Modeling Earth Systems and Environment
https://doi.org/10.1007/s40808-021-01135-2

ORIGINAL ARTICLE

# Visualisation of landscape alterations with the proposed linear projects and their impacts on the ecology

T. V. Ramachandra[1,2,3] · S. Vinay[1] · S. Bharath[1]

Received: 4 November 2020 / Accepted: 11 February 2021


## Abstract

Land-use transformations altering the ecosystem function have impacted the sustenance of natural resources. Implementation of unplanned developmental activities in the ecologically fragile regions has contributed to frequent landslides, conversion of perennial rivers to intermittent or seasonal rivers, reduced water retention capability, etc. Addressing these challenges entails understanding the drivers of land-use change and also their role in altering land uses. Large-scale linear projects such as roads and railways, though contribute to better infrastructure and enhance employment opportunities but severely change the landscape structure affecting peoples' livelihood due to the reduction of ecosystem goods and services. Planned interventions are essential for adopting appropriate land-use trends and shift the trajectory of ecosystem service provision through prior visualization of land-use dynamics with likely impacts. The current study analyses the possible land-use changes in the ecologically fragile central Western Ghats with the proposed railway networks, namely (i) Mysore–Kushalnagar and (ii) Mysore–Thalassery (limited to Karnataka state), using an agent-based model (Fuzzy-AHP-CA-Markov) considering the linear project regions with a buffer of 5 km. The analyses reveal a reduction of forests by 2 and 5%, respectively, during 2010 and 2019. This trend would continue with a significant forest decline by 2026. Areas under built-up have increased over 5% during 2010–2019, which would increase by 7% (2019 and 2026) at the expense of cultivation lands. Major cities such as Mysore and Kushalnagara would witness concentrated urban growth with sprawl in the peripheries, while other towns have undergone leapfrog developments. The spatial distribution of fauna and flora indicates that most parts of the buffer region endow endemic species and serve as foraging grounds. Prediction of likely land uses in 2026 suggests that these regions would undergo large-scale alterations threatening fauna and flora. Implementing linear projects in the ecologically fragile Western Ghats would further destabilize the region, posing a threat with the increased hazard frequencies and the sustenance of natural resources.

**Keywords** Biodiversity · Corridor · Land use · Linear projects · Visualisation · Western Ghats

## Introduction

Landscapes are the cluster of heterogeneous landforms arranged in a nested pattern with diverse land use elements. Biodiversity in a landscape depends on the structure and interactions among various landscape elements. During the post-industrialization and globalization period, unplanned developmental activities have contributed to large-scale land cover transitions, which impacted ecology, hydrologic regime, sustenance of natural resources, etc. Landscapes alterations have become intensive with human-induced activities such as transport corridors/networks, burgeoning built-up areas, increasing demand for food and other resources, etc. Analyses of landscape dynamics provide vital information for prudent

✉ T. V. Ramachandra
cestvr@ces.iisc.ernet.in; tvr@iisc.ac.in
http://ces.iisc.ernet.in/energy
http://ces.iisc.ernet.in/foss

1 Energy and Wetlands Research Group, Centre for Ecological Sciences (CES), Indian Institute of Science, Bangalore, Karnataka, India

2 Centre for Sustainable Technologies (Astra), Indian Institute of Science, Bangalore, Karnataka 560019, India

3 Centre for Infrastructure, Sustainable Transportation and Urban Planning (CiSTUP), Indian Institute of Science, Bangalore, Karnataka, India

decision-making towards the sustainable management of natural resources. Modeling and prediction of land-use dynamics with the proposed projects would help to evolve appropriate mitigation strategies.

Linear infrastructure projects (such as roads, railways, high-tension electrical lines) are being implemented to cater to the growing demand, improving the regional economy, and societal wellbeing (Biasotto and Kindel 2018). These projects would fragment ecosystems, hamper the hydrologic regime, and disrupt the rivers' ecological processes and functions (Blanton and Marcus 2009). The linear projects are closely related to land-use changes, and improvements in the transportation network provide impetus to urbanisation (and vice versa) and associated land-use transformations (Kasraian et al. 2016; Ramachandra et al. 2019a) and result in social, economic, and environmental impacts (Litman 1995).

Unplanned developmental projects have accentuated the degradation process leading to deforestation (Asher et al. 2017), affecting the wildlife habitat, animal movement path, foraging grounds, diversity, ecosystems (Bennett et al. 2011; CCIBIS 2018), frequent occurrence of landslides and mudslides, etc. Table 1 lists ecological and environmental consequences with the fragmentation of landscapes due to the implementation of transportation corridors. Railway network implemented in ecologically fragile regions would have disastrous effects, despite railway projects having the edge over roads in terms of safety, economy, pollution, etc. (Borda-de-Água et al. 2017).

Implementation of the transportation network would change the land cover with environmental impacts such as loss of forests, water bodies, fragmentation of animal habitats, a decline of biodiversity (Ramachandra et al. 2014; McGrane 2016; Miller and Hutchins 2017), which necessitates foreseeing the likely impacts of linear projects (Xiong et al. 2018). Simulation of land use dynamics provides insights into spatial patterns of land use changes and aids in planning site-specific mitigation measures, adopting environmentally sound alternatives, prudent management of natural resources, etc.

Advanced approaches of geoinformatics (GIS: Geographic Information Systems) using temporal-spatial data (remote sensing data) provide information about the landscape patterns, change dynamics, and causal factors (Lillesand et al. 2004; Setturu et al. 2014; Joshi et al. 2016) to understanding the landscape dynamics. Modeling and simulation of land-use changes help understand the influence of policies, decisions, and interventions (Bharath et al. 2014, 2017; Das Chatterjee et al. 2015). Numerous predictive models (agent-based models (ABM) and non-agent-based models/rule-based models) such as CA, CA-Markov, Geomod, SLEUTH, SLUCE, Dynamica, Dyna-CLUES, ANN, Regression, AHP, etc. have been widely applied for geo-visualization of landscape dynamics (Brown et al. 2008; Rafiee et al. 2009; Jokar Arsanjani et al. 2012; Johnston et al. 2013; Mishra et al. 2014; Jain et al. 2017; Chandan et al. 2019). The hybrid approach of integrating rule-based CA with Markov models has been extensively used worldwide to

**Table 1** The ecological implication of transportation corridors (Forman and Alexander 1998; Nyhus 2016; CCIBIS 2018; Shaffer et al. 2019)

| Category | Description |
|---|---|
| Habitat loss | Land cover changes, enhancing disturbance and barrier effects on the wildlife that contribute to the overall habitat fragmentation |
| Habitat modification | The native species tend to disappear, leading to change in species composition, population leading to loss of biodiversity (flora and fauna). Ecosystem changes would alter habitat, nutrient cycling, crop pollination, nutrient recycling, seed dispersal, aesthetics, etc |
| Disturbance | Vehicular traffic in the ecologically fragile regions would disturb and pollute the physical, chemical, and biological environment, hampering sustenance of the native fauna and flora diversity for a much wider zone beyond the transportation network |
| Mortality | Death of animals due to accidents while crossing the road or using it as habitat. In the recent past, globally, the mortality rates show an increasing trend |
| Barrier | Restriction of animal movement through fencing/elevation etc., making it inaccessible for animal movement. Due to this, the habitats are disconnected, isolating the fauna population |
| Conflict | Competition for food and other resources between man and wild has led to mortality of animals, people, damage to the crops, etc |
| Land-use change | Expansion of human settlements, agriculture fields, and monoculture plantations has led to loss of forest, habitat, and foraging grounds, which has forced the animals to contact people, resulting in higher frequency and severity of conflicts |
| Climate change | Enhanced emissions and loss of carbon sequestration with deforestation increase temperatures due to the land-use change, variability in rainfall runoff, and silt accumulation patterns. Increase in extreme conditions (floods or drought) |
| Pollution | pollutants due to vehicular movements would degrade water, soil, and air in the vicinity |
| Corridor | The transportation network (road/railway) acts as a refuge to animal or serves as movement path. These movement corridors would enhance the mortality of animals |

simulate the land-use changes. The hybrid CA-Markov fails to fit in the landscape elements precisely, and this challenge has been effectively overcome by the Agent-based models that combine the hybrid CA-Markov with various agents causing changes in land use or constricting the changes in land use through advanced spatio-numerical methods such as fuzzy logic, boolean algebra, neural networks, genetic algorithms, multi-criteria evaluation, regression, etc. ABM simulates landscape change trends and the direction of change, considering influencing factors and constraints, which can be used for appropriate decision-making (Ramachandra et al. 2019b). The current study focuses on understanding the landscape dynamics with the implementation of railway networks between i) Mysore and Kushalnagar and ii) Mysore and Thalassery, using remote sensing data, GIS and visualizing future changes using ABM.

## Study area

The study region is located in the Western Ghats (one among 36 global biodiversity hotspots), which extend along the west coast of India with pristine and fragile ecosystems (Subash Chandran 1997; Gunnel and Radhakrishna 2001; Daniels and Venkatesan 2008). The study region supports exceptional endemic biodiversity, benefiting both society and the environment due to various goods and services. The hydrological and watershed services are evident from the water provision sustaining dometic and irrigation requirements in peninsular India. The soil and water of this region sustain the livelihoods of millions of people. These fragile ecosystems are under threat due to the implementation of unplanned short-sighted developmental projects, which are escalating anthropogenic activities (Ramachandra et al. 2020). Globalization and consequent relaxation in Indian markets have given impetus to the implementation of numerous industries and linear infrastructure projects. Implementation of these projects would alter the hydrologic regime (floods and droughts), induces instability in the landscape (leading to frequent landslides and mud slides), impacts wildlife habitats, hinders movement paths, foraging areas, increases mortality of wild animals (Borda-de-Água et al. 2017; Gilhooly et al. 2019) and enhance the episodes of human–animal conflicts. Infrastructure projects proposed in this region are railway connectivity between i) Mysore Kushalnagar and ii) Mysore Thalassery, which originates from Mysore district and passes through Western Ghats (Fig. 1 and Table 2). A buffer zone of 5 km on either side of

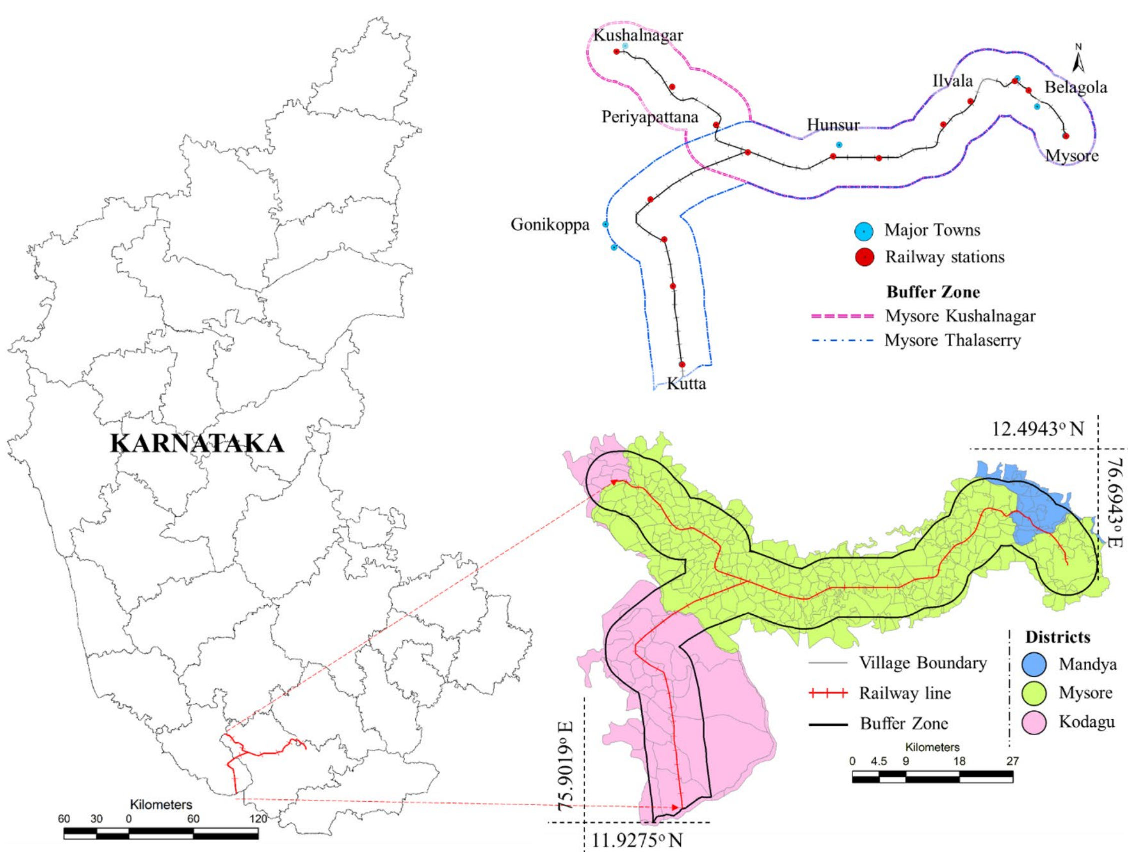



**Fig. 1** Study area

**Table 2** Details of the proposed railway projects

| Details | Alignment 1 | Alignment 2 |
|---|---|---|
| Alignments | Mysore Kushalnagar railway line (AL-1) | Mysore Thalassery railway line (AL-2) |
| Origin | Mysore city (Mysore district, Karnataka state) | Mysore City (Mysore District, Karnataka) |
| Destination | Kushalnagar town (Kodagu district, Karnataka state) | Thalassery (Kannur district, Kerala state)<br>Kutta village in Kodagu district, is the last station within Karnataka state |
| Distance | 86.5 km | 207 km<br>Over 90 km in Karnataka |
| Stations | 10<br>Mysore, Belagola, Krishnarajasagar, Ilvala, bilikere, Uddur, Hunsur, Satyagalakavalu, Titimati, Belele, Kanuru, Kutta | 12 (within Karnataka)<br>Mysore, Belagola, Krishnarajasagar, Ilvala, Bilikere, Uddur, Hunsur, Satyagalakavalu, Periyapatana, Doddahonnuru and Kushalnagar |
| | Note: Both railway lines originate from Mysore and split at Satyagalakavalu to link their respective destinations (Kushalnagar, Thalassery) | |
| Area under buffer zone | 1049 sq.km | 1213 sq.km |
| Towns/urban centers | 6<br>Mysore, Hebbal, Krishnarajasagar, Hunsur, Periyapattana, Kushalnagar | 7<br>Mysore, Hebbal, Krishnarajasagar, Hunsur, Gonikoppa, Periyapattana, Kutta |

the proposed railway lines was considered to understand the projects' influence on landscape and wildlife habitat/presence zones within Karnataka state. The buffer zone covers about 452 villages in the districts of Mysore (347), Kodagu (62) and Mandya (43).

## Data and method

The process toward understanding land use dynamics and impact on ecology in the study region (of linear railway projects) involved i) data collection and analyses, ii) land use analysis, iii) visualization of likely land-use changes, and iv) spatial patterns of biodiversity (Fig. 2).

### Data collation

This involved collecting (i) primary data from the field and (ii) secondary data from the government agencies and virtual data portals. Table 3 describes the various data used in the analysis. The cloud-free temporal remote sensing data IRS LISS 3 sensor for the years 2010 and 2019 was obtained from NRSC (National Remote Sensing Centre). Field data were collected using a pre-calibrated handheld Global Positioning System (GPS) at various locations along (and beyond) the study area aided as ground truth data (training data) that has helped in geo-rectification and classification of remote sensing data. These data are supplemented with the information from vegetation map (Pascal 1986), topographic maps (Survey of India 2018a) and virtual earth portals such as Bhuvan (National Remote Sensing Centre 2016) and Google Earth (Pascal 1986; National Remote Sensing Centre 2016; Survey of India 2018a; Google 2020).

### Land use analysis

Remote sensing data were preprocessed to rectify geometric error using ground control points obtained from field and virtual earth databases portal. Radiometric correction is done to enhance the scene radiometric properties (contrast enhancement) for better visual interpretation of the data (Jensen 1996; Lillesand et al. 2004; Gonzalez and Woods 2007). Training data (ground truth data) were collected from the field and supplemented with the secondary data covering over 15% of the study area. Gaussian maximum likelihood classifier was used to classify the remote sensing data into six land use classes (Table 4) using 60% of the training data (Bharath et al. 2018c). Accuracy of the land use classification was assessed through kappa statistics and computation of overall accuracy (Congalton and Green 2009), considering 40% of the training data. Figure 2 outlines the protocol adopted to assess and visualise landscape dynamics.

### Visualisation of land use dynamics through simulation and modeling

Agent-based modeling technique by combining various spatial and mathematical aspects of fuzzy logic, Boolean algebra, analytical hierarchical process (AHP), multi-criteria evaluation (MCE), cellular automata (CA), and Markov chains have been used to predict the likely land uses. ABM has proved to be a reliable, individual decision-making tool to capture spatial dynamics by incorporating socio-economic and environmental factors (Matthews et al. 1999; Hosseinali et al. 2013; Bharath et al. 2016a, 2018b).

Factors contributing to land-use changes along the proposed railway network are city centers, major roads,

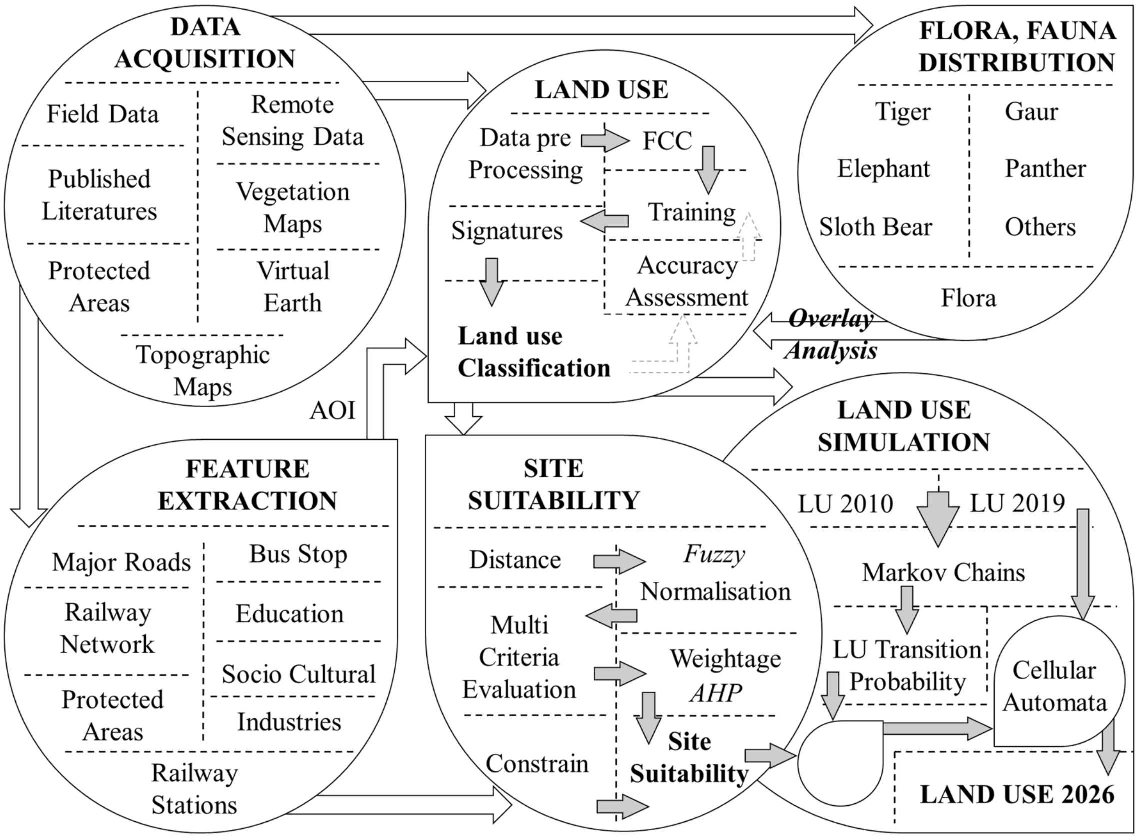



**Fig. 2** Method for assessing the landscape dynamics

educational institutions, bus stops, industries, and railway stations. Similarly, factors inhibiting land-use change considered are protected areas (forest department), lakes, and river course was derived from the secondary databases (government agencies of the spatial extent, etc.). Distance maps were prepared for each of the contributing factors and Boolean maps for each of the constrain (0 represented no change, 1 represents space that can change). Distance from each of the factors was overlaid on individual land use to determine the effective distance of influence. Fuzzy logic (Zadeh 1965) was used to understand the behavior of agents of growth across various land use classes and normalize the influences (Eastman 2012) between 0 and 1.

The distance of influence of each agent with a different degree of membership and representation function are measured and provide input to AHP weighing process, aided in multi-criteria decision-making. Multi-criteria evaluation was used to compare the influence of each of the factors on land-use change, based on expert opinion using analytical hierarchical process (AHP) (Kardi 2005; Gorsevski et al. 2012). Weights for different factors obtained from AHP and constrain maps as Boolean are used to derive site suitability maps using MCE (Li et al. 2013; Dapueto et al. 2015).

$$A = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & \ldots & a_{nn} \end{bmatrix}. \tag{1}$$

A response matrix $A = [a_{ij}]$ is generated to measure the relative dominance of item $i$ over item $j$ with the decision maker's assessments $a_{ij}$, that follow a uniform probability distribution.

$$a_{ij} = \frac{W_i}{W_j} \times e_{ij}, \tag{2}$$

where $W_i$ and $W_j$ are the priority weights and $\sum W_j = 1$, $e_{ij}$ is inconsistency observed in the analysis. The comparison matrix elements were compared pairwise to relate a single element at the level directly and ranked by eigenvector of the matrix (Zhang et al. 2015) and eigenvalue of $\lambda_{\max}$ is computed (Ying et al. 2007). A new vector $W'$ is obtained by multiplying pairwise comparison matrix and eigenvectors (Eqs. 3 and 4). The consistency of weightages is evaluated through consistency index (CI) (Eq. 5).

**Table 3** Data and source

| Sl.no | Data | Description | Source |
|---|---|---|---|
| 1 | IRS LISS IV 2010, 2019 | High spatial resolution data from Indian Remote Sensing Satellites for land use classification | NRSC |
| 2 | Field observation | GPS based field observations for satellite data calibration and training classification algorithms | Field visits (2018–2019) |
| 3 | Ancillary vegetation map | Used for classifying the land use into various forest classes. Data were derived from French institute maps, SOI topographic sheets | (Pascal 1986; Survey of India 2018b) |
| 4 | Virtual Earth | Aided in land use classification, feature extraction (roads, city centres, schools, bus stops, industries), used for land use modeling | (National Remote Sensing Centre 2016; Google 2020) |
| 5 | Proposed railway route and stations | Extraction of railway network and station on the spatial platform, used for land use modeling | |
| 6 | Protected areas | Certain areas of forests are earmarked for protection against any anthropogenic pressures. Used as a factor in land use modeling | Karnataka Forest Dept., |
| 7 | Flora, fauna | Published literatures such as forest reports, conference proceedings, journal articles, web portals to identify the spatial distribution of flora and fauna | Karnataka Forest Dept., National Tiger Conservation Authority., Wild Life Institute of India., Western Ghats Flora; Flora of Karnataka (Madhusudan et al. 2015; Ramachandra et al. 2016; Shankar 2016) |
| 8 | Topography | Elevation data for land use analysis and modeling | (U.S. Geological Survey 2000; National Remote Sensing Centre 2016; Alaska Satellite Facility 2018; Survey of India 2018b) |

$$\begin{bmatrix} 1 & a_{12} & \ldots\ldots & a_{n1} \\ a_{21} & 1 & \ldots\ldots & a_{n2} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \ldots\ldots & 1 \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} = \begin{bmatrix} W_1' \\ W_2' \\ \vdots \\ W_n' \end{bmatrix}, \tag{3}$$

$$\lambda_{\max} = \frac{1}{n} \times \left[ \frac{W_1'}{W_1} + \frac{W_2'}{W_2} + \ldots \frac{W_n'}{W_n} \right], \tag{4}$$

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1}, \tag{5}$$

where CI is the consistency index, $\lambda_{\max}$ is the largest or principal eigenvalue; n is the order of the matrix. If CI = 0, the matrix had a complete consistency. The worse consistency will represent greater value of CI.

$$\text{Consistancy ratio (CR)}=\frac{\mathrm{CI}}{\mathrm{RI}}, \tag{6}$$

where RI is the average of the resulting consistency index (random index) depending on the order of the matrix. If CR value is less than 0.10, the matrix had a reasonable consistency, otherwise, the matrix should be altered for better CR. Markov chains are statistical models used to predict the likely changes in the landscape from current state ($S(t)$) to future state ($S(t, t+1)$) based on transition probability ($P_{ij}$) of land use from one class to another (earlier to current) (Hamad et al. 2018). Mathematically Markov chain is given as Eq. 7

$$S(t, t+1) = P_{ij} \times S(t). \tag{7}$$

Cellular automata determines the state of each cell in the data, based on the cell state, neighborhood, rule dependencies (Bharath et al. 2016b; Gidey et al. 2017). These rule dependencies are derived based on the Markov chains and the site suitability maps obtained from AHP (Gidey et al. 2017; Bharath et al. 2018a; Ramachandra et al. 2019b). Site suitability maps, Markov chains, and cellular automata (CA) were integrated to visualize the landscape change patterns for the year 2026.

## Distribution of flora and fauna

Distribution of flora (Ramachandra et al. 2016; Shankar 2016) and fauna such as tiger (*Panthera tigris*), panther (*Panthera pardus*), sloth bear (*Melursus ursinus*), gaur (*Bos gaurus*), Asian elephant (*Elephas maximus*) was collated from publications of the Karnataka Forest Department (KFD 2018), National Tiger Conservation Authority (Jhala et al. 2011, 2019), Wildlife Institute of India, other published literatures (Madhusudan et al. 2015) and through field investigations. Spatial patterns of land use and distribution of flora

**Table 4** Land use classes and associated features

| Sl. no | Class | Features |
|---|---|---|
| 1 | Built-up | Residential area, industrial area, paved surfaces, mixed pixels with built-up area |
| 2 | Water | Tanks, lakes, reservoirs, rivers, water-logged areas, etc |
| 3 | Forest | Evergreen forest, Deciduous forest, Grass land, Scrub land |
| 4 | Forest plantation | Teak, acacia, bamboo, eucalyptus |
| 5 | Horticulture | Banana, areca nut, coconut, rubber, coffee |
| 6 | Agriculture | Current fallow, current sown |

and fauna were compared to understand the possible regions of anthropogenic influence on biodiversity.

## Results and discussion

Land-use changes in the study region (proposed railway lines with buffer) are depicted in Fig. 3. The results highlight that built-up and monoculture cultivation are increasing with reductions in forests and agriculture areas. Improved infrastructure and industrialization in the vicinity of Mysore has led to population influx, thereby leading to urban sprawl with the increase in built-up surfaces (concentrated growth, edge growth). Similar patterns of urbanization were noticed in and around Kushalnagar due to developing industrial areas in its vicinity. The expansion of small towns such as Ponnampete, Husur, is due to industrialization at Kushalnagara and Mysore. Land-use changes in the study regions are discussed below:

Mysore and Kushalnagar (Alignment 1): Built-up and horticulture land uses have increased from 8.4 to 13.9% and 5.7 to 7.9% respectively, with the decline of agriculture (from 69.9 to 63.4%) and forests (12.9–11.2%), while other land use classes showed least variations. Urban area intensification and spread was observed at the core and outskirts of Mysore city during 2010 and 2019. Kushalnagar, Hunsur, Periyapattana have witnessed linear urban growth along the direction of major roads.

Mysore and Kutta (Alignment 2): Built-up has increased at Mysore city and its suburbs, Hunsuru with new industrial

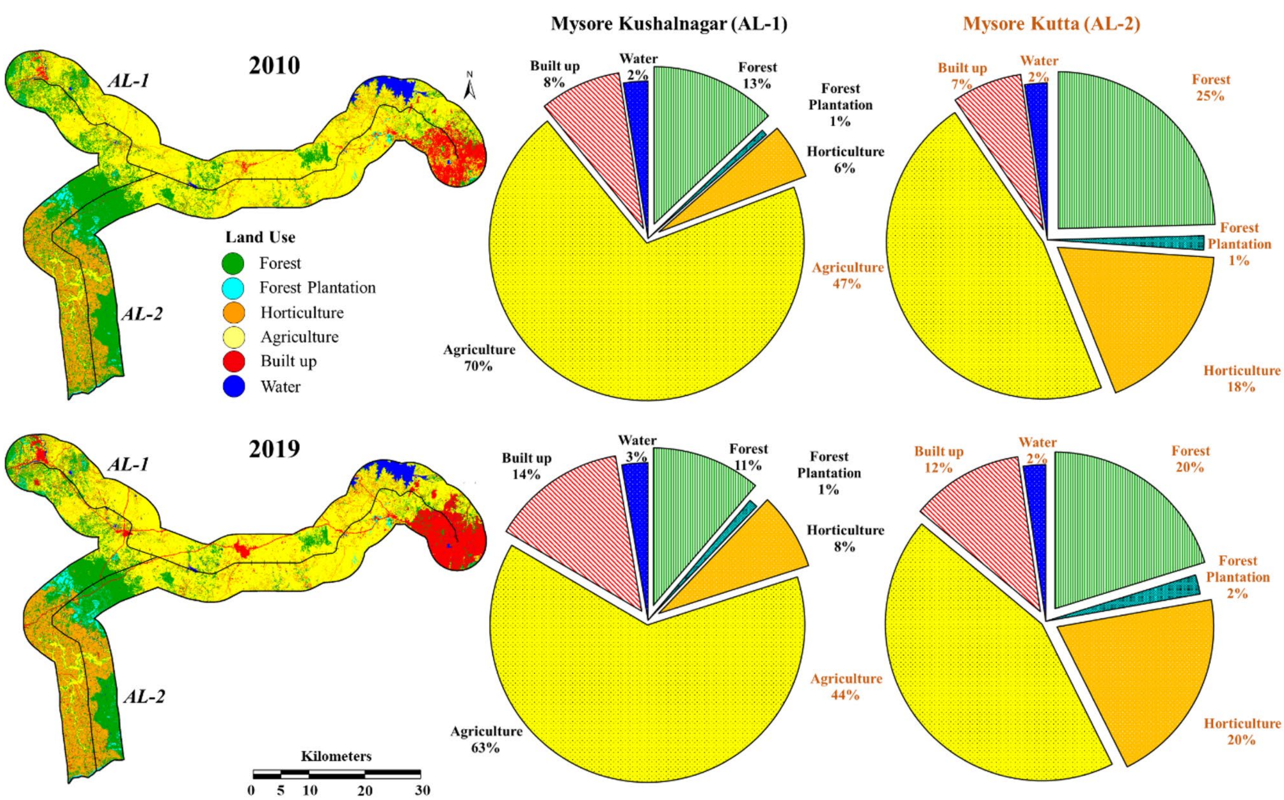



**Fig. 3** Land use dynamics along the proposed railway corridor

layout in Mysore and enhanced job opportunities. Reduction in agriculture area by 24.6% and forests by 20.2% in the last eight years (2010–2019) has paved the way for built-up, evident from 7.2 to 11.6% increase.

Modeling land-use changes considering various scenarios helps in visualizing likely changes (Ramachandra et al. 2019a). The study's focus is to understand the potential implications of the proposed railway network on land-use changes, predicted considering agents/factors (Fig. 4) such as railway stations, city centres, bus stops, educational institutions, industries, roads in the study region (Fig. 1). Protected areas such as Nagaraholé and wildlife sanctuary were considered as a constraint. Fuzzy logic was used to determine each factor's influence and normalize the ranges between 0 and 1 (Table 2). MCE-AHP was used to understand each of the growth factor's relative importance and determine the weightage of each factor contributing to the change across each land use class (Table 5). The outcome of AHP shows factors such as railway line, city centre, railway station and bus tops have highest influence and contributed to the growth of built-up, horticulture and agriculture activities. Weightages were assigned to all factors influencing change depending on the likely level of influence. Site suitability maps were created for each land use classes considering the weights, factors, and growth constraints. The site suitability maps along with the transition probabilities (Table 6) obtained from Markov chains with cellular automata were used to simulate land uses for the year 2026.

Prediction of land uses in 2026 is carried out considering 2019 as the base year and transition rules based on the probability of land-use changes during 2010 and 2019 and site suitability(for each land use). Predicted land uses for the year 2026 depict an increase in the built-up areas by almost 1.5 times at the cost of forest areas and agricultural lands (Fig. 5) with the implementation of railway projects. Other than the protected forests such as Wildlife sanctuaries (Nagaraholé.), the unprotected forests are highly vulnerable to land-use changes evident with forest loss near Kushalnagar, Hunsur and Kutta. Agriculture areas in the proximity of city centers, and railway stations tend to change to built-up areas (leapfrog and edge growth developments), as in the vicinities of Mysore, Kushalnagar, Ponnampete, Hunsur, Gonikoppa. Kutta and surrounding villages. In alignment 1, built-up and horticulture are likely to increase to 21.9 and 11.5%, respectively, with the decline of forest (9.2%) and agriculture lands (53.3%). Similarly, in alignment 2, forests and agriculture would reduce to 16 and 38%, respectively, while built-up and horticulture land uses increase, respectively, to 18.9 and 22.3%.

With the current trends of land use (2010–2019) in Kodagu and Mysore, societal demands and pressures have led to the damage of animal habitat, movement paths, forage grounds, etc. leading to biotic mortality (human and animals), crop damage (Karanth et al. 2013; Gubbi et al. 2014; Venkataramana et al. 2017). Figure 6 highlights the distribution of flora and fauna such as tiger, panther, elephant, sloth bear, gaur, etc. based on field investigations and the information compiled from the published literatures (Jhala et al. 2011, 2019; Madhusudan et al. 2015; Shankar 2016; KFD 2018).

The proposed railway lines are in the elephant forage zones (confirmed elephant presence zones), and Mysore Thalassery line passes through dense tiger areas. Both the corridors would directly affect the animal forage grounds and movement paths beyond the protected forests. Land use patterns of 2026 show a declining forest cover and agriculture area with escalations in human activities into the vulnerable pockets of animal presence zones, particularly at Hunsur, Periyapattana, Kutta, Gonikoppa, Kushalnagar that would aggravate the problems related to human and wild.

The spatial analyses highlight the need for a holistic approach considering the region's ecological fragility while implementing developmental projects. The simulation of land uses reveals of likely increase in urban areas at the cost

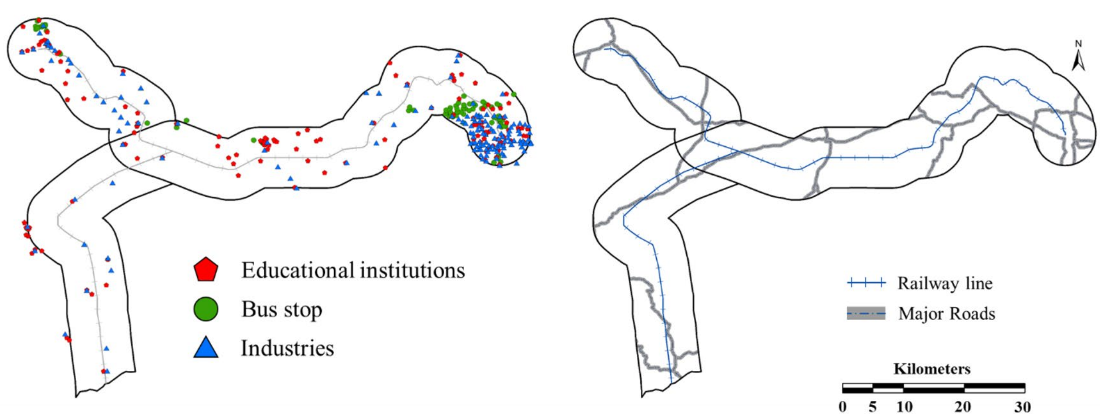



**Fig. 4** Factors contributing to land use change

**Table 5** Various Factors, range and type of infuse and weights across various land use class (Example of Mysore Kushalnagar railway corridor—Alignment 1)

| Sl.no | Land use | Factor | Range | Influence | Weight |
|---|---|---|---|---|---|
| 1 | Built-up | Railway track | 4500–5000 | Decreasing* | 0.25 |
| | | City centre | 3500–7000 | Decreasing# | 0.19 |
| | | Railway station | 0–3700 | Increasing$# | 0.19 |
| | | | 4900–6500 | Decreasing$# | |
| | | Bus stop | 300–3000 | Decreasing# | 0.15 |
| | | Roads | 0–3000 | Decreasing# | 0.08 |
| | | Industries | 0–5000 | Decreasing# | 0.07 |
| | | Education | 600–3000 | Decreasing# | 0.07 |
| 2 | Agriculture | Railway track | 4500–5000 | Decreasing* | 0.143 |
| | | City centre | 0–2100 | Increasing$# | 0.143 |
| | | | 2100–16,300 | Decreasing$# | |
| | | Railway station | 0–2600 | Increasing$# | 0.143 |
| | | | 5100–9200 | Decreasing$# | |
| | | Bus stop | 0–1400 | Increasing$# | 0.143 |
| | | | 3000–5300 | Decreasing$# | |
| | | Education | 0–900 | Increasing$# | 0.143 |
| | | | 2600–5300 | Decreasing$# | |
| | | Industries | 0–4400 | Increasing$# | 0.143 |
| | | | 7100–14,300 | Decreasing$# | |
| | | Roads | 1500–6500 | Decreasing# | 0.143 |
| 3 | Horticulture | Railway track | 4500–5000 | Decreasing* | 0.143 |
| | | City centre | 0–1500 | Increasing$# | 0.143 |
| | | | 12,000–15,600 | Decreasing$# | |
| | | Railway station | 0–2300 | Increasing$# | 0.143 |
| | | | 5300–9300 | Decreasing$# | |
| | | Bus stop | 0–1400 | Increasing$# | 0.143 |
| | | | 3300–5900 | Decreasing$# | |
| | | Education | 0–900 | Increasing$# | 0.143 |
| | | | 4200–6200 | Decreasing$# | |
| | | Industries | 0–3800 | Increasing$# | 0.143 |
| | | | 10,700–17,600 | Decreasing$# | |
| | | Roads | 0–7500 | Decreasing# | 0.143 |

*Liner function, #Sigmoidal function, $Symmetric

**Table 6** Probable land use changes from 2019 to 2026 (Alignment 1)

| Land use | | TO | | | | | |
|---|---|---|---|---|---|---|---|
| | | Forest (%) | Forest Plantation (%) | Horticulture (%) | Agriculture (%) | Built-up (%) | Water (%) |
| From | Forest | 77.3 | 3.2 | 9.6 | 7.6 | 1.7 | 0.7 |
| | Forest Plantation | 0.0 | 83.3 | 4.3 | 6.0 | 5.9 | 0.5 |
| | Horticulture | 0.0 | 0.0 | 86.8 | 0.0 | 13.2 | 0.0 |
| | Agriculture | 0.0 | 0.3 | 4.8 | 82.9 | 11.7 | 0.3 |
| | Built-up | 2.0 | 2.0 | 2.0 | 2.0 | 90.0 | 2.0 |
| | Water | 0.0 | 0.2 | 9.5 | 6.0 | 1.3 | 83.0 |

of forests. These land-use changes would lead to habitat loss, loss of foraging grounds (which span beyond the protected forested areas), making it necessary to mitigate disastrous impacts by shunning projects that are likely to aid as catalyst in the large-scale land cover changes. Holistic approaches in regional planning are quintessential to conserve ecologically

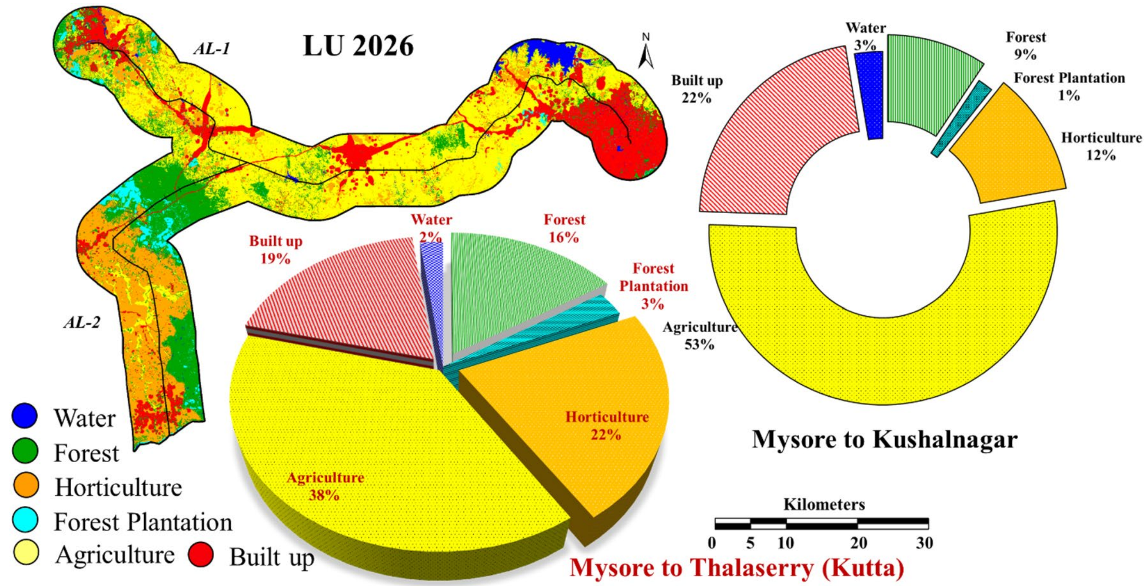



**Fig. 5** Simulated land use 2026

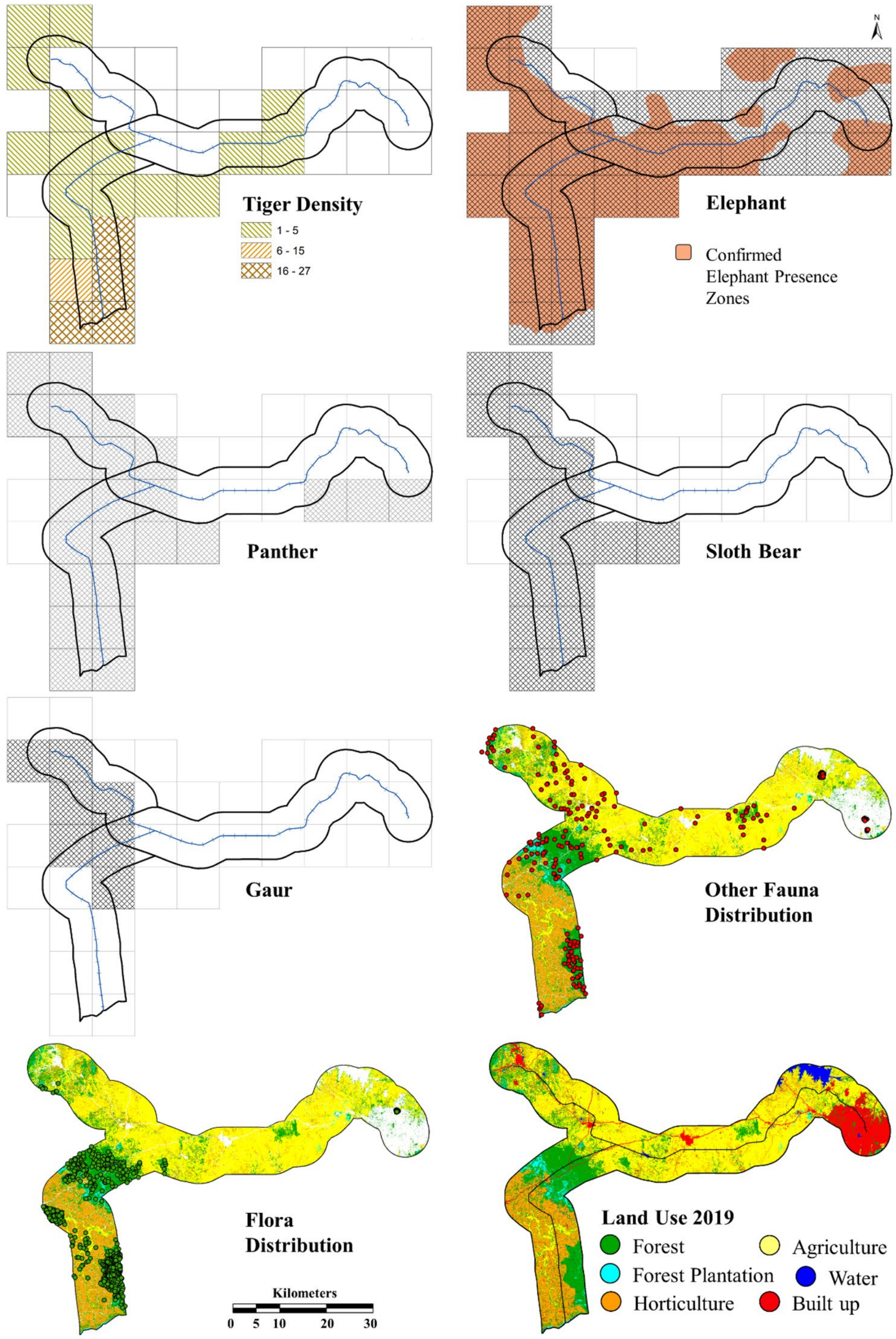
important region and support people's livelihood with the sustenance of natural resources, mitigation of environmental impacts such as frequent occurrences of land or mudslides, human–animal conflicts, forest fires, flooding, water scarcity, etc.

## Conclusion

Spatio-temporal patterns of land uses in the study regions of the proposed railway corridors i.e., Mysore–Kushalnagar and Mysore–Thalassery show that built-up areas would increase with the reduction of agriculture areas and natural vegetation. Built-up area has increased from 8% (2010) to 14% (2019), which is predicted to increase to 22% (2026) with the decrease in agriculture and forested areas, along the Mysore Kushalnagar corridor. Similarly, along the Myosre Thalassery railway corridor, built-up areas have increased from 7 to 12% and are expected to increase to 19%. Visualisation of land uses show major urban agglomeration at Mysore and Kushalnagar, while cities such as Hunsur, Ponnampere, Gonikoppa, and Kutta (Hamlet) show escalating of built-up areas, which could be associated with the railway networks and proposed railway stations. The spatial distribution of flora and fauna indicates that human activities (built-up/agriculture/horticulture) have intruded into animal movement/forage paths hampering their survival. Human activities would further extend to the animal territories disturbing their habitats, foraging grounds, thereby leading to higher instances of frequent human–animal conflicts and mortalities with railway connectivity implementation.

The proposed infrastructure activities through the ecologically fragile Western Ghats (and surroundings) would fragment the ecosystem that would lead to resource (food, wood, water, fodder etc.) scarcity, invasion of animal habitats, loss of biodiversity (flora and fauna). Further alteration in land use would impact the hydrological regime, with escalations in extreme scenarios (floods and droughts). Hence, conservation and sustainable management of ecologically fragile regions are essential. It is prudent to maintain intergeneration equity by maintaining Western Ghats landscape integrity without any major developmental projects, including the proposed linear projects.

**Fig. 6** Distribution of fauna and flora



**Funding** We acknowledge the financial support for this study from Coorg Wildlife Society, Kodagu and we thank (i) ENVIS division, The Ministry of Environment, Forests and Climate Change, Government of India. (iii) Indian Institute of Science for the sustained support to the ecological research in Western Ghats. We thank Vishnu Mukri and Srikanth Naik for the assistance during field data collection.

**Data availability** Data used in the analyses are compiled from the field. Data are anlysed 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/

## Compliance with ethical standards

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

**Ethical approval** The publication is based on the original research and has not been submitted elsewhere for publication or web hosting. The research does not involve either humans, animals or tissues.

## References

Alaska Satellite Facility (2018) Vertex: ASF's Data Portal. https://www.asf.alaska.edu/doi/palsar-documents-tools/. Accessed 10 May 2019

Asher S, Garg T, Novosad P (2017) The Ecological Footprint of Transportation Infrastructure. In: Pacific Development Conference PacDev 2018. Davis, p 62

Bennett VJ, Smith WP, Betts MG (2011) Toward understanding the ecological impact of transportation corridors. USDA For Serv - Gen Tech Rep PNW-GTR

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

Bharath H, Vinay S, Ramachandra T V (2016a) Comparative assessment of Agent based and Rule based Models for urban growth visualization. In: Kerala Environment Congress KEC-2016. Centre for Environemnt and Development, Thiruvananthapuram, p 117

Bharath HA, Vinay S, Ramachandra TV (2016b) Agent based modelling urban dynamics of Bhopal, India. J Settlements Spat Plan 7:1–14. https://doi.org/10.19188/01JSSP012016

Bharath HA, Vinay S, Ramachandra TV (2017) Characterization and visualization of spatial patterns of urbanisation and sprawl through metrics and modeling. Cities Environ 10:33

Bharath HA, Chandan MC, Vinay S, Ramachandra TV (2018a) Modelling urban dynamics in rapidly urbanising Indian cities. Egypt J Remote SensSpSci 21:201–210. https://doi.org/10.1016/j.ejrs.2017.08.002

Bharath HA, Chandan MC, Vinay S, Ramachandra T V (2018b) Urbanization in India: Patterns, visualization of cities, and greenhouse gas inventory for developing an urban observatory. In: Urban Remote Sensing, Second Edition

Bharath HA, Vinay S, Chandan MC, Gouri BA, Ramachandra TV (2018c) Green to gray: Silicon Valley of India. J Environ Manage 206:1287–1295. https://doi.org/10.1016/j.jenvman.2017.06.072

Biasotto LD, Kindel A (2018) Power lines and impacts on biodiversity: a systematic review. Environ Impact Assess Rev 71:110–119. https://doi.org/10.1016/j.eiar.2018.04.010

Blanton P, Marcus WA (2009) Railroads, roads and lateral disconnection in the river landscapes of the continental United States. Geomorphology. https://doi.org/10.1016/j.geomorph.2009.06.008

Borda-de-Água L, Barrientos R, Beja P, Pereira HM (eds) (2017) Railway ecology. Cham, Switzerland

Brown DG, Robinson DT, An L et al (2008) Exurbia from the bottom-up: confronting empirical challenges to characterizing a complex system. Geoforum 39:805–818. https://doi.org/10.1016/j.geoforum.2007.02.010

CCIBIS (2018) Transportation and ecological corridors. In: Carpathian Integr. Biodivers. Inf. Syst. http://www.ccibis.org/carpathian-features/110-transportation-and-ecological-corridors. Accessed 3 Oct 2019

Chandan MC, Nimish G, Bharath HA (2019) Analysing spatial patterns and trend of future urban expansion using SLEUTH. Spat Inf Res. https://doi.org/10.1007/s41324-019-00262-4

Congalton RG, Green K (2009) Assessing the accuracy of remotely sensed data: principles and practices. The Photogrammetric Record. https://doi.org/10.1111/j.1477-9730.2010.00574_2.x

Daniels RRJ, Venkatesan J (2008) Western ghats-biodiversity, people, conservation. Rupa & Company, India

Dapueto G, Massa F, Costa S et al (2015) A spatial multi-criteria evaluation for site selection of offshore marine fish farm in the Ligurian Sea, Italy. Ocean Coast Manag 116:64–77. https://doi.org/10.1016/j.ocecoaman.2015.06.030

Das Chatterjee N, Chatterjee S, Khan A (2015) Spatial modeling of urban sprawl around Greater Bhubaneswar city, India. Model Earth Syst Environ 2:14. https://doi.org/10.1007/s40808-015-0065-7

Eastman JR (2012) IDRISI Selva Manual—Guide to GIS and Image Processing. Clark Labs, Clark University, Worcester

Forman RTT, Alexander LE (1998) Roads and their major ecological effects. Annu Rev EcolSyst 29:207–231. https://doi.org/10.1146/annurev.ecolsys.29.1.207

U.S. Geological Survey (2000) Earthexplorer. https://earthexplorer.usgs.gov. Accessed 24 Jun 2019

Gidey E, Dikinya O, Sebego R et al (2017) Cellular automata and Markov Chain (CA_Markov) model-based predictions of future land use and land cover scenarios (2015–2033) in Raya, northern Ethiopia. Model Earth Syst Environ 3:1245–1262. https://doi.org/10.1007/s40808-017-0397-6

Gilhooly PS, Nielsen SE, WhittingtonSt. Clair JCC (2019) Wildlife mortality on roads and railways following highway mitigation. Ecosphere 10:1–16. https://doi.org/10.1002/ecs2.2597

Gonzalez RC, Woods RE (2007) Digital Image Processing, 3nd edn. Pearson, ISBN: 9780131687288

Google (2020) Google Earth. https://www.google.com/intl/en_in/earth/. Accessed 3 Mar 2019

Gorsevski PV, Donevska KR, Mitrovski CD, Frizado JP (2012) Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: a case study using ordered weighted average. Waste Manag 32:287–296. https://doi.org/10.1016/j.wasman.2011.09.023

Gubbi S, Swaminath MH, Poornesha HC et al (2014) An elephantine challenge: human–elephant conflict distribution in the largest Asian elephant population, southern India. BiodiversConserv 23:633–647. https://doi.org/10.1007/s10531-014-0621-x

Gunnel Y, Radhakrishna BP (eds) (2001) Sahyadri: the great escarpment of the Indian subcontinent. Geological Society of India, Bangalore

Hamad R, Balzter H, Kolo K (2018) Predicting land use/land cover changes using a CA-Markov model under two different scenarios. Sustainability 10:3421. https://doi.org/10.3390/su10103421

Hosseinali F, Alesheikh AA, Nourian F (2013) Agent-based modeling of urban land-use development, case study: simulating future scenarios of Qazvin city. Cities 31:105–113. https://doi.org/10.1016/j.cities.2012.09.002

Survey of India (2018a) Topographic Maps. In: Dep. Sci. Technol. http://www.surveyofindia.gov.in/. Accessed 9 Feb 2018

National Remote Sensing Centre (2016) Bhuvan. In: Indian Sp. Res. Organ. Gov. India. http://bhuvan.nrsc.gov.in/. Accessed 3 Mar 2018

Jain RK, Jain K, Rehan A (2017) Modeling urban land cover growth dynamics based on Land change modeler (LCM) using remote sensing: a case study of Gurgaon, India. AdvComputSciTechnol 10:2947–2961

Jensen JR (1996) Introductory digital image processing: a remote sensing perspective, 2nd edn. https://doi.org/10.2113/gseegeosci.13.1.89

Jhala YV, Qureshi Q, Nayak AK (eds) (2019) Status of tigers, co-predators and prey in India 2018. National Tiger Conservation Authority Government of India, Deharadun

Jhala Y, Qureshi Q, Gopal R, Sinha PR (eds) (2011) Status of tigers, co-predators, and prey in India. National Tiger Conservation Authority and Wildlife Institute of India, India

Johnston KM, North MJ, Brown DG (2013) Introducing agent based modeling in the GIS environment, 1st edn. ESRI Press, California

JokarArsanjani J, Helbich M, Kainz W et al (2012) Integration of logistic regression, Markov chain and cellular automata models to simulate urban expansion. Int J Appl Earth ObsGeoinf 21:265–275. https://doi.org/10.1016/j.jag.2011.12.014

Joshi N, Baumann M, Ehammer A et al (2016) A review of the application of optical and radar remote sensing data fusion to land use mapping and monitoring. Remote Sens 8:70. https://doi.org/10.3390/rs8010070

Karanth KK, Gopalaswamy AM, Prasad PK, Dasgupta S (2013) Patterns of human–wildlife conflicts and compensation: Insights from Western Ghats protected areas. BiolConserv 166:175–185. https://doi.org/10.1016/j.biocon.2013.06.027

Kardi T (2005) Analytical Hierarchical Process AHP Tutorial. In: Revoledu. https://pdfs.semanticscholar.org/7e27/b5a124c2e6829e1ff0d3e1279c2dbc9ebe2a.pdf. Accessed 23 Dec 2015

Kasraian D, Maat K, Stead D, van Wee B (2016) Long-term impacts of transport infrastructure networks on land-use change: an international review of empirical studies. Transp Rev 36:772–792. https://doi.org/10.1080/01441647.2016.1168887

KFD (2018) Karnataka Forest Department. In: Gov. Karnataka. http://aranya.gov.in. Accessed 13 Feb 2019

Lillesand TM, Kiefer RW, Chipman JW (2004) Remote sensing and image interpretation, 7th edn. Wiley, New York

Litman T (1995) Land use impact costs of transportation. World Transp Policy Pract 1:9–16. https://doi.org/10.1108/13527619510101981

Li C, Huang Z, Peng M, Zhou H (2013) The location analysis of indemnificatory housing based on SMCE. In: International Conference on Geoinformatics

Madhusudan MD, Sharma N, Raghunath R et al (2015) Distribution, relative abundance, and conservation status of Asian elephants in Karnataka, southern India. BiolConserv 187:34–40. https://doi.org/10.1016/j.biocon.2015.04.003

Matthews KB, Craw S, Sibbald AR (1999) Implementation of a spatial decision support system for rural land use planning: integrating geographic system and environmental models with search and optimization algorithms. Comput Electron Agric. https://doi.org/10.1016/S0168-1699(99)00005-8

McGrane SJ (2016) Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: a review. HydrolSci J 61:2295–2311. https://doi.org/10.1080/02626667.2015.1128084

Miller JD, Hutchins M (2017) The impacts of urbanisation and climate change on urban flooding and urban water quality: a review of the evidence concerning the United Kingdom. J HydrolReg Stud 12:345–362

Mishra V, Rai P, Mohan K (2014) Prediction of land use changes based on land change modeler (LCM) using remote sensing: a case study of Muzaffarpur (Bihar), India. J GeogrInst Jovan Cvijic SASA 64:111–127. https://doi.org/10.2298/IJGI1401111M

Nyhus PJ (2016) Human-Wildlife Conflict and Coexistence. Annu Rev Environ Resour 41:143–171. https://doi.org/10.1146/annurev-environ-110615-085634

Pascal JP (1986) Explanatory booklet on the forest map of South India. French Institute of Pondicherry, Pondicherry

Rafiee R, Mahiny AS, Khorasani N et al (2009) Simulating urban growth in Mashad City, Iran through the SLEUTH model (UGM). Cities 26:19–26. https://doi.org/10.1016/j.cities.2008.11.005

Ramachandra TV, Bharath S, Bharath HA (2014) Spatio-Temporal dynamics along the terrain gradient of diverse landscape. J Environ EngLandscManag 22:50–63. https://doi.org/10.3846/16486897.2013.808639

Ramachandra TV, Joshi N V, Subash Chandran MD (2016) Floristic Diversity in Western Ghats: Documentation, Conservation and Bioprospection– a priority agenda for action. In: Sahyadri E News. http://wgbis.ces.iisc.ernet.in/biodiversity/sahyadri_enews/newsletter/issue38/index.htm. Accessed 11 Mar 2018

Ramachandra TV, Bharath S, Vinay S (2019) Visualisation of impacts due to the proposed developmental projects in the ecologically fragile regions-Kodagu district, Karnataka. Prog Disaster Sci 3:100038. https://doi.org/10.1016/j.pdisas.2019.100038

Ramachandra TV, Sellers JM, Bharath HA, Vinay S (2019) Modeling urban dynamics along two major industrial corridors in India. Spat Inf Res 27:37–48. https://doi.org/10.1007/s41324-018-0217-8

Ramachandra TV, Vinay S, Bharath S et al (2020) Insights into riverscape dynamics with the hydrological, ecological and social dimensions for water sustenance. Curr Sci 118:1379–1393. https://doi.org/10.18520/cs/v118/i9/1379-1393

Setturu B, Bharath HA, Rajan K, Ramachandra T (2014) Cost effective mapping, monitoring and visualisation of spatial patterns of urbanisation using FOSS. Researchgate Net. OSGeo, Hyderabad, pp 1–6

Shaffer LJ, Khadka KK, Van Den Hoek J, Naithani KJ (2019) Human-Elephant conflict: a review of current management strategies and future directions. Front EcolEvol. https://doi.org/10.3389/fevo.2018.00235

Shankar RK (2016) Digital Flora of Karnataka. In: Herb. JCB, IISc. http://florakarnataka.ces.iisc.ac.in/hjcb2/contact.php. Accessed 13 Feb 2019

SubashChandran MD (1997) On the ecological history of the Western Ghats. CurrSci 73:146–155. https://doi.org/10.2307/24098268

Survey of India (2018b) Nakshe. In: Dep. Sci. Technol. http://www.soinakshe.uk.gov.in/. Accessed 10 Feb 2018

Venkataramana GV, Sreenivasa LHG (2017) An assessment of crop damage and economic loss caused by elephants in Harohalli and Kodihalli ranges of Bannerghatta National Park, Karnataka, India. Curr Sci 113:161. https://doi.org/10.18520/cs/v113/i01/161-167

Xiong C, Beckmann V, Tan R (2018) Effects of infrastructure on land use and land cover change (LUCC): the case of Hangzhou International Airport, China. Sustainability 10:2013. https://doi.org/10.3390/su10062013

Zadeh LA (1965) Fuzzy sets. Inf Control 8:338–353. https://doi.org/10.1016/S0019-9958(65)90241-X