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Modeling Landscape Dynamics of Policy Interventions in Karnataka State, India

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Abstract

The availability of multi-resolution spatial data and advances in modeling techniques have given an impetus to land use land cover (LULC) change analyses. Geo-visualization of possible land uses (LU) with policy decisions is vital for formulating appropriate sustainable resource management policies. For the prudent management of natural resources, LU planning has to take environmental dimensions into account. LU dynamics helps to understand the macro background of regional population growth, economic development, social progress, and changes in the natural environment. In this study, LU transitions from 1985 to 2019 were assessed through a supervised classifier based on the Gaussian maximum likelihood estimation algorithm. Geo-visualization of landscape dynamics was implemented through a fuzzy analytical hierarchy process (AHP) with Markov cellular automata (MCA) for Karnataka state, India. It considered five policy scenarios, namely, (i) business as usual (BAU), (ii) agent-based land use transition (ALT), (iii) reserve forest protection (RFP), (iv) afforestation (AF), and (v) sustainable development plan (SDP). Prior knowledge of likely LU aids in assessing the implications of chosen policies forms a base for sustainable resource management with conservation of biological diversity. LU analyses revealed that forests in Karnataka state constituted 21% in 1985, witnessed large-scale transitions, and reduced to 15% of the geographical area in 2019. BAU depicts a likely increase in the built-up area to 11.5% from 3% (2019). The SDP scenario (with stringent policy implementation) indicates that the forest cover would remain at 11% (compared to 15% in 2019), which is the least possible loss among all considered scenarios (BAU, ALT, RFP, AF, and SDP). Modeling and visualization of landscape dynamics aids in regional LU planning as a spatial decision support system (SDSS) towards achieving sustainable development goals.

Keywords Modeling · Land use dynamics · Scenarios · Sustainable development · Policy

Introduction

Landscapes are dynamic with a mosaic of heterogeneous ecosystem elements that change in size, shape, and spatial arrangements due to complex and multi-scalar processes. Landscape dynamics involving changes in the structure of the landscape will have implications for ecosystem functions and processes. Land use land cover (LULC) changes leading to land degradation have escalated the carbon footprint while lowering the ability to sequester carbon, which is instrumental in accelerating global warming. Drivers of large-scale land use (LU) changes include regional economics, policies, culture, management, and environmental factors. LULC changes have been eroding ecosystem services, which is evident from the decline in biodiversity and alterations in the hydrologic regime, affecting the sustainability of natural resources (Vose et al. 2004; Polasky et al. 2011; Bharath et al. 2013; Vinay et al. 2013; Ramachandra et al. 2021). Alteration in bio-geochemical cycles has impaired the exchange of moisture, heat, and albedo at the local and global scales, intensely impacting climate feedback of the land surface. Degradation of forest landscapes results in lowered evapotranspiration, affecting the hydrologic regime and releasing the carbon

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stored in the soil and vegetation due to changes in the physical and chemical integrity of the ecosystem, thus contributing to higher levels of atmospheric greenhouse gases (GHG) (Ramachandra et al. 2020; Ramachandra and Bharath 2021). Unplanned developmental activities leading to LULC changes have affected the carrying capacity, which is evident from barren hilltops, conversion of perennial streams to intermittent or seasonal streams, and lower crop productivity.

The dynamics in landscapes, involving changes in the structure of forest ecosystems, have accelerated due to globalization (during the post-1990s) with the opening up of markets and consequent urbanization. During the past decade, global forests have witnessed a loss of 2.3 million sq. km. to cater to the demands of the burgeoning population coupled with unplanned developmental activities. Mitigation of these impacts entails actions toward the preservation of ecosystems at the local level. Knowledge of landscape dynamics and agents of LU transitions and LULC change analyses will provide valuable insights and aid in evolving prudent management strategies to sustain natural resources and mitigate climate change.

Urban expansions are taking place rapidly, with a higher rate of rural migration to the fringes and successively to core cities (Ramachandra and Aithal 2016). In recent decades, the urbanizing economy has contributed to urban sprawl. There is an expansion to peri-urban areas to develop residential layouts, create special economic zones, and transform ecological and agricultural spaces in cities into industrial setups (Ramachandra et al. 2012). LU models and advanced visualization of likely land use associated with policy decisions will help mitigate the impacts of rapid urbanization on vulnerable ecological spaces (Fu et al. 2018; Chandan et al. 2020; Dadashpoor and Panahi 2021). Scenario-based modeling helps in designing policies while taking into account the geomorphology (environment), connectivity (mobility), facilities, government (development plans), demographic and socio-economic factors, and sustainability (water bodies and green spaces) (Wahyudi and Liu 2013).

Spatially explicit data helps in understanding the heterogeneity within a landscape. This supports local and regional policy coordination by establishing a standard, agreed set of data and relationship between the environment and economic and human activity within the ecosystem accounting framework. The availability of coherent data supports the incorporation of environmental data into decision-making by business and finance sectors; this complements the wide range of initiatives underway in those sectors by recognising the importance of ecosystems and biodiversity. Thus, data from ecosystem accounts are used in conjunction with other methods and tools in modeling and scenario analyses to aid policy and decision-making. The exercise of informed decision-making and the use of scenarios to assess the outcomes and effectiveness of various policy intervention options is often termed policy scenario analysis (SEEA 2017).

Some of the simulation models used to visualize LU dynamics are Markov chain-cellular automata (MCA), SLEUTH, CLUE-S, multi-criteria evaluation (MCE), Fuzzy analytical hierarchy process (AHP) models, agent-based models (ABM), and CA-artificial neural network (ANN). The existing modeling techniques such as MCA, constrained-CA, MCE-CA, and logistic-CA have advantages such as the generation of richer forms of cells at individual class levels (Verburg et al. 2002; Batty 2005; Li and Liu 2006; Crooks 2010; Santé et al. 2010; Ramachandra et al. 2019). The lacunae with these models are calibration, optimization of factors (of cell state transitions), and intermixing of cells. CA models are simple, flexible, and intuitive (Eckhardt 1987; Batty and Xie 1994; Itami 1994; Torrens 2000; Bharath et al. 2021). Hence, CA is used widely in diverse fields ranging from landscape dynamics, flood modeling, forest fire modeling, medicine or biological modelling and urbanization, (Ermentrout and Edelstein-Keshet 1993; Bharath et al. 2014; Guidolin et al. 2016; Li and Gong 2016; Ramachandra and Bharath 2019b). The Fuzzy AHP CA is a cellular model tied to a system dynamics model and is considered very effective. It integrates qualitative knowledge with quantitative information, enabling the modeler to determine where the given LUs are likely to occur (Bharath et al. 2021). It represents individual decision-making with temporal and spatial dynamics more effectively compared to previous models (Mosadeghi et al. 2015). The rule-based MCA technique aids in modeling likely LU changes. Markov's approach provides information on transition probability between LU classes at a time (t) to LU at a time (t+1), and transitional area matrix concerning likely LU class (extent) changes. The transition probability matrix [P] and transition area matrix [A] are provided by equations 1 and 2.

$$P = \begin{bmatrix} P_{11} & P_{12} & \dots P_{1n} \\ \vdots & \vdots & \vdots \\ P_{n1} & P_{n2} & \dots P_{nn} \end{bmatrix} \tag{1}$$

where P_{ij} is the probability of i^{th} LU converting into j^{th} class during the transition period and n is the number of LU classes.

$$A = \begin{bmatrix} A_{11} & A_{12} & \dots A_{1n} \\ \vdots & \vdots & \vdots \\ A_{n1} & A_{n2} & \dots A_{nn} \end{bmatrix} \tag{2}$$

where A_{ij} is the area of i^{th} LU transition into j^{th} LU class.

Cellular automata aids in simulating and predicting land use (LU) changes based on transitional rules depending on

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the state of cell changes according to the neighbourhood cells (and the current cell's previous state), with interactions at the local and regional levels. LU change patterns follow Markovian random properties with various constraints that include the average stable transfer state of LU structure.

A different Markov is used for deriving the LU change probability of the study region. LU is predicted using CA with Markov chain as per equation 3. MCA provides better results by collectively incorporating transitional rules and probabilities.

$$L_{(t+1)} = P * L_{(t)} \quad (3)$$

where $L_{(t+1)}$ = LU at t+1 and $L_{(t)}$ = LU at t.

The MCA model-simulated LU is compared with the actual LU to compute prediction accuracy with the revised Kappa statistics (Pontius and Malanson 2005).

The relative weights for a group of factors considered in the model are developed through AHP by providing a series of pairwise comparisons of their relative importance to pixel suitability for the respective activity (Bunruamkaew and Murayam 2011; Ramachandra et al. 2021). AHP incorporates a measure of consistency for the individual comparison matrix of the decision problem (Ramachandra et al. 2017a). Pairwise comparison is made by considering two factors, and weights are assigned 0 to 9 scale. The consistency index computed as per equation 4 depends on the principal eigenvector (λ max). The consistency of pairwise comparisons or the consistency ratio (CR) is given by Eq. 5.

$$\mathrm{CI} = \frac{\lambda\mathrm{max} - \mathrm{n}}{\mathrm{n} - 1} \quad (4)$$

$$\mathrm{CR} = \frac{\mathrm{CONSISTENCY\ INDEX}}{\mathrm{RANDOM\ CONSISTENCY\ INDEX}} \quad (5)$$

where λ max $= \sum$ (*eigen vector* $*$reciprocal *matrix col. sum*)

Lower values of CR are ideal for high accuracy; CR of 0.10 is preferred to attain minimum accuracy (Saaty 1980). MCE helps generate site suitability maps for future LU prediction in CA models (Clarke 2008; Spencer 2009).

Through an appraisal of changing behaviour, ABM considers individual actions of various agents in the simulation (Holland and Sigmund 1995; Franklin and Graesser 1996; Axtell 2000; Macal and North 2009; Crooks and Heppenstall 2012). Agents need to learn, engage in dynamic relationships with other agents, adding a spatial component to identify behavior and interactions of agents in the real-world environment, adapt and change behaviours. The interaction of agents with the landscape leads to likely relations such as agents' self-influencing behaviour, their effect on the landscape, self-influencing state of a landscape at any given time, and landscape's effect on agents (Crooks and Heppenstall 2012). The advantages of ABM compared to traditional modeling techniques are that it: (a) captures the emerging spatio-temporal footprint of LU changes; (b) provides a domain-specific environment of the region under investigation; and (c) is highly flexible for developing geospatial models (Bernard 1999). The advantages of Fuzzy AHP CA over conventional modeling techniques are that it: (a) encompasses dynamic spatial transitions through the integration of influence of distances of each factor on respective LU, unlike considering a LU category; (b) links macro to micro driver's responses, taking into account social, economic, dynamic and spatio-temporal dimensions; (iii) prioritizes comparison ratios for decision-making, based on site suitability (probability of a cell changing to a given class in future) and state of the neighbouring pixels; and (iv) is simple and provides improved visualization by translating qualitative assessment into quantitative data and delivering more logical and precise results.

The objectives of the current research endeavour are to account for the spatio-temporal LU changes for Karnataka state and evaluate the likely LU changes under five policy scenarios, using the Fuzzy AHP MCA model for improved decision-making.

Materials and Method

Figure 1 outlines the method used to assess LU transitions in Karnataka state using the Fuzzy AHP MCA modeling technique, considering various scenarios. The method incorporates (i) spatial data acquisition and processing, (ii) LULC extraction, and (iii) hybrid modeling.

Study Area

Karnataka state is located in the southwest region of India, bounded by Goa, Maharashtra, Telangana, Andhra Pradesh, Tamil Nadu, and Kerala with a spatial extent of 1,91,791 km^2. The region has 320 km of coastline with significant forest cover and a rich natural resources base, extending 760 km N–S (11°34' N and 18°27' N) and 420 km E–W (74°3' E and 78° 34' E). Karnataka is demarcated into 30 administrative districts consisting of 178 sub-districts (taluks) for decentralized governance, comprising over 27,481 villages and 367 towns with a population of 64.06 million (density: 320 persons per km^2) (Fig. 2). The forest ecosystem of Karnataka is unique and highly diverse. The different forest ecosystems have resulted from an interplay of topographic, climatic, and edaphic factors, influenced by altitude and distance from the sea. The forest types include tropical evergreen, semi-evergreen, moist deciduous, dry deciduous, thorny scrubs, sholas, and coastal mangroves. Karnataka state is a repository of rich biodiversity with more than 1.2 lakh known species, including 4,500 flowering

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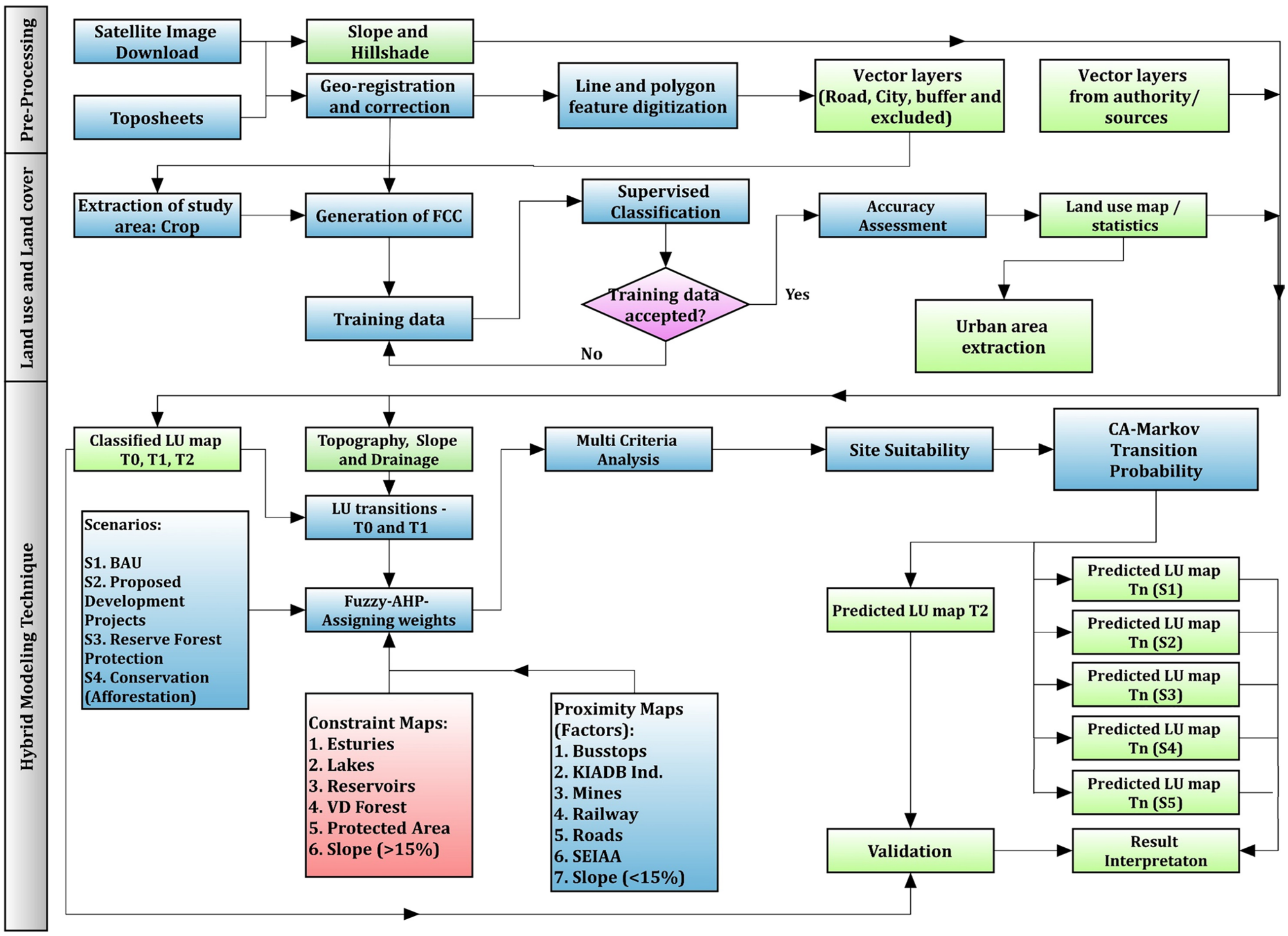

Fig. 1 Method of LU transitions assessment

plants, 800 fishes, 600 birds, 160 reptiles, 120 mammals, and 1,493 medicinal plants; half the biodiversity of Western Ghats is present in Karnataka. The forests support a wide range of endemic flora and fauna through a network of well-connected and protected wildlife sanctuaries and national parks. There are five national parks and 30 wildlife sanctuaries covering an area of 9,586.02 km^2 (Ramachandra et al. 2018). Apart from these, there are 15 conservation reserves; there is one community reserve comprising 652.369 km^2.

Data

The process of data acquisition involves primary data collection such as temporal RS data (USGS Earth Explorer (https://earthexplorer.usgs.gov/) has a repository of Landsat data starting from 1984 to date), field data through sampling.

The ancillary data included cadastral maps (1:6000), topographic maps (1:50000 and 1:250000) of the Survey of India (SOI), and vegetation maps of South India (1:250000) developed by the French Institute of Pondicherry (Pascal 1986). Ground control points (GCPs), digitized from the topographic maps, were used to geo-register the scanned paper maps and geo-rectify RS data. Various forest cover types were digitized using the vegetation map of South India (1:250000) (Pascal 1986) to classify RS data of the 1980s. Other ancillary data included land cover maps, administration boundary data and transportation data (road networks). False colour composites (FCCs) helped in digitizing training data corresponding to heterogeneous patches distributed across the scene. Pre-calibrated GPS (global positioning system—Garmin GPS) units were used to collect attribute data of digitized training data (polygons), required for RS data classification and validation. This was supplemented with vector layers of ancillary point, line, and polygon data from virtual online spatial repositories such as Google Earth (http://earth.google.com) and Bhuvan (http://bhuvan.nrsc.gov.in). Table 1 lists the data used for analyses.

The agents of LU transitions, given in Table 2, were digitized from reference maps as points, lines, and polygons. The proposed large-scale project details were compiled from the Infrastructure Development & Inland Water Transport Department, Government of Karnataka (https://idd.karnataka.gov.in/).

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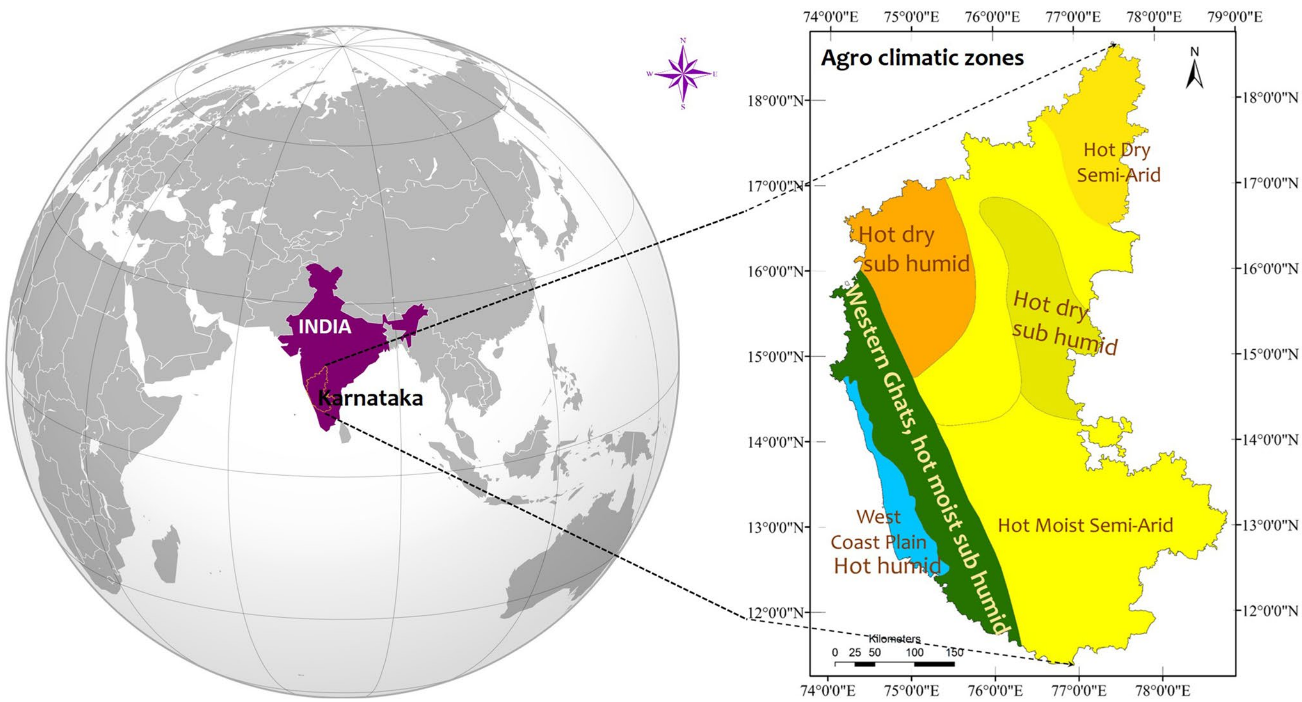

Fig. 2 Study area: Karnataka state, India

Table 1 Data used for assessing LU dynamics and description

Sno	Data	Description	Source
1	Landsat-5 TM Landsat-7 ETM+ Landsat-8 OLI-TIRS	30 m data collected for Karnataka State are used to generate LU information such as urban, forest, agriculture, etc.	https://earthexplorer.usgs.gov/ https://landsat.gsfc.nasa.gov/ https://landsat.gsfc.nasa.gov/data/more-free-data
2	ASTER DEM - 30 m data	generated slope map for Karnataka	https://asterweb.jpl.nasa.gov/gdem.asp
3	Open street map	Road data updated with classified images (originally vector, rasterized)	https://www.openstreetmap.org/search?query=karnataka#map=7/15.067/78.849
4	City Development Plans	To create excluded maps or regions restricted from future development	http://www.bdabangalore.org/ http://www.uddkar.gov.in/
5	Google Earth and Bhuvan	Geo-rectification, classification of RS data, and validation of LU information. Collection of point, line, and polygon data (originally vector, rasterized)	https://www.google.com/earth/ https://bhuvan-app1.nrsc.gov.in/thematic/thematic/index.php
6	Field data - GPS	Geo-correction, training data and validation data, Agents Extraction	

Method

Quantification of Temporal Ecosystem Extent

The LU analyses involved (a) downloading Landsat data of 2005; (b) procuring IRS MSS data for Karnataka state from the National Remote Sensing Centre (NRSC), Hyderabad (iii) geo-rectification of RS data scenes; (iv) generating FCCs of RS data (bands—green, red, and near-infrared (NIR), depending on the data LANDSAT/IRS) (Fig. 3). The FCCs aided in digitizing the training polygons corresponding to heterogeneous landscape elements; (v) digitizing the training polygons (uniformly distributed over the study region) covering 10% of the study region and loading these polygon coordinates into pre-calibrated GPS. The GPS aided in locating polygons during the field survey; (vi) collecting attribute data (LU) of these polygons from the field; (vii) augmenting attribute information corresponding to these training polygons from online portals (Bhuvan, Google Earth) and validating from the field using GPS. The training data was used for classification (60%), and the remaining 40% was used for

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Table 2 Description of various agents and constraints considered for modeling

Sno	Agent type	Description	Source
1	Power plants	Details of power plant projects in Karnataka with attributes such as power Station, latitude, longitude, type (Hydel, thermal, mini, solar, and wind), and total capacity in Megawatts.	http://karnatakapower.com/en/generation/ https://energy.karnataka.gov.in/ https://ksei.gov.in/
2	Ports and harbors	Details of major and minor ports situated along the coastline. The State has one major and 12 minor ports functional from the North to the South: Karwar, Belekeri, Tadri, Pavinakurve, Honnavar, Manki, Bhatkal Kundapur, Hangarkatta, Malpe, Padubidri & Old Mangalore Port.	https://kum.karnataka.gov.in/KUM/PDFS/PortPolicy.pdf http://dpal.kar.nic.in/
3	Large scale industries	Details of industries such as iron, steel, aluminum, cement, and concrete across the State were digitized as point layers.	https://ebiz.karnataka.gov.in/kum/index.aspx https://www.karnatakaindustry.gov.in/
4	Special Economic Zones	Details of various special economic projects include information and biotechnology parks, business parks, pharmaceutical, engineering, automobile, aerospace industry, electronic hardware, and textile.	https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1578141 https://vtpc.karnataka.gov.in/storage/pdf-files/SEZ_EOU/SEZ%20Status%20Report.pdf https://planning.karnataka.gov.in/
5	Hotels	Details of major hotels in Karnataka.	https://www.kstdc.co/
6	Airports	Various types of airports such as international, domestic, airbase, flying school, private and proposed.	http://www.ksiidc.com/airstrips.html https://idd.karnataka.gov.in/info-2/Airports++Airstrips+and+Helipad/Airports/en
7	Ecology and environment	Layers related to ecotourism destinations, lake rejuvenation projects, recreation places, forest regions, and waterfalls.	https://aranya.gov.in/ https://parisaramahiti.karnataka.gov.in/ https://www.karnatakatourism.org/ https://www.kstdc.co/ https://empri.karnataka.gov.in/storage/pdf-files/Reports/SoER%20final%20Kannada.pdf
8	Road and the railway line (existing and proposed)	Various types of roads such as NH, SH, MDR, ODR, and sub-arterial road. Existing railway networks and proposed railway network connecting major cities of Karnataka.	https://transport.karnataka.gov.in/english http://www.kship.in/en/ http://www.shdpkar.in/ http://89.238.162.147/cucpl/About_us.aspx https://kride.in/ https://transportsec.karnataka.gov.in/
9	KIADB and SEIAA industrial layout	Point and polygon digitization of industries location as well as plots sanctioned by the government.	http://164.100.133.168/kiadbgisportal/ http://seiaa.karnataka.gov.in/
10	Mines	Demarcating major mines of Karnataka such as granite, coal, metal, etc.	https://karunadu.karnataka.gov.in/dmg/english/Pages/home.aspx https://mines.gov.in/writereaddata/UploadFile/Karnataka.pdf
11	Bus stops	Details of various urban bus stops	https://kgis.ksrsac.in/kgis1/portal.aspx
Constraints			
Sno	Constraint type	Description	Source

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Table 2 (continued)

Sno	Agent type	Description	Source
1	Protected Areas	National Parks (IUCN Category II), Wildlife Sanctuaries (IUCN Category IV), Community Reserves (IUCN Category V and VI, respectively), Tiger Reserves, Sanctuaries, etc., are declared as protected areas under the Wildlife Protection Act 1972 by the union government on the specific request of state government. Protected areas protected by India's Union government are regions of conservation importance with biological diversity, providing goods and services to sustain livelihoods to local communities. These regions act as wildlife corridors and habitats for endemic plants and animals.	https://aranya.gov.in/aranyacms/English/WildLife.aspx http://www.wiienvis.nic.in/Database/Maps_PAs_1267.aspx https://www.protectedplanet.net/en
2	Reserve Forest Boundary	The respective state governments earmark reserved forests under section 29 of the Indian forest act 1927 to reduce the pressure on forests. Activities such as hunting, grazing, etc., are banned in reserved forests unless specific orders are issued otherwise.	https://aranya.gov.in/aranyacms/English/WildLife.aspx https://parisaramahiti.karnataka.gov.in/
3	Water Bodies	Lakes, Reservoirs, check dams are considered prime sources for agriculture and help maintain the ecosystem.	https://soinakshe.uk.gov.in/ https://indiawris.gov.in/wris/#/
4	Very Dense forests	Interior forest is also known as intact forests which are not having any disturbances. They act as a primary habitat for numerous flora and fauna.	LU analysis, Fragmentation analysis (Ramachandra and Bharath 2021)

accuracy assessment, and (viii) classifying LU through a supervised classifier considering training data (collected from the field) based on a Gaussian maximum likelihood (GML) algorithm.

The GML algorithm quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel of RS data, assuming Gaussian distribution of data points. The statistical probability of a given pixel value being a member of a particular class was computed. After evaluating the probability of each category, the pixel was assigned to the most likely LU category/class (highest probability value). LU analysis was carried out using the free and open-source GRASS (geographical resources analysis support system) GIS software (http://wgbis.ces.iisc.ernet.in/grass/index.php); this is a robust support for processing both vector and raster data. The temporal, spatial data acquired from space-borne sensors were classified based on a GML classifier using available temporal ground truth information. The classification of RS data (of earlier times) was done using the information compiled from historical published vegetation maps, revenue maps, topographic maps, and land records.

The accuracy of LU classification was assessed through an error matrix (or confusion matrix) with overall (producer's and user's) accuracies and kappa (κ) statistics. The producer's accuracy measures omission errors, and the user's accuracy (UA) measures commission errors. Kappa compares two or more matrices and weighs cells in the error matrix according to the magnitude of misclassification.

Modeling of Landscape Dynamics

The modeling of landscape dynamics was carried out using the hybrid Fuzzy AHP MCA technique using temporal LU details and integrating agents with distance-based relationships of driving forces. Hybrid models aid in ascertaining criteria (n) and alternatives (m) in interactive decision-making by assessing the relative significance of two elements (criteria or alternatives) i and j for a given pairwise comparison matrix of the likelihood of events for all possible alternative ranking outcomes. This technique integrates expert knowledge of spatial data to determine the weight of each factor influencing land suitability classification, which helps to evaluate various decision-making policies. The urbanizing agents, constraints, and classified data were considered as base layers for modeling. The constraints exclude areas from being considered and are represented by Boolean images, where "0" is assigned to areas that are not suitable, and "1" is given to suitable areas for a type of LU. The constraints considered in this study include water bodies, forest zones, protected areas, and catchment areas based on regional and city development plans. The factors are assigned a relative degree of suitability represented by a fuzzy scale for each location. For example, land suitability for urban development is enhanced by a factor of proximity

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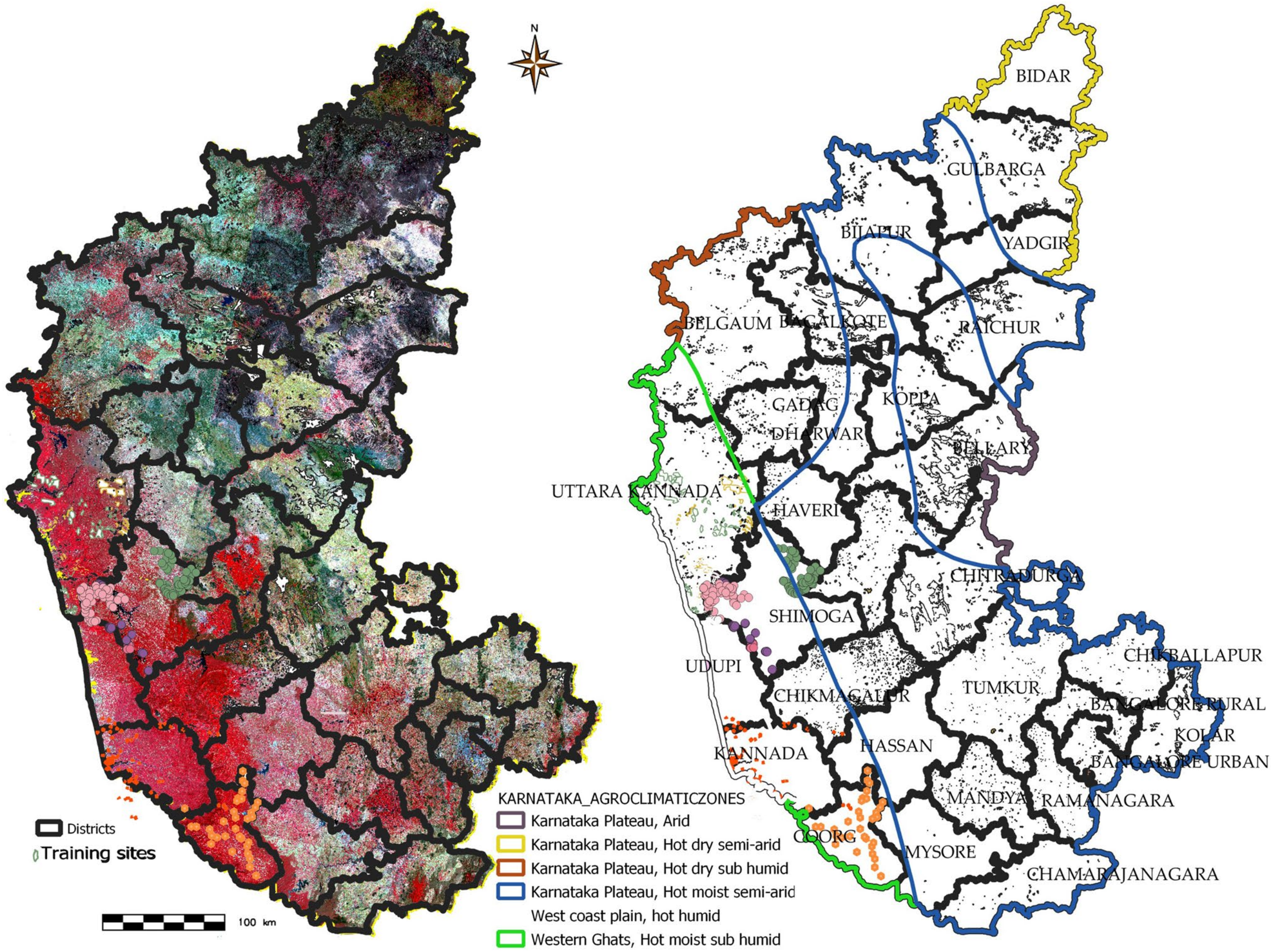

Fig. 3 FCC and digitized training polygons across agroclimatic zones

to roads. The driving factors used in modeling include road and railway networks, bus stops and railway stations, industries, educational institutes, places of religious importance, and service centers (such as hospitals, hotels, police stations, and shopping malls). Figure 4 depicts the agents of LU changes, and Figure 5 shows the constraints considered for modeling. The identification of these factors and constraints was made by developing attribute information using Google Earth data.

Prediction Based on Policy Scenarios

Policy scenarios were considered for geo-visualization of likely LU in 2033, based on various complex factors provided by the development plans of the Karnataka region, 2033. These were business as usual (BAU), agent-based land use transition (ALT), reserve forest protection (RFP), afforestation (AF), and sustainable development plan (SDP) scenarios. Many researchers have successfully demonstrated the use of BAU scenario, which considers past and recent growth patterns and factors such as population, socio-economic trends and urban density (Samie et al. 2017; Hamad et al. 2018; Guzman et al. 2020). The scenario-based prediction is also known as the 'what-if" prediction. Here, the simulation conducted is based entirely on the assumption of certain layers and factors, which implies 'what will happen if factor-a, factor-b, and factor-c are considered" (Singh 2003). A knowledge of the impact of LU changes and possible placement of new infrastructure, green area conservation, regulation of zones, upgradation of existing transport corridors, and related changes in LU categories inside the perimeter of the study region will be highly significant for municipal authorities for urban planning. The details of chosen scenarios to visualize (using modelling) likely LU in 2033 are as follows.

Scenario 1—Business as usual (BAU): BAU assumes that the historical trend of LU changes from 1985–2019 will continue during 2019-2033, without any change in the environmental and economic development policies.

Scenario 2—Agent-based land use transition (ALT): This scenario evaluates the role of various drivers (agents) such as proposed (new) developments by regulatory agencies,

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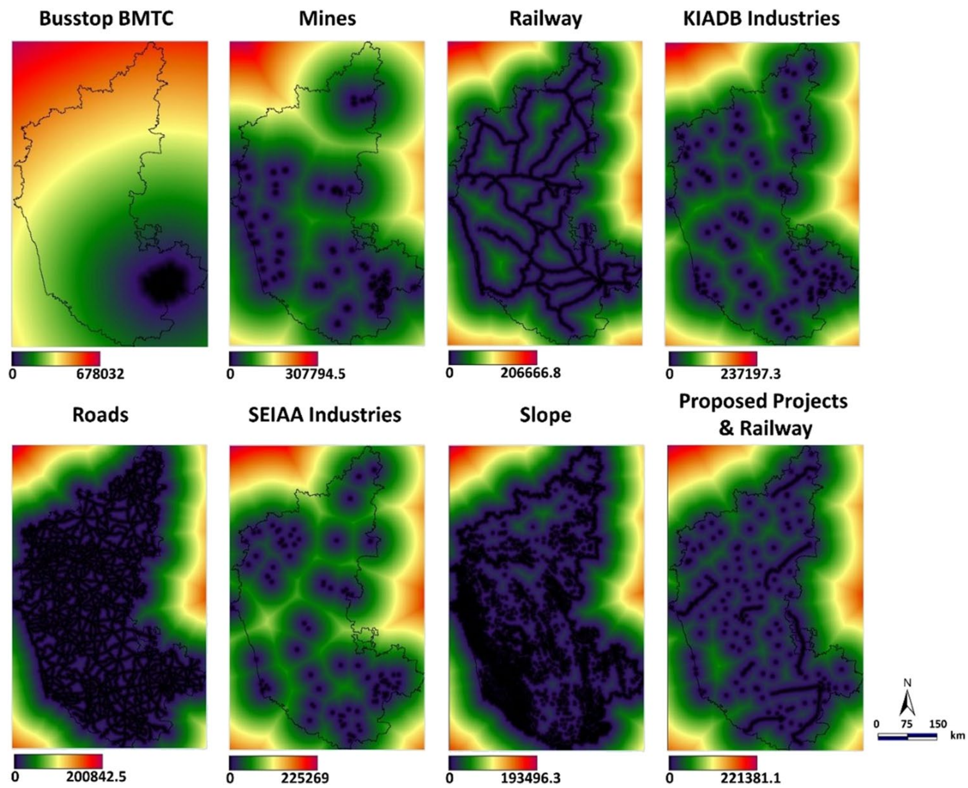

Fig. 4 Distance maps of various urban growth factors

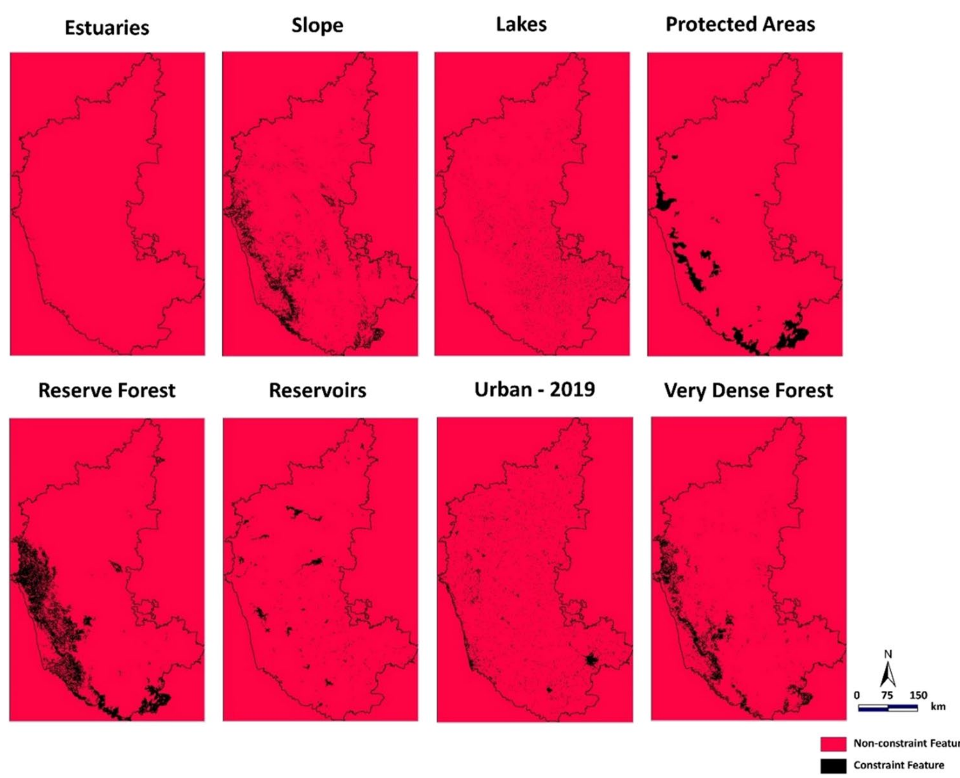

Fig. 5 Constraints of LU changes

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existing industries, linear projects, urbanization, slope, core built-up areas, and special economic zones (SEZs).

Scenario 3—Reserve forest protection (RFP): This scenario assumes a policy to protect reserve forests and protected areas from further degradation and allow growth in regions other than reserve forest areas.

Scenario 4—Afforestation (AF): The AF (high conservation) scenario accounts for afforested areas by the Karnataka forest department. It assumes the protection and afforestation activities as a prime variable in the model to account for the policy decision.

Scenario 5—Sustainable development policy (SDP): This scenario integrates reserve forest protection with stringent norms and afforestation of degraded lands (scenarios 3 and 4).

Table 3 gives details of the chosen policy scenarios with the modeling technique to visualize likely LU in 2033.

Results and Discussion

Assessment of Historical LU Transitions and Simulation

Temporal LU analyses were carried out using RS data of 1985, 2005, and 2019 through a supervised classifier based on the Gaussian maximum likelihood algorithm. Figure 6 depicts LU in Karnataka, indicating that the Western Ghats districts have a higher forest cover. The state has witnessed large-scale transitions with the decline of forests from 21% (1985) to 15% (2019). LU transitions gained impetus with globalization and consequent industrialization, urbanization, and infrastructure development during the post-1990s. Unplanned developmental activities have resulted in the loss of forest cover in the Western Ghats districts of Belgaum, Uttara Kannada, Dakshina Kannada, Shimoga, Kodagu, and Chikmagalur. Large tracts of forests were lost due to developmental activities such as constructing dams and reservoirs, land conversion for built-up areas, creating SEZs and townships. The abrupt LU changes are evident from the decline of productive agricultural lands near cities such as Bengaluru, Mysore, Hubli-Dharwad, and Shimoga. The forest cover is restricted to major conservation reserves such as protected areas, national parks, and wildlife sanctuaries. The category-wise LU dynamics are presented in Table 4, highlighting an increase in the built-up cover from 0.47 to 3% and horticulture area from 8.8% (1985) to 11.1% (2019). The decline in the spatial extent of agricultural lands, forests, and lakes highlights the need for sustainable LU policies to arrest deforestation and abrupt land conversions.

The natural forests show a decline, evident from the decrease in evergreen forests from 7.5% (1985) to 5.7% (2019), moist deciduous forests from 5.7% (1985) to 4.1% (2019), and dry deciduous forests from 4.0% (1985) to 2.2 % (2019). An accuracy assessment of the classified RS data was done through the computation of category-wise accuracies and Kappa statistics. Table 5 lists the category-wise accuracies, which indicate that the overall accuracy ranges from 86.84% (1985), 90.08% (2005) to 89.39% (2019), and Kappa ranges from 0.85 (1985) to 0.88 (2019). The LU transitions across ecosystems for Karnataka are provided in Table 6. New urban agglomerations were noticed across cities and major towns such as Bengaluru, Mangalore, Hubli, Hassan, and Mysuru. Large-scale monoculture plantations of eucalyptus, rubber, acacia, teak, and areca nut have increased and now cover 12% of the state. These abrupt changes result in an imbalance of ecosystem services, affecting the hydrologic regime and availability of natural resources. Tier-1 cities such as Bengaluru and Mangalore, and tier-2 cities such as Mysuru, Hubli-Dharwad, and Belgaum are experiencing loss of agricultural areas in the sub-urban regions, with new layouts and satellite towns.

Table 7 summarizes the ecosystem extent account for LULC in Karnataka state. The LU transition from 1985 to 2009 was accounted to understand the area of change and probability of change in each LU type from time t_1 to time t_2 using the Markovian process. The accuracy for the simulated 2019 LU map was assessed by accounting for the consistency of land quantity and spatial position similarity at the pixel level (Table 8). Kappa statistics were computed to evaluate the consistency of land quantity simulated in comparison with the actual LU. The similarity of the spatial position of simulated LU with actual with respect to a certain pixel was also assessed. Figure 7 illustrates the simulated LUs of 2019 with area details. The simulated LU depicts the expansion of existing built-up cover in peri-urban regions, through LU conversion from agriculture, based on the transition accounted for from 2005 (as per CA neighbourhood influence). The accuracy of the model was found to be 95%; the simulated LU and actual LU appear visually consistent, but spatial differences exist.

Scenario-Based Prediction and Validation

The distance maps for various urban growth factors (agents) were prepared (Fig. 8), including slope maps, distance to road, proposed railway projects, and industries. Five different constraints maps were prepared for the chosen scenarios. The site suitability maps were generated to define the suitability of each pixel for transition to any LU type. Each pixel in the suitability maps has a value ranging from 0 to 255, with 0 representing unsuitable and 255 representing the highly suitable area for a particular LU type (Pontius and Malanson 2005).

The distance influence of each agent on specific LUs was evaluated; this helped in effectively deriving the weights, unlike traditional weighing. Figure 4 shows the influence of factors such as roads and industries on the built-up area. Industries have influence up to 2000 m from urban areas and moderate influence up to 10,000 m; the influence gradually

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Table 3 Details of modeling techniques in the visualization of policy scenarios

Scenario	Method	Data sets	Scope
(i) Business as usual scenario (BAU):	**CA Markov** Likely, LU in 2033 is generated BAU assumes the current development will continue and evaluates the various agents responsible for the change, and forecast what would be the future landscape status	LU transitions (based on temporal, spatial extent of ecosystems)	Ecosystems in Karnataka State
Policy Context			
(ii) Agent-based LU transition scenario (ALT)	Likely LUs in 2033 is generated under various scenarios considering (1) Markov Chain transition of base LUs, (2) evaluating the driving factors (agents) and constraints, (3) fuzzy-AHP based estimation of weightage metric score and site suitability map generation by MCE, (4) simulation and prediction of LU through MCA algorithms.	Drivers (agents) considered include existing and proposed (new) developments by the government, which include (i) industries, (ii) linear projects, (iii) urbanization, (iv) slope, (v) core built-up areas, (vi) special economic zones (SEZ), etc., responsible for the LU changes in the neighbourhood.	All ecosystems, Karnataka State, India
(iii) Reserve Forest Protection (RFP) and stringent conservation of national parks and sanctuaries scenario	Considering protected areas **-Modeling approach same as (ii)**	The spatial extent of reserve forests, national parks, sanctuaries	All ecosystems, Karnataka State, India
Afforestation (High conservation) scenario (AF)	Considering afforestation initiatives **-same as (ii)**	The spatial extent of afforestation data (during the past decade) and proposed afforestation	All ecosystems, Karnataka State, India
(iv) Sustainable Development Policy (SDP)	Includes constraints as in scenarios 3 and 4, allows the growth in other than forest areas. Though the scenario 3 and 4, the modeling approaches focus on “Ecological Protection Priority.”	SDP scenario is more conservative as well as a focused growth scenario. This scenario further allows the comparison of development and conservation trade-offs effectively. This scenario stresses the strict implementation of spatial policies such as not allowing LU change within natural forests, increased plantation forests in barren lands, and degraded woodlands, and protection of water bodies.	All ecosystems, Karnataka State, India

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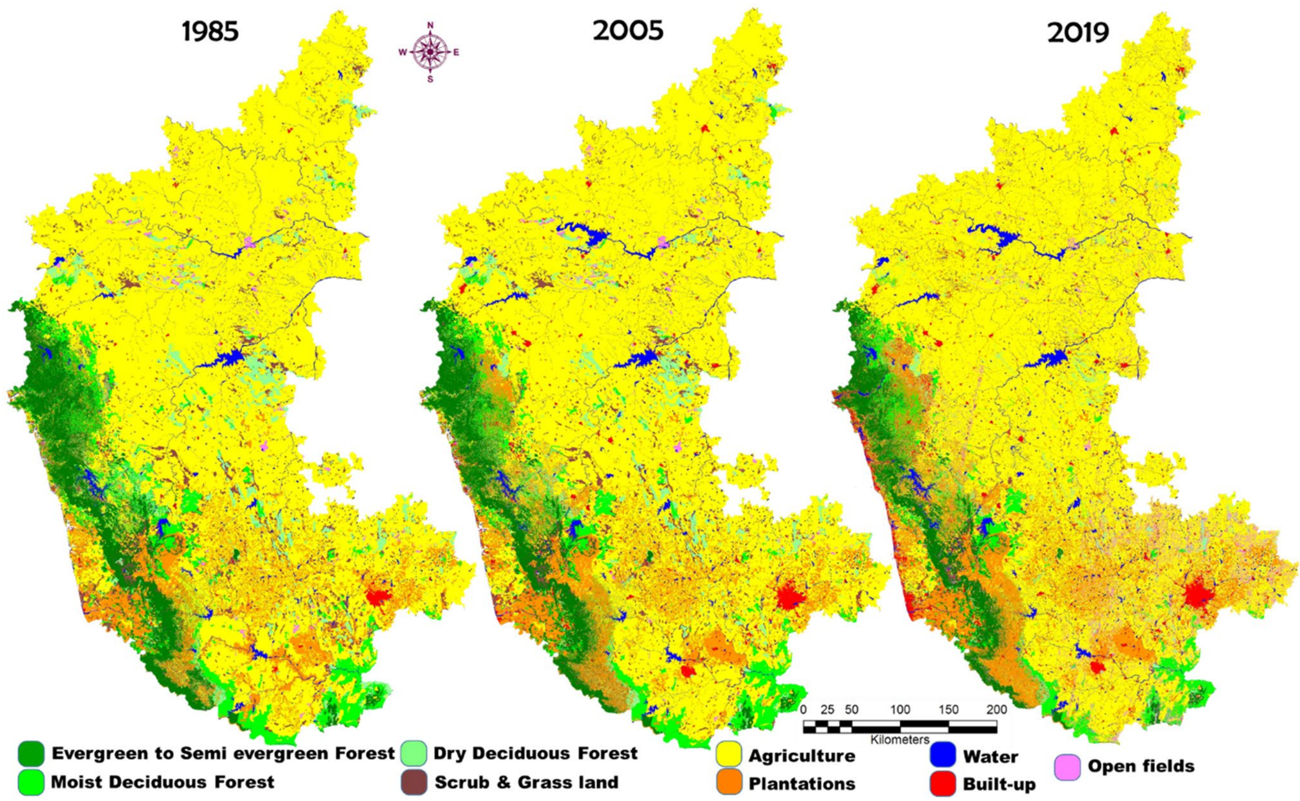

Fig. 6 LU changes from 1985 to 2019 in Karnataka

decreases after that. Roads have shown significant influence up to 500 m, with a reduction in influence after 1000 m. Figure 9 shows the factors that influence forest cover LU, which helped in understanding the distance influence of each factor. Industries show high conversion of forests to other LU up to 7000 m, and after that, the influence reduced; roads showed stronger influence up to 2000 m.

The AHP was used to assign weights and evaluated its consistency by computing the consistency ratio. Scenario-wise weights were assigned for each factor and are given in Annexure 1 (Tables 10, 11, 12, 13, 14). A consistency ratio of <0.1 was achieved for each scenario, and the eigenvector weights for individual factors considered for the scenario are listed in Tables a–e (Annexure). The site suitability of LU transition was accounted for using MCE and was provided as an input for CA-based prediction. The CA has been used for computing projected LUs under five different scenarios based on varied inputs (Fig. 10).

BAU can be considered as a base case that helps in comparing or differentiating with alternative growth strategies. It depicts the likely increase in built-up area to 11.5% (2033) from 3% in 2019 (Table 9, Fig. 11). The forest cover and the agricultural regions would lose significant tract in case of likely expansion of built-up cover. The dry and moist deciduous forest cover has witnessed a higher change with a loss of 6.5% forest cover. The existing infrastructure and built-up cover will transform deciduous forests and agriculture areas along highways across the State. The cities such as Bengaluru, Mangalore, and Dharwad (tier-1) depicted compact growth, whereas Mysuru, Belgaum, Hassan, and Tumkur (tier-2) indicated peri-urban development.

Upgrading urban infrastructure (roads, commercial establishments, information networks, industrial units, and sports/recreation centers) will result in a built-up cover of 15% compared to BAU. The ALT scenario will increase paved surfaces by 2033 due to the development of towns and compact urban centers (consisting of high-density residential and industrial layouts). The BAU and ALT scenario predictions indicate a significant reduction in forest area and agricultural LU. The ALT scenario shows that forest cover would likely be only 9% compared to 15% in 2019 (Table 9, Fig. 11). The agricultural area showed a loss of 2%, which might affect food availability in the region. The regions where dry crops are grown will witness higher transformation, which signifies the external driver's role in LU alterations. The ALT scenario indicates higher LU conversion due to transportation and other projects with compact, peri-urban, and mixed LU developments; this necessitates effective LU policies.

The RFP scenario visualizes protecting reserve forests without any alterations for unplanned developmental

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Table 4 Ecosystem Extent—Karnataka state (extent in km^2 and percentages)—based on temporal RS data analyses

LU Categories		Built-up	Cropland	Horticulture	Fallow land	Evergreen Forest	Moist Deciduous	Dry Deciduous	Scrub \Grass lands	Water	Total Area
Year	Units										
1985	(km^2)	904	128468	16790	1678	14293	10960	7622	6733	4344	191791
	%	0.5	67	8.8	0.9	7.5	5.7	4	3.5	2.3	100
2005	(km^2)	2666	127196	20209	1185	12445	9900	7410	5604	5177	191791
	%	1.4	66.3	10.5	0.6	6.5	5.2	3.9	2.9	2.7	21.13
2019	(km^2)	5748	127962	21325	2854	10888	7892	4281	4907	5934	191791
	%	3	66.7	11.1	1.5	5.7	4.1	2.2	2.6	3.1	17.68
LU Changes during 1985 to 2019											
1985	(km^2)	904	128468	16790	1678	14293	10960	7622	6733	4344	191791
2019	(km^2)	5748	127962	21325	2854	10888	7892	4281	4907	5934	191791
Net change of extent (during 1985 to 2019)											
Extent	(km^2)	4844	-505	4536	1175	-3405	-3068	-3341	-1826	1590	0
	%	535.8	-0.4	27	70	-23.8	-28	-43.8	-27.1	36.6	

activities and expansion of earlier LUs. The regions covered under reserve forest protection do not favour development and other LU conversions. The districts that are part of the Western Ghats region might not affect the BAU and ALT scenarios. The regions with dry deciduous forest cover and not falling under reserve forest area protection will experience abrupt growth due to transportation corridors and urban clusters. Unlike other scenarios, urban areas of 2019 are considered as a factor influencing LU changes. The RFP scenario shows a likely built-up cover of 11%, retaining a good amount of evergreen forest cover of 5% (Table 9). As depicted in Fig. 11, the AF scenario shows likely improvement in forest cover due to plantation activities and protection of degraded forests from uncontrolled LU conversion. Here, the forest cover is 9.3%, a slight increase as compared to BAU and ALT. The built-up cover will limit existing cities and towns by over 11%. The new plantation activities will compensate for the abrupt LU conversion, especially in moist, dry deciduous cover regions. Districts such as Bidar, Kolar, and Koppala did not show any improvement due to the availability of the least forest land area.

The SDP scenario signifies stringent policy implementation initiatives with minor disturbances, and the simulated LU using this scenario is depicted in Fig. 11. The forest cover will remain 11% compared to 17% in 2019 (Table 9), the least probable loss among all the scenarios. The existing built-up cover will remain in the tier-1 and tier-2 cities; the least increase was shown in peri-urban areas. Districts such as Bidar, Gulbarga, Bagalkot, and Kolar might experience higher LU conversion rates due to existing infrastructure and be devoid of any forest policy. Overall, the RFP, AF, and SDP scenarios favour the protection of evergreen and moist deciduous forest categories. The BAU and ALT scenarios show a merging of urban clusters, indicating that smaller clusters of paved areas are no longer available and tend to agglomerate with bigger ones to form urban centers, satellite towns, and dispersed growth at the periphery of tier-2 city limits. There might be new constructions in the rural hinterland, resulting in loss of evergreen, moist deciduous cover and agricultural areas. Categories such as plantation, water, and open field had similar values across all scenarios. The scenarios will directly help decision-makers and planners to mitigate environmental impact with strict growth rules; otherwise, the conversion of primary, secondary forest/moist/dry deciduous forest into urban areas will be favored (BAU and ALT) can induce ecological imbalances. Another important observation in terms of statistics was that slope steepness restriction played an important role in restricting urban settlements from further infiltrating into forested areas. Collectively, sustainable development seems feasible with scenarios 3–5, without altering the existing edges of agriculture, forest, water bodies, and other protected areas or conservation zones.

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Table 5 Accuracy assessment

Year	1985		2005		2019	
Category	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)
Built-up	93.97	95.19	92.58	88.01	98.99	96.27
Cropland	94.01	94.71	97.85	100.00	93.97	93.15
Horticulture	63.98	69.40	90.34	81.38	93.13	88.27
Fallow land	84.58	76.09	98.14	100.00	91.34	90.88
Evergreen Forest	91.77	47.95	88.53	52.43	79.46	100.00
Moist Deciduous Forest	94.89	75.42	67.05	86.23	66.95	83.99
Dry Deciduous Forest	69.93	69.70	77.77	79.76	93.80	87.63
Scrub_Grass lands	66.95	64.54	80.24	92.82	39.21	81.23
Water	91.45	79.95	91.60	100.00	97.62	86.39
Overall Accuracy (%)	86.84		90.08		89.39	
Kappa	0.85		0.87		0.88	

The limitations of the current study lie in the factors considered, which vary based on developmental issues and regional dynamics. The model results may vary depending on the assumptions, modeling strategies, computational approaches, and data. The driving factors are generally region-specific, and the likely LU changes are expressed based on local variations in geographic and socio-economic conditions. The modeled scenarios applied at the micro (e.g., cities) level might show variations in results than the entire study region (state). The challenges to be addressed in LU transition models are: (a) lack of framework for systematic assessment of LULC changes and hence, its validation considering the decision-making process and authenticity of interactions between various agents in a system; (b) resolution of data, availability, and trade-offs between different resolutions. LU change is dependent on the land management policy framed by local, regional, national, and global agencies. Therefore, there is a need to integrate these factors along with human-environment interactions to achieve desirable results.

The modeled scenarios aid as a base for the decision-making process, to balance LU changes associated with developmental activities and conservation. The abrupt changes induced by developmental activities such as creating industries, upgradation of infrastructure, and establishing new linear corridors in regions dominated by forests will enhance deforestation and degradation. The unscientific LU changes in forest landscapes result in ecosystem imbalance and increased carbon emissions in the atmosphere (Ramachandra and Bharath 2019a). Landscapes with increased paved surfaces tend to have considerably greater air temperature than their peri-urban/rural surroundings, altered microclimatic conditions, increased anthropogenic heat release, and increased land surface temperature, which further contributes to global warming (Yao et al. 2017). The buildings and road surfaces act as high heat storages, exposing humans to health-threatening heat. The increase in paved surfaces due to uncontrolled urbanization in Karnataka state can result in an urban heat island effect due to the conversion of latent heat flux into sensible heat flux, thereby threatening human well-being (Ramachandra and Uttam 2009). Other consequences of unregulated paved surfaces in a landscape are: (a) increase in the energy consumption for cooling with enhanced land surface temperature (Ramachandra et al. 2017b), (ii) escalation in the carbon footprint (Ramachandra and Shwetmala 2009), (iii) reduction in water availability (Ramachandra et al. 2020), (iv) alteration in the seasonal rainfall pattern (Buyantuyev and Wu 2012), (v) increase in flood instances (Kumar et al. 2021), (vi) effect on air quality (Feizizadeh and Blaschke 2013; Fuladlu and Altan 2021), (vii) phenological changes (Allen et al. 2015), (ix) impact on biodiversity (Ramachandra et al. 2018), (x) reduction in the net primary productivity of vegetation (Jackson and Baker 2010; Bharath et al. 2013; Alavipanah et al. 2015), and finally (xi) vegetation die-off (Breshears et al. 2005; Zhou et al. 2016). In this regard, the Karnataka state authorities should focus on sustainable developmental planning with judicious resource usage and existing vegetation cover improvement. Banning highly-polluting industries, illegal mining, and unscientific land conversion, and regulating urbanization should be prioritized to mitigate impending climate change.

Conclusion

LULC information provides an overview of interactions among human–natural landscape systems and feedback on the subsequent development of these interactions. Modelling LU dynamics in Karnataka state has aided in effectively capturing likely changes under five different scenarios, which forms a base for sustainable landscape management. The forest cover accounts for 15% (2019) in comparison to 21% earlier (1985), highlighting a 6%

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Table 6 Transitions across LU categories during 1985 to 2019—Karnataka state (extent in km^2 and percentages)

2019 LU Categories 1985	Units	Built-up	Cropland	Horticulture	Fallow land	Evergreen Forest	Moist deciduous	Dry Deciduous Forest	Scrub / Grass lands	Water	Total (Opening Stock) 1985
Built-up	(km^2)	859	20	15	2	1	3	1	2	2	904
	%	95.0	2.2	1.7	0.2	0.2	0.4	0.1	0.2	0.3	
Cropland	(km^2)	3169	114150	4050	4529	69	119	117	254	2008	128468
	%	2.5	88.9	3.2	3.5	0.1	0.1	0.1	0.2	1.6	
Horticulture	(km^2)	775	3344	11661	185	243	258	93	108	122	16790
	%	4.6	19.9	69.5	1.1	1.4	1.5	0.6	0.6	0.7	
Fallow land	(km^2)	50	843	32	710	1	2	12	13	15	1678
	%	3.0	50.2	1.9	42.3	0.1	0.1	0.7	0.8	0.9	
Evergreen Forest	(km^2)	175	416	2372	151	9097	1402	211	286	182	14293
	%	1.2	2.9	16.6	1.1	63.6	9.8	1.5	2.0	1.3	
Moist Deciduous Forest	(km^2)	190	1973	1648	485	388	5581	470	164	61	10960
	%	1.7	18.0	15.0	4.4	0.4	54.1	4.3	1.5	0.6	
Dry Deciduous Forest	(km^2)	85	3374	779	458	68	419	2306	87	47	7622
	%	1.1	44.3	10.2	6.0	0.9	5.5	30.3	1.1	0.6	
Scrub/Grass lands	(km^2)	327	3056	701	438	136	113	72	1787	103	6733
	%	4.9	45.4	10.4	6.5	2.0	1.7	1.1	26.5	1.5	
Water	(km^2)	93	734	114	35	14	16	7	9	3321	4344
	%	2.1	16.9	2.6	0.8	0.3	0.4	0.2	0.2	76.5	
Closing Stock, 2019	(km^2)	5725	127910	21371	6994	10018	7914	3288	2710	5862	191791
	%	3.0	66.7	11.1	3.6	5.2	4.1	1.7	1.4	3.1	100

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Table 7 Ecosystem extent account for LULC in Karnataka state, India

Level-1	Level-2	Karnataka				
		Opening Stock 1985	Additions to Stock	Reduction in Stock	Closing Stock 2019	Net change (in%) during 1985 to 2019
Built-up land	Built-up	904	4866	45	5725	533.1
	Urban					
	Sub-Total 1	904	4866	45	5725	533.1
Agricultural Land	Horticulture	16790	9711	5129	21371	27.3
	Cropland	128468	13760	14317	127910	-0.4
	Fallow Land	1678	6284	968	6994	316.7
	Sub-Total 2	146936	29754	20414	156275	6.4
Forests	Evergreen/Semi-Evergreen	14293	921	5196	10018	-29.9
	Moist Deciduous	10960	2333	5379	7914	-27.8
	Dry Deciduous	7622	981	5316	3288	-56.9
	Scrub Forest	6733	922	4946	2710	-59.8
	Forest Plantation					
	Swamp/Mangroves					
	Sub-Total 4	39607	5158	20836	23929	-39.6
Grass / Grazing	Grass / Grazing					
	Sub-Total 5					
Wetlands / Water bodies	Coastal Wetland					
	River/stream/canals					
	Waterbodies	4344	2541	1023	5862	35.0
	Sub-Total 6	4344	2541	1023	5862	35.0
Grand Total (Sq. Km)		191791	42319	42319	191791	

Table 8 Accuracy of the simulation

Information of Allocation	No [n]	Medium [m]	Perfect [p]	Kappa
Perfect [P(x)]	P(n)=0.3706	P(m)= 0.9541	P(p)=1	Kno=0.9003
Perfect Stratum [K(x)]	K(n)=0.3706	K(m)=0.9541	K(p)=1	Klocation=0.9273
Medium Grid [M(x)]	M(n)=0.3559	M(m)=0.9102	M(p)=0.9009	KlocationStrata=0.9273
Medium Stratum [H(x)]	H(n)=0.1	H(m)=0.3502	H(p)=0.3598	Kstandard=0.8619
No [N(x)]	N(n)=0.1	N(m)=0.3502	N(p)=0.3598	

loss in forest cover due to anthropogenic pressure leading to forest degradation and deforestation. Industrialization, urbanization, and other anthropogenic pressures are responsible for higher LU transitions from post-1990. BAU depicts a likely increase in built-up area by 11.5% (2033) from 3% (2019). The tier-1 cities such as Bengaluru, Mangalore, and Dharwad might depict higher compact growth, whereas the tier-2 cities such as Mysuru, Belgaum, Hassan, and Tumkur indicate peri-urban development. Incorporating the likely developmental activities shows an increase in built-up cover of 15%, based on the ALT scenario. Both BAU and ALT scenario projections indicate a significant reduction in forest areas and agricultural LU due to new developmental projects and other urban infrastructure. The districts that are part of the Western Ghats region will be protected under RFP, AF, and SDP scenarios due to policy interventions. The AF and SDP scenarios indicate stringent policy implementation initiatives with the least disturbances. The forest cover will remain 11% (2033) compared to 17% in 2019, which is the least possible loss among all considered scenarios (BAU, ALT, and RFP). The policy scenarios favour the protection of evergreen and moist deciduous forest categories. The existing urbanization process will restrict the existing tier-1 and tier-2 cities; the least increase was shown in peri-urban areas. This information

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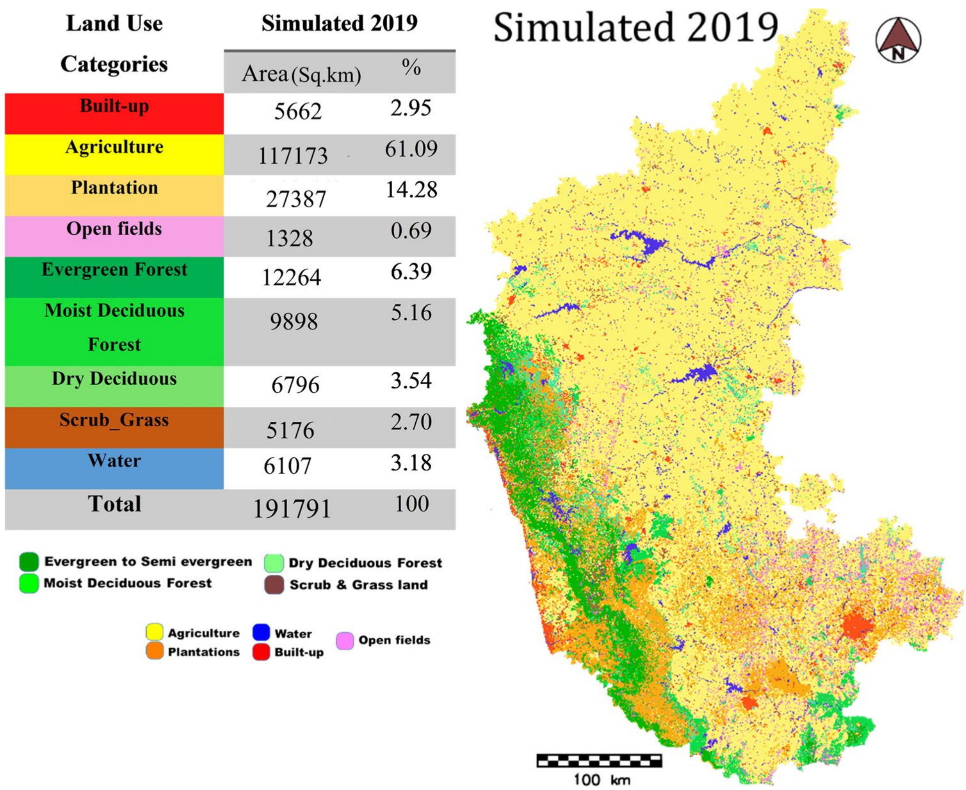
Fig. 7 Simulated land uses in 2019



Land Use Categories	Simulated 2019 Area(Sq.km)	%
Built-up	5662	2.95
Agriculture	117173	61.09
Plantation	27387	14.28
Open fields	1328	0.69
Evergreen Forest	12264	6.39
Moist Deciduous Forest	9898	5.16
Dry Deciduous	6796	3.54
Scrub_Grass	5176	2.70
Water	6107	3.18
Total	191791	100

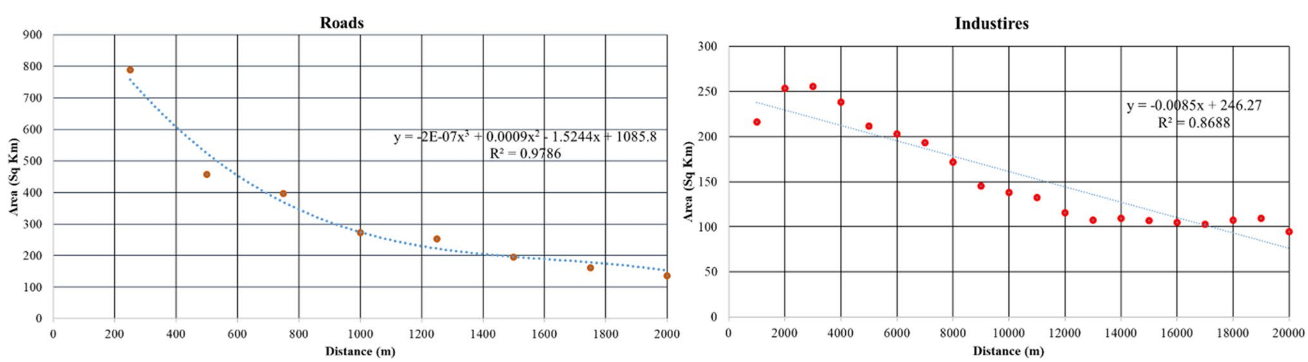


Fig. 8 Distance influence on LU change-built-up

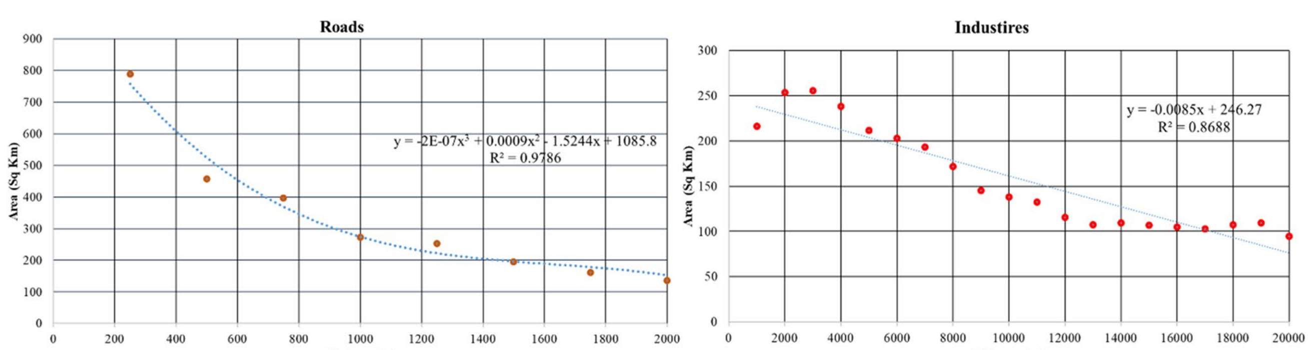


Fig. 9 Distance influence on LU change-forest

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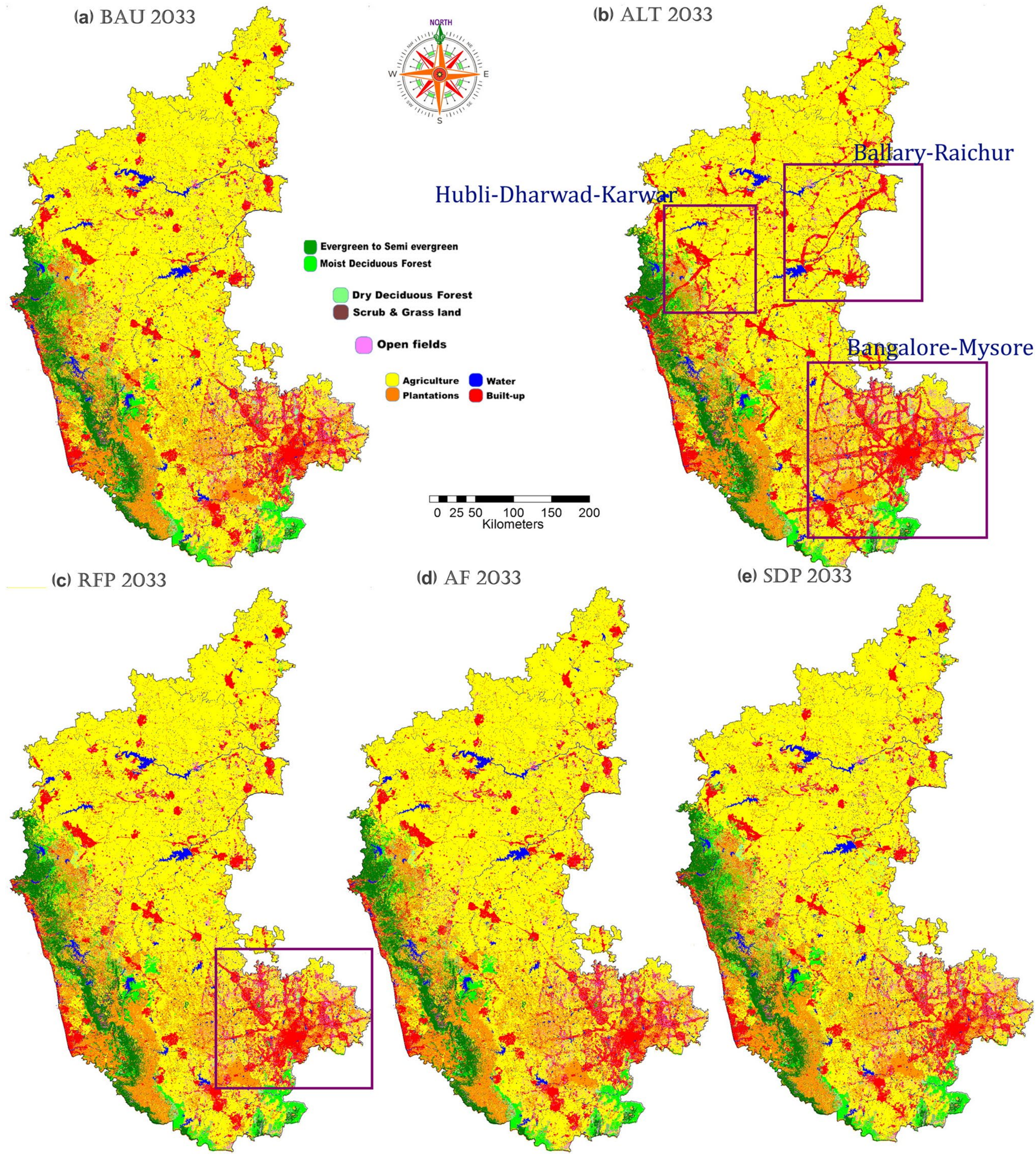

Fig. 10 Projected LU under BAU, ALT, RFP, AF, and SDP scenarios

can form a strong base for decision-makers to validate policy options, thereby proposing appropriate strategies to achieve sustainable development. The policy scenarios suggested here emphasize a planned growth strategy for a habitable region. Integrated planning will pave the way to self-sufficient towns with regulated LU conversion, and sustainable development along newly developed public transport corridors.

The concept of cumulative effects of incremental reduction and erosion of natural systems' integrity from

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Table 9 Likely LU in 2033 for various scenarios

Land use categories	BAU_2033		ALT_2033		RFP_2033		AF_2033		SDP_2033	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Built-up	22,015	11.5	28,100	14.7	21,703	11.2	21,462	11.2	20,720	10.8
Cropland	1,17,646	61.3	1,13,309	59.1	1,18,946	62.0	1,18,586	61.8	1,16,672	60.8
Plantation	21,777	11.4	20,667	10.8	21,984	11.5	21,692	11.3	21,521	11.2
Horticulture	6,688	3.5	6,688	3.5	6,851	3.6	6,688	3.5	6,851	3.6
Evergreen Forest	9,209	4.8	9,152	4.8	9,328	4.9	9,591	5.0	9,725	5.1
Moist Deciduous Forest	5,774	3.0	5,721	2.9	5,414	2.8	5,752	3.0	6,670	3.5
Dry Deciduous	1,524	0.8	1,512	0.8	1,246	0.7	1,569	0.8	2,369	1.2
Scrub_Grass	1,160	0.6	1,144	0.6	915	0.5	979	0.5	1,967	1.0
Water	5,997	3.1	5,497	2.8	5,404	2.8	5,471	2.9	5,298	2.8
Total	**1,91,791**									

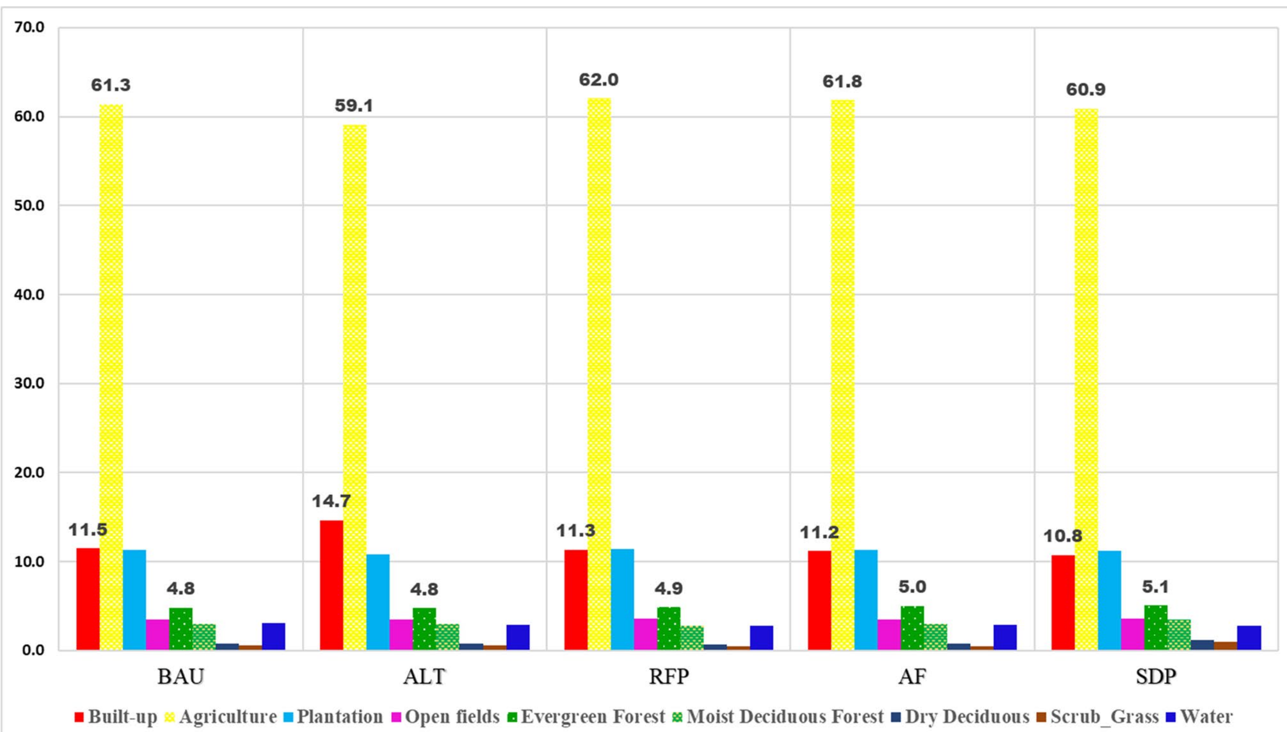

Fig. 11 Projected LU (2033) of policy scenarios

interactions of developmental activities highlights a need to redirect impact analysis to deal with the driving causes of unsustainable development. The conservation importance of an area is determined by assessing its ecological values and functions, which entails inventorying, mapping, and monitoring of natural resources to arrive at viable management strategies. This is achieved by accounting for ecosystem extent and conditions using temporal RS data coupled with field data. The scenarios presented here will strengthen decision-making by prudent LULC planning through geovisualization of likely LU changes. Geographic models and biophysical constraints of LU changes can be integrated with socio-economic factors, LU change factors, ecological conditions factors, and economic system feedback.

The current research underscores the need to adopt a sustainable development plan, integrating reserve forest protection with stringent norms and afforestation of degraded lands. This will minimize abrupt LULC changes and ensure the sustenance of natural resources to sustain the livelihood of local people. It entails prioritizing natural resources-rich zones at disaggregated levels (Panchayat levels—administrative unit as per the 73rd and

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Table 10 Weights based on AHP for BAU

Factors	BAU								Eigen Vector of Weight
	BS	KP	MA	RA	RO	SI		SL	
Bus Stops (BS)	1								0.02
KIDAB Plots (KP)	9	1							0.32
Mining Areas (MA)	3	1/3	1						0.06
Railway (RA)	5	1/3	3	1					0.10
Roads (RO)	9	1/3	3	1	1				0.15
SEIAA Industries (SI)	7	1/3	3	3	3	1			0.23
Slope (SL)	7	1/3	3	3	1/3	1/3		1	0.12
Less Important				Equal	More Important				CR: 0.09
Extremely	**Very Strongly**	**Strongly**	**Moderate**		**Moderate**	**Strongly**	**Very Strongly**	**Extremely**	**Status: Acceptable**
1/9	1/7	1/5	1/3	1	3	5	7	9	(Standard <=0.1)

Table 11 Weights based on AHP for ALT

Factors	ALT								Eigen Vector of Weight
	BS	KP	MA	RA	RO	SI	SL	PP	
Bus Stops (BS)	1								0.02
KIDAB Plots (KP)	9	1							0.22
Mining Areas (MA)	3	1/7	1						0.04
Railway (RA)	5	1/5	1	1					0.07
Roads (RO)	7	1/3	3	3	1				0.17
SEIAA Industries (SI)	5	1/3	3	3	1/3	1			0.11
Slope (SL)	3	1/3	3	1/3	1/3	1/3	1		0.06
PP	7	3	5	3	3	3	3	1	0.30
Less Important				Equal	More Important				CR: 0.08
Extremely	**Very Strongly**	**Strongly**	**Moderate**		**Moderate**	**Strongly**	**Very Strongly**	**Extremely**	**Status: Acceptable**
1/9	1/7	1/5	1/3	1	3	5	7	9	(Standard <=0.1)

Table 12 Weights based on AHP for RFP

Factors	RFP								
	BS	KP	MA	RA	RO	SI	SL	U19	Eigen Vector of Weight
Bus Stops (BS)	1								0.02
KIDAB Plots (KP)	9	1							0.28
Mining Areas (MA)	3	1/7	1						0.05
Railway (RA)	5	1/5	1	1					0.12
Roads (RO)	7	1/3	3	3	1				0.25
SEIAA Industries (SI)	5	1/3	3	1	1/3	1			0.10
Slope (SL)	3	1/3	3	1/3	1/3	1/3	1		0.06
Urban_2019 (U19)	5	1/3	3	1/3	1/5	3	3	1	0.12
Less Important				Equal	More Important				CR: 0.10
Extremely	**Very Strongly**	**Strongly**	**Moderate**		**Moderate**	**Strongly**	**Very Strongly**	**Extremely**	**Status: Acceptable**
1/9	1/7	1/5	1/3	1	3	5	7	9	(Standard <=0.1)

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Table 13 Weights based on AHP for AF

Factors	AF								
	BS	KP	MA	RA	RO	SI	SL	PL	Eigen Vector of Weight
Bus Stops (BS)	1								0.02
KIDAB Plots (KP)	7	1							0.27
Mining Areas (MA)	3	1/7	1						0.05
Railway (RA)	5	1/5	1	1					0.06
Roads (RO)	7	1	3	3	1				0.27
SEIAA Industries (SI)	5	1/3	3	3	1/3	1			0.11
Slope (SL)	3	1/3	3	1	1/3	1/3	1		0.07
Plantations (PL)	5	1/3	3	3	1/5	3	3	1	0.15
Less Important				Equal	More Important				Consistency Ratio: 0.07
Extremely	**Very Strongly**	**Strongly**	**Moderate**		**Moderate**	**Strongly**	**Very Strongly**	**Extremely**	**Status: Acceptable**
1/9	1/7	1/5	1/3	1	3	5	7	9	(Standard <=0.1)

Table 14 Weights based on AHP for SDP

Factors	SDP								
	BS	KP	MA	RA	RO	SI	PP	PL	Eigen Vector of Weight
Bus Stops (BS)	1								0.02
KIDAB Plots (KP)	7	1							0.22
Mining Areas (MA)	3	1/7	1						0.04
Railway (RA)	5	1/7	1	1					0.05
Roads (RO)	7	1	3	3	1				0.18
SEIAA Industries (SI)	7	1/3	3	3	1/3	1			0.12
Proposed Projects (PP)	3	1/3	3	3	1/3	1/3	1		0.10
Plantations (PL)	7	3	5	5	3	3	1	1	0.28
Less Important				Equal	More Important				Consistency Ratio : 0.09
Extremely	**Very Strongly**	**Strongly**	**Moderate**		**Moderate**	**Strongly**	**Very Strongly**	**Extremely**	**Status: Acceptable**
1/9	1/7	1/5	1/3	1	3	5	7	9	(Satndard <=0.1)

74th Constitutional Amendment Acts, 1992 for ensuring local self-governance through empowering local bodies; Biodiversity act, 2002, Government of India) in Karnataka state by aggregating bio-geo-climatic, land, ecological, energy, and social variables. Sustainable LU management policies will help to efficiently address abrupt transitions and assist in optimal resource usage, protecting the environment at the local and global scales.

Annexure 1

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the ENVIS division, The Ministry of Environment Forests and Climate Change (MoEFCC), Government of India. We are grateful to the ENVIS Division, the Ministry of Environment, Forests and Climate Change, Government of India.

Author Contribution **Ramachandra T V:** Concept Design, field data collection, data analysis and interpretation of data; revising the article critically for important intellectual content; final editing

Bharath Setturu: Design of the experiment, field data collection and analysis, interpretation of data, manuscript writing

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Data Availability Data used in the analyses are compiled from the field. Data is analyzed and organized in the form of table, which are presented in the manuscript. Also, synthesized data are archived at http://wgbis.ces.iisc.ernet.in/energy/water/paper/researchpaper2.html#ce. http://wgbis.ces.iisc.ernet.in/biodiversity/

Declarations

Ethics Approval The research does not involve either humans, animals, or tissues.

Consent for Publication The publication is based on the original research and has not been submitted elsewhere for publication or web hosting.

Conflict of Interest The authors declare no competing interests.

Permission to Carry Out Fieldwork Our research is commissioned by the Ministry of Environment and Forests (ENVIS Division), Government of India, and hence no further permission is required as the field work was carried out in in the non-restricted areas / protected areas.

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