically continuous models such as CA-Markov (Brown, Riolo, Robinson, North, & Rand, 2005; Li, Oyana, & Mukwaya, 2016). AGB involves the identification of agents which have the ability to satisfy internal goals through actions based on a set of rules of a temporal framework within which those agents perform actions but computationally intensive ones (Daniel, Frid, Sleeter, & Fortin, 2016; Mozumder, Tripathi, & Losiri, 2016; Nicholls, Amelung, & Student, 2016; Rand et al., 2003). The multi-agent models with human perceptions, which encapsulate hierarchically the behaviours of biophysical drivers, will increase the precision of prediction.

BNP, a part of Western Ghats and a repository of unique flora and fauna with biological, social, hydrological and ecological significance, needs immediate measures with prudent biodiversity conservation policies. Due to water and food security in peninsular India with perennial water resources, the Western Ghats is aptly known as the water tower for peninsular India. Any imbalances in the ecologically sensitive regions would not only affect the local population but also threaten global climate. The community-based conservation (CBC) path involving local stakeholders is crucial to conserving biological diversity and sustaining natural resources. The involvement of local stakeholders in decision-making and enhancing the livelihood prospects of the dependent population would help in the protection of forest ecosystems. The local community's knowledge and the experience of wildlife and their habitats would help in strengthening conservation endeavours. Ecologically hazardous activities such as mining, the expansion of agriculture and horticulture in the core area must be restricted immediately to protect wildlife and flora. Incentives to support organic farming, setting up agro-processing industries, establishing cottage industries to support local livelihoods and setting up fodder farms to support local livestock population would help in minimizing forest degradation. Steps have to be taken to enrich forests impoverished of wild animal fodder plants. Appropriate cropping has to be encouraged with strict regulations to minimize instances of human-animal conflicts (Radha Devi, 2003). Other conservation and awareness initiatives include involving education institutions to document biodiversity in the neighbourhood (at the village level); eco clubs at all schools; students to take part in environment monitoring (part of the curriculum), the development of forest nurseries of local species through the active participation of women and incentives to villagers for conservation and so on. Adopting the integrated clustering development of villages for inclusive growth is suggested to promote eco-friendly, local resources, local skills and manpower-based thematic developmental programmes through a stronger foundation for sustainable growth (Ramachandra, Hegde, Subash Chandran, Tejaswini, & Vishnumayananda, 2015).

Conclusion

The analyses of the state and transitions of the landscape help in understanding LULC dynamics, which in turn helps in the sustainable management of natural resources. Prudent natural resource management requires a synoptic ecosystem approach, accounting for natural variability as well as anthropogenic activities. Landscape management planning and the role of governance have become crucial with increasing population pressure on land resources and urbanization. Arresting the deforestation process or enhancing forest cover is essential to mitigate climate change impacts. The study region being ecologically sensitive is undergoing large-scale land cover changes due to unplanned and senseless urbanization processes in Bangalore because of fragmented and uncoordinated governance. The conservation of an ecologically vital BNP is crucial for the survival of Bangaloreans and global population as BNP has been helping in sequestering carbon (emissions) and moderating climate and wide array of flora of medicinal importance. Land use land cover (LULC) analyses through temporal RS data from 1973 to 2015 reveal that the region has lost moist deciduous cover from 26.1 per cent to 13.8 per cent and that there has been an increase in horticulture, from 8.5 per cent to 11 per cent. Urban sprawl or dispersed growth in the region is due to illegal housing projects and industrial projects accounting to 5,462 ha (built-up area). The visualization of likely land uses in 2027 through the CA-Markov modelling framework shows the loss of natural forest cover from 41.38 per cent to 35.59 per cent with a spurt in urban pockets from 4.49 per cent to 9.62 per cent. This highlights the need for sensible policy interventions by promoting native species to rehabilitate degraded lands, strict monitoring, increasing community awareness and stringent implementation to protect BNP, the repository of unique flora and fauna with biological, social, hydrological and ecological significance.

Recommendations/Suggestions

Millions of hectares of tropical forests are being converted into agricultural fields and pastures every year, threatening many species with extinction. Vegetation succession on lands abandoned after human use often brought back natural forests but not the primary forests that were lost. At the same time there were patches of original forests enmeshed amidst secondary forests or in the midst of human habitations, often preserved by communities. While conceding the need to adopt more sophisticated experimental designs in the future, this study, so far, has indicated strongly the need for adoption of holistic ecosystem management of the ecologically fragile regions. The premium should be on conservation of the remaining native forests, which are vital for the perenniality (the availability of water during all seasons) of water bodies. There still is a chance to restore the lost natural forests with endemic flora and fauna by appropriate management. The natural forests in BNP are more fragile and prone to losing their endemic biodiversity. These forests also are associated with high watershed value and perform considerable ecosystem services. Therefore, studies need to be undertaken to identify these forests and demarcate them for special protection by the state or in collaboration with local communities. Suggestions for the conservation of forests are as follows.

- Ecosystems through the establishment of long-term monitoring ecological plots must be monitored, involving research scholars from education institutions and the network of students and teachers from schools and colleges in the district.
- Local forest dwelling communities must be involved in raising plant nurseries of native species and also the management and maintenance of the afforested regions.
- Open areas and hill tops have to be planted with native species which provide NTFPs and fruits to dependent species.
- Provisions have to be made to provide fuel wood to villagers regularly. The collection of fuel wood and poles must be discontinued for effective regeneration in the shrub layer.
- The collection of NTFPs has to be effectively monitored for non-destructive collection.
- Trenches and fencing can be undertaken in more human-populated areas to protect forests from grazing and encroachment.
- There should be restrictions on environmentally harmful activities such as mining (granite, sand, etc.).
- The physical and biological integrity of BNP buffer regions has to be maintained with restrictions on locating large-scale industries, housing and commercial layouts and raising monoculture plantations of exotic species.
- There has to be restrictions on inappropriate crops and inefficient water management.
- Removal of bottlenecks along the wild animal movement path and enriching animal path regions with fodder and fruit crops as well as water bodies are important.

Acknowledgements

We are grateful to (a) the Natural Resources Data Management System (NRDMS) division, the Ministry of Science and Technology (DST), Government of India; (b) the Ministry of Environment, Forests and Climate Change, Government of India; and (c) the Indian Institute of Science for their sustained financial and infrastructure support. We thank Dr Sunil Panwar, Deputy Conservator of Forest (DCF), Bannerghatta National Park, Karnataka Forest Department, for entrusting the study and seeing to all necessary arrangements during our field research. We are grateful to Mr Vishnu Narain and Rama Krishna (RK) Mission, Shivanahalli, for arranging local logistics.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding

The authors received no financial support for the research, authorship and/or publication of this article.

References

Akber, M. A., & Shrestha, R. P. (2015). Land use change and its effect on biodiversity in Chiang Rai province of Thailand. *Journal of Land Use Science*, *10*(1), 108–128.

Anderson, J. R., Hardy, E. E., Roach, J. T., & Witmer, R. E. (1976). *A land use and land cover classification system for use with remote sensor data* (Vol. 964). Washington, DC: US Government Printing Office.

Bharath, S., Rajan, K. S., & Ramachandra, T. V. (2013). Land surface temperature responses to land use land cover dynamics. *Geoinformatics Geostatistics: An Overview*, *1*(4), 1–10.

———. (2016). Geo-visualisation of landscape dynamics in Sirsi and Haliyal forest divisions of Central Western Ghats. In *Proceedings of National Conference on Challenges of Civil Engineering Innovations (NCCCEI 2016)*. Bangalore: Sri Venkateshwara College of Engineering.

Bharath, H. A., Vinay, S., & Ramachandra, T. V. (2014). Landscape dynamics modeling through integrated Markov, Fuzzy-AHP and cellular automata. In *Geoscience and Remote Sensing Symposium (IGARSS), 2014 IEEE International* (pp. 3160–3163). IEEE.

Briassoulis, H. (2000). Analysis of land use change: Theoretical and modelling approaches. In Loveridge, S. (Ed.), *The web book of regional science* (pp. 1–82). Morgantown, WV: Regional Research Institute, West Virginia University.

Brown, D. G., Riolo, R., Robinson, D. T., North, M., & Rand, W. (2005). Spatial process and data models: Toward integration of agent-based models and GIS. *Journal of Geographical Systems*, *7*(1), 25–47.

Chase, T. N., Pielke Sr, R. A., Kittel, T. G. F., Nemani, R. R., & Running, S. W. (2000). Simulated impacts of historical land cover changes on global climate in northern winter. *Climate Dynamics*, *16*(2–3), 93–105.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, *37*(1), 35–46.

Daniel, C. J., Frid, L., Sleeter, B. M., & Fortin, M. J. (2016). State-and-transition simulation models: A framework for forecasting landscape change. *Methods in Ecology and Evolution*, *7*(11), 1413–1423.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., … Helkowski, J. H. (2005). Global consequences of land use. *Science*, *309*(5734), 570–574.

García-Llorente, M., Martín-López, B., Nunes, P. A. L. D., Castro, A. J., & Montes, C. (2012). A choice experiment study for land-use scenarios in semi-arid watershed environments. *Journal of Arid Environments*, *87*, 219–230.

Haase, D., & Nuissl, H. (2010). The urban-to-rural gradient of land use change and impervious cover: A long-term trajectory for the city of Leipzig. *Journal of Land Use Science*, *5*(2), 123–141.

Halmy, M. W. A., & Gessler, P. E. (2015). The application of ensemble techniques for land-cover classification in arid lands. *International Journal of Remote Sensing*, *36*(22), 5613–5636.

Houghton, R. A., House, J. I., Pongratz, J., Van Der Werf, G. R., DeFries, R. S., Hansen, M. C., … Ramankutty, N. (2012). Carbon emissions from land use and land-cover change. *Biogeosciences*, *9*(12), 5125–5142.

Jensen, J. R. (2005). Thematic map accuracy assessment. In J. R. Jensen (Ed.), *Introductory digital image processing: A remote sensing perspective* (Series in Geographic Information Science, pp. 476–482). Saddle River, NJ: Prentice Hall.

Jiang, G., Zhang, F., & Kong, X. (2009). Determining conversion direction of rural residential land consolidation in Beijing mountainous areas. *Transactions of the Chinese Society of Agricultural Engineering*, *25*(2), 214–221.

Kamusoko, C., Aniya, M., Adi, B., & Manjoro, M. (2009). Rural sustainability under threat in Zimbabwe–simulation of future land use/cover changes in the Bindura district based on the Markov-cellular automata model. *Applied Geography*, *29*(3), 435–447.

Kang, H. Q., Zhu, B., Zhu, T., Sun, J. L., & Ou, J. J. (2014). Impact of megacity Shanghai on the urban heat-island effects over the downstream city Kunshan. *Boundary-Layer Meteorology*, *152*(3), 411–426.

Keshtkar, H., & Voigt, W. (2016). Potential impacts of climate and landscape fragmentation changes on plant distributions: Coupling multi-temporal satellite imagery with GIS-based cellular automata model. *Ecological Informatics*, *32*, 145–155.

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, *28*(1), 205–241.

Li, J., Oyana, T. J., & Mukwaya, P. I. (2016). An examination of historical and future land use changes in Uganda using change detection methods and agent-based modelling. *African Geographical Review*, *35*(3), 247–271.

Lillesand, T., Kiefer, R. W., & Chipman, J. (2014). *Remote sensing and image interpretation*. Hoboken, NJ: John Wiley & Sons.

Liu, C., Frazier, P., & Kumar, L. (2007). Comparative assessment of the measures of thematic classification accuracy. *Remote Sensing of Environment*, *107*(4), 606–616.

Liu, Y., Feng, Y., Zhao, Z., Zhang, Q., & Su, S. (2016). Socioeconomic drivers of forest loss and fragmentation: A comparison between different land use planning schemes and policy implications. *Land Use Policy*, *54*, 58–68.

Mozumder, C., Tripathi, N. K., & Losiri, C. (2016). Comparing three transition potential models: A case study of built-up transitions in North-East India. *Computers, Environment and Urban Systems*, *59*, 38–49.

Nicholls, S., Amelung, B., & Student, J. (2017). Agent-based modeling: A powerful tool for tourism researchers. *Journal of Travel Research*, *56*(1), 3–15.

Pielke Sr, R. A., Pitman, A., Niyogi, D., Mahmood, R., McAlpine, C., Hossain, F., … Reichstein, M. (2011). Land use/land cover changes and climate: Modeling analysis and observational evidence. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(6), 828–850.

Polasky, S., Nelson, E., Pennington, D., & Johnson, K. A. (2011). The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the state of Minnesota. *Environmental and Resource Economics*, *48*(2), 219–242.

Radha Devi, A. (2003). *Karnataka forest department master plan for consolidation of Bannerghatta National Park boundaries and elephant corridors*. Bangalore: Karnataka Forest Department.

Ramachandra, T. V., & Bharath, H. A. (2016). Bengaluru's reality: Towards unlivable status with unplanned urban trajectory. *Current Science*, *110*(12), 2207–2208.

Ramachandra, T. V., Bharath, S., & Bharath, H. A. (2014). Spatio-temporal dynamics along the terrain gradient of diverse landscape. *Journal of Environmental Engineering and Landscape Management*, *22*(1), 50–63.

Ramachandra, T. V., Bharath, S., & Gupta, N. (2018). Modelling landscape dynamics with LST in protected areas of Western Ghats, Karnataka. *Journal of Environmental Management*, *206*, 1253–1262.

Ramachandra, T. V., Bharath, H. A., & Sanna, D. D. (2012). Insights to urban dynamics through landscape spatial pattern analysis. *International Journal of Applied Earth Observation and Geoinformation*, *18*, 329–343.

Ramachandra, T. V., Bharath, H. A., & Sreejith, K. (2015). GHG footprint of major cities in India. *Renewable and Sustainable Energy Reviews*, *44*(C), 473–495.

Ramachandra, T. V., Hegde, G., Subash Chandran, M. D., Tejaswini, A. K., & Vishnumayananda, S. (2015). *SMART Ragihalli: Effort towards self-reliant & self-sufficient system empowering man power (rural youth) with appropriate rural technologies* (ETR No. 90). Bangalore: Energy & Wetlands Research Group, CES, Indian Institute of Science.

Ramachandra, T. V., Setturu, B., & Bharath, H. A. (2012). Peri-urban to urban landscape patterns elucidation through spatial metrics. *International Journal of Engineering Research and Development*, *2*(12), 58–81.

Ramachandra, T. V., Setturu, B., & Chandran, S. (2016). Geospatial analysis of forest fragmentation in Uttara Kannada District, India. *Forest Ecosystems*, *3*(1), 10.

Rand, W., Brown, D. G., Page, S. E., Riolo, R., Fernandez, L. E., & Zellner, M. (2003, April). Statistical validation of spatial patterns in agent-based models. In C. Macal and D. Sallac (Eds.), *Proceedings of agent based simulation* (Vol. 4). Chicago: University of Chicago and Argonne National Lab.

Rands, M. R., Adams, W. M., Bennun, L., Butchart, S. H., Clements, A., Coomes, D., … Sutherland, W. J. (2010). Biodiversity conservation: Challenges beyond 2010. *Science*, *329*(5997), 1298–1303.

Schägner, J. P., Brander, L., Maes, J., & Hartje, V. (2013). Mapping ecosystem services' values: Current practice and future prospects. *Ecosystem Services*, *4*, 33–46.

Schneider, A., Friedl, M. A., & Potere, D. (2009). A new map of global urban extent from MODIS satellite data. *Environmental Research Letters*, *4*(4), 044003.

Sexton, J. O., Song, X. P., Feng, M., Noojipady, P., Anand, A., Huang, C., … Townshend, J. R. (2013). Global, 30-m resolution continuous fields of tree cover: Landsat-based rescaling of MODIS vegetation continuous fields with lidar-based estimates of error. *International Journal of Digital Earth*, *6*(5), 427–448.

Truong, Q. C., Taillandier, P., Gaudou, B., Vo, M. Q., Nguyen, T. H., & Drogoul, A. (2015, May). Exploring agent architectures for farmer behavior in land-use change. A case study in coastal area of the Vietnamese Mekong Delta. In Gaudou, B., Sichman, J. S. (Eds.), *International Workshop on Multi-agent Systems and Agent-based Simulation* (pp. 146–158). Cham: Springer.

Van der Werf, G. R., Morton, D. C., DeFries, R. S., Olivier, J. G., Kasibhatla, P. S., Jackson, R. B., … Randerson, J. T. (2009). CO_2 emissions from forest loss. *Nature Geoscience*, *2*(11), 737.

Vázquez-Quintero, G., Solís-Moreno, R., Pompa-García, M., Villarreal-Guerrero, F., Pinedo-Alvarez, C., & Pinedo-Alvarez, A. (2016). Detection and projection of forest changes by using the Markov Chain Model and cellular automata. *Sustainability*, *8*(3), 236.

Vinay, S., Bharath, S., Bharath, H. A., & Ramachandra, T. V (2013, November). Hydrologic model with landscape dynamics for drought monitoring. In ISPRS (Ed.), *Proceeding of Joint International Workshop of ISPRS WG VIII/1 and WG IV/4 on Geospatial Data for Disaster and Risk Reduction, Hyderabad, November* (pp. 21–22).

Verburg, P. H., Schot, P. P., Dijst, M. J., & Veldkamp, A. (2004). Land use change modelling: Current practice and research priorities. *GeoJournal*, *61*(4), 309–324.

Wimberly, M. C., Sohl, T. L., Liu, Z., & Lamsal, A. (2015). Simulating forest landscape disturbances as coupled human and natural systems. In *Simulation modeling of forest landscape disturbances* (pp. 233–261). Cham: Springer.

Wu, Z., Ge, Q., & Dai, E. (2017). Modeling the relative contributions of land use change and harvest to forest landscape change in the Taihe county, China. *Sustainability*, *9*(5), 708.

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