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Visualisation of impacts due to the proposed developmental projects in the ecologically fragile regions- Kodagu district, Karnataka☆

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ABSTRACT

Assessing land use land cover changes in forested regions reflect the extent of anthropogenic pressure, ecosystem degradation and their impact on local wellbeing. The rapid expansion of linear developments such as roads, power lines will have an irreversible loss of habitat, as a result of forest fragmentation and consequent disruptions in the local ecological processes. The spatiotemporal land use analysis of Kodagu highlights the loss of forest cover due to an uncontrolled expansion of coffee plantations and other driving forces. The major cover of evergreen forest (40.47 to 27.14%) has lost due to interventions in terms of road, built-up areas and other changes. Around 66,892 ha of pristine forest cover was lost due to un-interrupted exploitation. Kushalnagara and Madikere taluks have lost the major chunk of forests due to construction (roads, homestays, villas, etc.) activities. Forest fragmentation analyses portray the status of forests in their condition across the temporal scale. The region had 32% of forest cover under interior or intact forests in 1973, whereas in 2018 it covers only 19% under various protected areas. Though Kodagu district is well connected with national and state high ways, the Government has now proposed to increase the road width of existing major highways (7) and a new railway line connecting Tellicherry and Mysore. The scenario based analysis has been done considering business as usual and with the expansion of linear alignments using Fuzzy-MCE-AHP-MCA. Forecasting future land use changes resulting from linear developments suggest the loss of core forest with the expansion of pre-existing roads. The loss of 8% forest cover with the expansion of linear alignments will have irreversible impacts on Kodagu landscape. The study reveals the causal factors for the disaster are the absence of prudent management of a landscape in the ecologically fragile region evident from the conversion of native forests to other land uses, disruption of stream network, construction of buildings along the water course disrupting the natural water flow, construction or expansion of existing roads, steep vertical cuts leading to structural instability, removal of native vegetation cover in highly undulating terrains with steep slopes leading to the weakening of terrain due to the lowered binding capability of soil, encroachment of local water bodies (such as ponds/tanks), etc. The study emphasizes the need for restoration of stream network, catchment treatment through planting of native species, arresting deforestation and restrictions of large-scale developmental projects with the detrimental land use changes. The outcome of the current research helps in evolving appropriate policies to review the proposed linear projects towards sustainable management of natural resources.

1. Introduction

The conservation and sustainable management of ecosystems is essential for the development path to be ecologically sustainable, economically feasible and socially viable. Sustainable development of a region requires accounting of natural variability and the effects of human interventions on key indicators of biodiversity and ecosystem productivity. This requires an understanding of the structure of a landscape, complex functioning of ecosystems, diversity of resources, values, ecological services and their significant ability in influencing climate at local as well as global scale [8,28,41,63]. Conservation has been a challenging task with burgeoning

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anthropogenic pressures on the ecosystem and enhanced cascading impacts [62]. Unplanned developmental activities will heighten the risks associated with environmental degradation, induce disasters, disrupting the sustainable economic growth and loss of biodiversity [14]. In this regard, policy approaches considering all components and functions of the ecosystems in developmental planning is quintessential.

Forests constitute the vital natural resources aiding in socioeconomic development and environmental protection for human's livelihood [51]. Forest ecosystem plays a vital role in sustaining hydrologic regime with the ecology, biodiversity, food security, economic growth and human well-being. [64,65]. The natural forests across the world are experiencing transformation due to the escalating anthropogenic pressures in the post industrialization era [21]. Deforestation has been the prime driver of global warming and consequent changes in the climate [45,61]. Land use and land cover (LULC) are prime variables that reflects the landscape structure. Understanding LULC dynamics in a landscape provide insights to land cover changes during the past few years. Alterations of forest structure through LU changes results in the fragmentation of contiguous forests, which will influence the functional abilities evident from the decline of water availability, carbon sequestration potential, etc. [7,44,61]. Forest fragmentation is the consequence of a simultaneous reduction of forest area, increase in forest edge, and the sub-division of large forest areas into smaller non-contiguous fragments causing a disruption in continuity of the natural landscape and ecological processes [47]. Subsequent edge effects of fragmented forests extend into interior forest areas and alter forest structure, composition microclimate, forest density and dynamics. The edge effects may even perish large trees within 300 m of the forest edge and result in mortality of trees, increase in canopy gaps, affecting biogeochemistry, resource availability, mortality of underground biota, replaced by densely spaced short-lived pioneers [35,52,53], resulting in decreases in forest biomass (25% lower than interior), basal area and carbon sequestration potential [9,60].

Linear corridors (such as roads, power line, and oil and natural gas lines) in forested landscapes have impacted wildlife populations and also impaired ecological services [33]. It is estimated that globally the number of roads and expansion of existing roads will expand dramatically at least 25 million kilometers by 2050, a 60% increase in the total length of roads compared to 2010 [34]. Barrier effects created by linear corridors restrict the movement of wildlife species [39], alter home ranges [69], decrease gene flow, decline of genetic diversity and increase in-breeding [23]. The extent of linear infrastructure development is burgeoning worldwide, but their impacts are inadequately understood and hence most of the projects are implemented with the inadequate and inappropriate mitigation measures. Deterring the ecological "road effect zone" due to the linear infrastructure projects (roads and highways) is a prime research concern to understand the convolution effects caused by them. The quantification of environmental impacts from biotic perspective has been attempted earlier for linear infrastructure impacts [15,46,66] and very few studies considered abiotic aspects [37,42]. The fragmentation of forests and changes in habitat due to an increase in paved surfaces with the large scale landscape alterations, have resulted in the reduced quantum and duration of stream flows due to lowered catchment's capability to retain water [64]. The fragmented patches due to the decline of vegetation have reduced the soil binding capability and the regions have become vulnerable during high intensity rainfall with the instances of landslides and mudslides. Likelihood of landslide and surface erosion is higher in the areas disturbed by linear infrastructure through alteration of hill slopes, topography as compared to undisturbed steep forests. Increase in high storm runoff, loss of infiltration capacity and the interception of subsurface flow at road cuts accelerate the disasters such as landslides [59].

The conservation and sustainable management of riverine ecosystems are vital in the pursuit of development goals as imbalance would result in the unrivaled changes in socio-economic conditions [48,50]. The conservation planning requires an understanding of landscape structure dynamics through temporal land use analyses, likely changes in the landscape due to the natural phenomenon as well as due to the proposed large scale projects (if any), assessment of the status of natural resources, mitigation measures in cases of large scale land cover changes, catchment treatment initiatives with the active participation and collaboration of local stakeholders, etc. [20,30].

The consistent data available at regular intervals from space borne sensors (on satellite platforms) have been useful in understanding forest cover dynamics as well as the extent of anthropogenic pressure. The satellite remote sensing (RS) has made the most valuable contributions to natural resource management and biodiversity assessment with an accurate estimation of forest cover and deforestation rates [43]. Modelling and simulation of LULC changes is necessary to understand trends in landscape changes, the direction of changes, influencing factors, constraints, to foresee the influence of policies and interventions [3,4,50]. Visualization and modelling probable landscape dynamics can be carried out using non-agent based or agent based models (ABM). ABM by combining various spatial and mathematical approaches such as Fuzzy logic, Boolean algebra, Analytical Hierarchical process, Multi Criteria Evaluation, Cellular Automata, and Markov Chains are the most effective technique [5,6,38,40,49]. ABM has evolved with the incorporation of various causal factors influencing landscape dynamics during the past decade [22] and this approach has proved to be superior over conventional modelling techniques [4,6,10,18,24,67] with unique characteristics such as i) bottom up approach accounting the behavior of factors in urban evolution, ii) aids as knowledge base, iii) considers complex, heterogeneous, and nonlinear interactions, iv) flexible and can work at different levels of abstraction, v) autonomous, and vi) evolving with superior quality [58]. ABM exhibits an extensive knowledge base on how the agents of changes interact with each other to be responsible for the social and physical environment of built-up areas and their immediate vicinity.

The conservation of an ecosystem will be fruitful through mitigate human induced perturbations based on the degree of connectivity and management activities. The proposed expansion of existing infrastructure in Kodagu (Coorg) district is to improve capacity building for tourism, ease of movement of goods from Kerala. However, the unabated land use changes leading to the large scale alterations of landscape structure have resulted in floods and landslides during August 2018 at various locations in Kodagu. The rampant forest degradation due to the unplanned developmental activities during the past three decades, have resulted in severe calamity with the damages to the property (800 houses), large scale displacements (4000 habitants), loss of life (16 people) and livelihood (death of livestock, silting of rivers and wells, loss of horticulture crops, etc.). The implementation of the proposed linear projects will aggravate persisting human-wildlife conflicts. This signifies the necessity of understanding land use status and visualization of likely impacts with the proposed projects on forest cover. In this regard, current research tries to understand the landscape dynamics, and also the impact of multiple liner expansions proposed in Kodagu district of Karnataka. This entails:

i. analysis of landscape dynamics through spatial analyses of temporal remote sensing data;
ii. assessment of biodiversity through field sampling and data mining in published literature;
iii. simulation of likely land use changes and visualization of impacts due to the proposed liner projects; and
iv. Prioritizing activities based on the ecological fragileness towards prudent management of natural resources (land, water, biodiversity) and sustenance of people's livelihood in the district.

2. Materials and methods

2.1. Study area

Kodagu District (Coorg) also known as "Kashmir of South" and "Switzerland of India", is located in a nerve point of central and southern

Western Ghats, which forms an important ecological section with abundant natural resources, native forests, mountains, lush green valleys, misty woods, paddy fields, numerous lakes, racing rivers and enchanting waterfalls, wildlife, tribal life, archaeological remains, historical monuments, great religious and cultural heritage (Fig. 1). The district encompasses an area of 4102 km^2 with a population of 5,54,762 as per 2011 census. The elevation ranges from 900 to 1750 m above mean sea level and mean temperature range from 20°-24 °C in with an average rainfall of 4000 mm. Madikeri, a hill town is the headquarters and located 252 km away from Bengaluru (Karnataka's capital). The district is divided into the two forest divisions, namely Madikeri and Virajpet which include three wildlife sanctuaries (WLS-Bramhagiri, Talacauvery, and Pushpagiri) and one national park (NP-Nagaraholé). The region is a home to endangered Myristica swamps having Critically Endangered *Syzigium travancoricum* and *Gymnacranthera canarica* (Vulnerable) are amongst many other species [25]. The area has a large number of medicinal plants and non-timber forest product (NTFP) yielding plants. Kodagu covers 25% faunal species found in India and also a part of the Nilgiri biosphere reserve, home to two of the most prestigious and important wildlife Schemes-Project Elephant and Project Tiger. Kodagu forms (approximately 1600–1700 elephants present) a primary elephant movement path connecting the northern and southern portions of Mysore elephant reserve boundary (Karnataka Forest Department, Government of Karnataka) [29].

The economy of the district is driven by a thriving rural agrarian economy (agriculture, horticulture, livestock), which is supplemented by cash crops and incomes from tourism. The Kodagu produces more than one third of India's coffee with a share of 56% in Karnataka. The district alone produces 2% of the world's coffee. Coffee revenue has helped Kodagu to become one of the richest districts in India [11]. The region has rivers such as Cauvery (Harangi, Lakshmanathirtha, Taraka, Cauvery, Hemavathi, and Kabini), Aralampuzha, Kuppanam, Payaswini, Valapattanam, Netravathi (Kumaradhara), etc., acting as a lifeline for Karnataka, Tamilnadu, Kerala states. Sacred groves or devarakadu or *kan* forests are culturally protected patches of forests continue to thrive as a living tradition in Kodagu district. The district has highest density of groves in the world with at least a grove for every 300-ha, aid as islands for protecting the diversity of rare species in high human dominated landscape [17]. However, the recent changes in socio-cultural and religious belief of the communities also have contributed to the degradation of groves [32]. The district is well connected with national and state high ways. The Government has now proposed to increase the road width of existing seven major highways in Kodagu and a new railway line connecting Talassery and Mysore (Appendix 1: Table A1). All the proposed expansions are either passing through sensitive habitats of wildlife and through buffer regions or running parallel to the protected area boundary.

2.2. Method

Fig. 2 outlines the overall method adopted for the spatial analysis to visualize likely environmental impacts with the proposed linear projects in the district. The process of land use classification and modelling likely changes have been carried out in three phases i) data preprocessing and classification – land use analyses, (ii) forest fragmentation analyses, and (iii) modelling-visualization of likely land use changes.

2.2.1. Data preprocessing and classification

The process of data acquisition involves the collection of primary spatial data (temporal RS data of Landsat series and field data) and secondary data (collection of ancillary data such as vegetation maps developed by French institute Puducherry, topographic maps (the Survey of India) and virtual earth data (Google Earth). Field surveys were done using pre-calibrated GPS (Global Positioning System) and AGPS (Assisted GPS) in order to collect ground control points (for geo registering RS data) and training data for supervised land use analysis. Data preprocessing involves geo-referencing and radiometric correction of RS data. Field data along with Google Earth (http://earth.google.com),

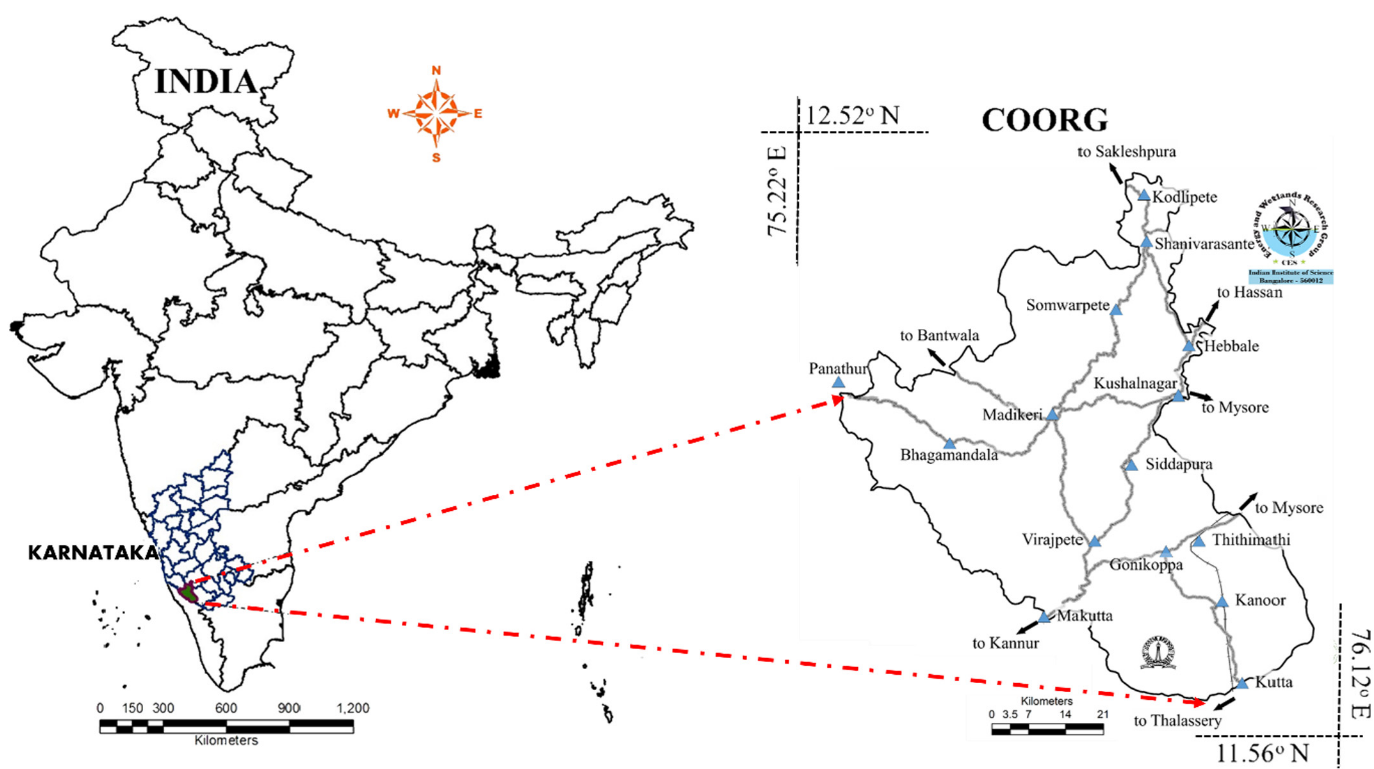

Fig. 1. Kodagu district, Karnataka state.

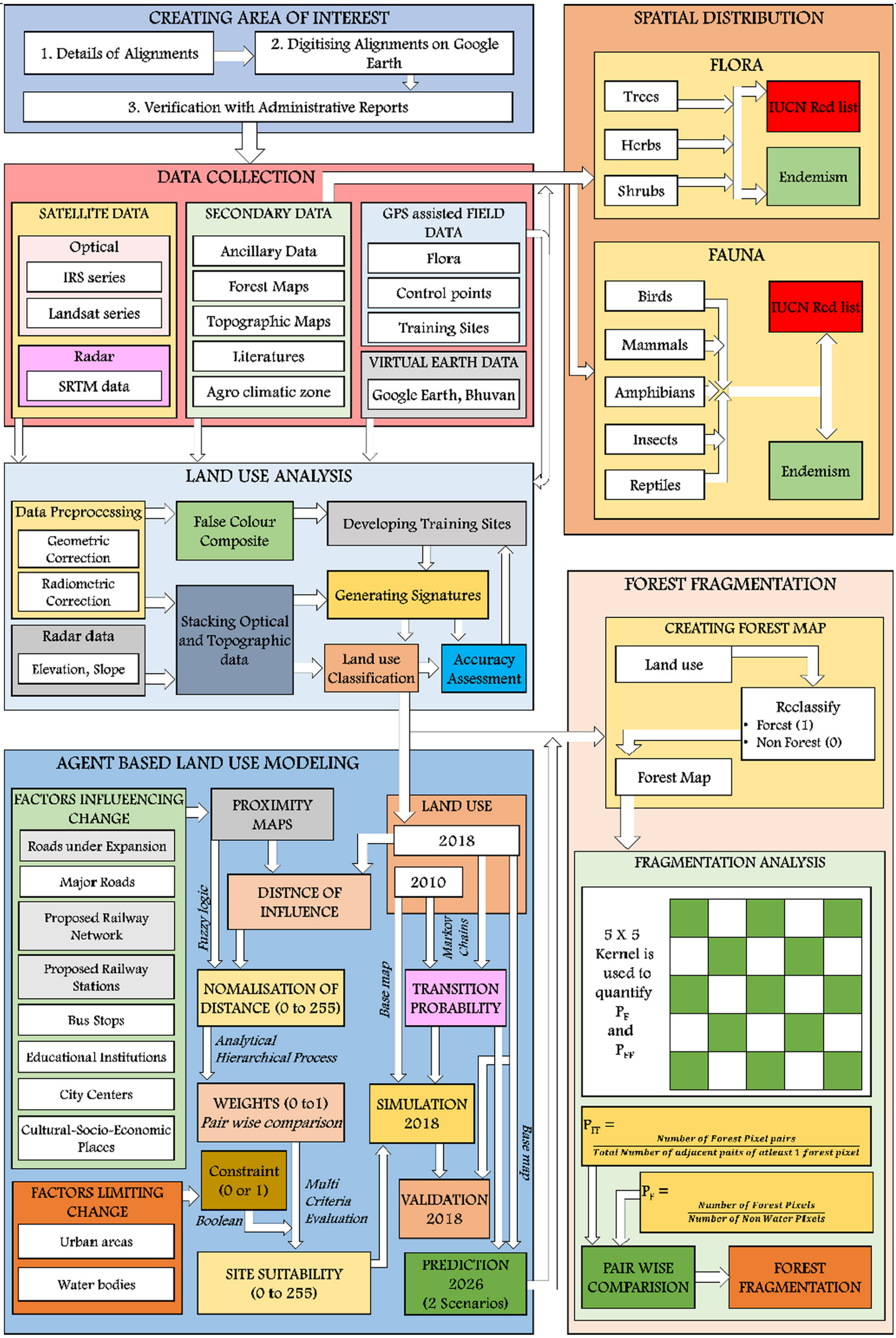

Fig. 2. Method adopted for spatial analyses – LU, Agent based modelling, forest fragmentation, biodiversity distribution.

Bhuvan (http://bhuvan.nrsc.gov.in) were used to geo-reference and geo-rectify remote sensing data. The process of classification involves creation of false color composite (FCC), selection of training sites, collection of attribute data from the field for the training polygons, LU classification and accuracy assessment. Secondary data and field data were used in association with RS data to delineate heterogeneous features covering at least 15% of the scene area. The supervised classification technique based on the Gaussian maximum likelihood classifier (GMLC) algorithm [16] with the higher classification accuracies [3,47,48,50,64] was adopted for land use analysis to derive information under 10 different land use categories using GRASS GIS (Geographical Analysis Support System). GRASS is a free and open source geospatial software with the robust functionalities for processing vector and raster data available at (http://wgbis.ces.iisc.ernet.in/grass/). The training data (60%) collected has been used for classification, while the balance used for accuracy assessment to validate and build error matrix (also referred as confusion matrix), kappa (κ) statistics and overall (producer's and user's) accuracies [36].

2.2.2. Forest fragmentation

Fragmentation of natural forest was estimated through the computation of P_f and P_{ff} (in cardinal directions only) indices as given in Eqs. (1) and (2) [31,47,55]. P_f and P_{ff} were computed through a moving window of 5 × 5 pixels in order to maintain a fair representation of the proportion as given that the results of the model are scale dependent and threshold dependent [31,54,55]. Water bodies or river courses are considered non-fragmenting features, and constitute natural corridors in a forested landscape, while anthropogenic landscape elements (such as buildings, roads, agricultural field and barren land) are drivers of forest fragmentation.

$$P_f = \frac{\text{Proportion of number of forest pixels}}{\text{Total number of non–Water pixels in window}} \quad (1)$$

$$P_{ff} = \frac{\text{Proportion of number of forest pixel pairs}}{\text{Total number of adjacent pairs of at least one forest pixel}} \quad (2)$$

2.2.3. Modelling and visualization

Modelling and predicting future LULC changes was done using hybrid Fuzzy-Multicriteria Evaluation-Analytical Hierarchical Process-Markov Cellular Automata method (Fuzzy-MCE-AHP-MCA). Agents (such as road network, railway network, bus and railway stations, industrial areas, educational institutions, hospitals and other socio economic installations) contributing to LULC changes were delineated from the virtual earth databases (such as Google Earth, Bhuvan, open street maps and the Survey of India topographic maps). Fuzzy Logic was used to standardize criteria for agents of growth due to its capability to mimic human control [19]. Similar to Fuzzy, Boolean algebra has been used to standardize the constraints of growth. AHP MCE approach was implemented, which uses a pairwise comparison approach for decision making [26], wherein the factors were organized in a hierarchical structure [56]. The pairwise, comparison matrices were generated and their relative weights as Eigenvectors were estimated using AHP [2] to measure the degree of importance between criteria or factors i and j. 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}, as pairwise comparisons that follow a uniform probability distribution (Eq. 3).

$$a_{ij} = \frac{W_i}{W_j} * e_{ij} \quad (3)$$

W_i and W_j are the priority weights belongs to vector W and $\Sigma W_j = 1$, e_{ij} is inconsistency observed in the analysis.

The comparison matrix elements were compared pairwise to relate single element at the level directly and ranked by eigenvector of the matrix [70] and eigenvalue of λ_{max} is computed [68]. The consistency index CI was computed to evaluate consistency of the judgment matrix (Eq. (4)). Consistency ratio (CR) of 0.03 to 0.08 was obtained for each land use, based on Eq. (5), which is below 0.1 indicates the consistency of model [57]. Site Suitability [13] is one of the major aspects that need to be understood for identifying potential locations for development.

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

CI is the consistency index, λ_{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 a greater value of CI. The consistency ratio (CR) is calculated as shown in Eq. (5).

$$CR = \frac{CI}{RI} \quad (5)$$

RI is the average of the resulting consistency index depending on the order of the matrix. Transition probability matrix produced by Markov process and site suitability maps provided by Fuzzy-AHP-MCE were used as an input for CA to simulate and forecast LU changes. Validation was carried out through Kappa statistics by comparing the simulated land uses (map) as against the actual land uses. The model was calibrated by varying the input variables in order to achieve higher accuracy. The calibrated model was used to predict and visualize the land use change pattern for the year 2026. Land uses of 2001, 2010 and 2018 were re-classified under six categories namely forest, forest plantations, horticulture, agriculture, built up and water to predict future growth under two different scenarios.

- ***Scenario 1 (SC1):*** Business as usual scenario assumes that the existing growth patterns would continue (without any infrastructural interventions). The current protection measures will continue in the absence of large-scale developmental activities.
- ***Scenario 2 (SC2):*** Interventions with the infrastructural activities scenario considers the implementation of road expansions and constructing a new railway network to model future landscape in the region. This approach doesn't include sustainable developmental goals.

3. Results and discussion

3.1. Spatiotemporal land use changes in Kodagu

The Kodagu landscape was known for its diverse forests and waterscapes. The spatiotemporal land use analyses highlight the decline of forest cover due to a rampant uncontrolled expansion of coffee plantations, tourism and other driving factors. Fig. 3 and Table 1 depicts the decline of evergreen forest from 40.47 to 27.14% due to the expansion of coffee plantations and other LU across the district (with an overall classification accuracy of >85%). The interventions in terms of road, built-up areas and other changes have led to the loss of forest cover. Around 66,892 ha of pristine forest cover has been lost due to large scale LC changes with coffee plantations expansions (Fig. 3). The Kushalnagara and Madikere taluks have lost a major chunk of forests due to commercial activities (homestays, villas construction, etc.). Regularisation of forest land encrochments (small holdings < 40 ha as per Section 2 of forest conservation act 1980 or Scheduled Tribes and other forest dwellers act (forest rights act), 2006) for short term political gains have caused tremendous changes in the district's landscape. Coffee, rubber and other horticulture varieties cover 37% of the district. Forests or relic forest occur as remnant patches in protected areas. The vast area of forest patches, next to Bramhagiri WLS region is

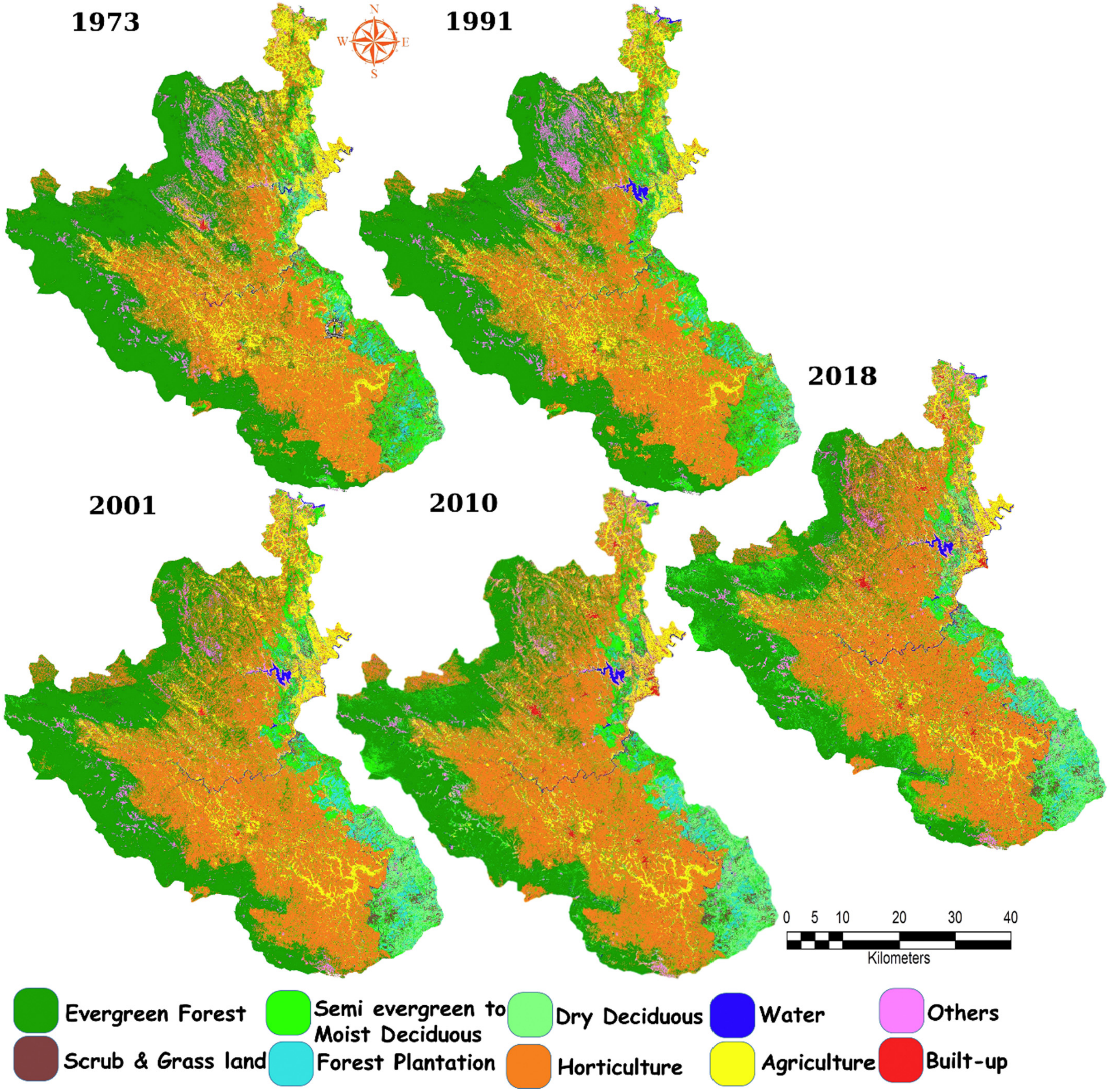

Fig. 3. Spatio temporal land use of Kodagu.

Table 1
Land use dynamics during 1973 to 2018 in Kodagu district.

Year/Category (%)	1973	1991	2001	2010	2018
Evergreen forest	**40.47**	38.23	31.46	26.61	**24.17**
Semi-evergreen to moist deciduous	6.27	8.62	7.32	10.03	10.25
Dry deciduous forest	2.48	1.77	5.02	5.47	5.88
Scrub/Grass land	2.14	2.15	2.75	2.82	3.70
Forest plantations	1.46	1.97	2.22	2.03	1.99
Coffee plantations	**30.83**	30.97	36.69	37.41	**37.08**
Agriculture	10.70	10.17	9.02	7.81	8.27
Built-up	**0.42**	0.63	0.38	1.66	**2.34**
Water	0.48	0.56	0.63	1.06	1.02
Open spaces	4.73	4.91	4.51	5.09	5.30
Overall accuracy	84.17	85.87	86.39	89.3	90.58
Kappa	0.81	83	82.97	0.88	0.89

transformed into the coffee plantation and agriculture. The ginger cultivation through a high amount of pesticides input in Kushalnagara, Virajpet taluk is posing an additional threat to chemical integrity of pristine water resources affecting hydrology and ecology in the region. Forest fragmentation analyses portray the status of forests and dynamics (Fig. 4). The region had 32% of forest cover under interior or intact forests in 1973, whereas in 2018, it covers only 19% under various protected areas. The health of forests is disturbed with the irreversible land use changes during the past four decades. The increase in patches and edge forest types will only highlight the increase in the unregulated anthropogenic activities. The weed infestation in large areas of Kushalnagar and Nagarholé portions of Virajpet taluks emphasizes the absence of effective forest management strategies.

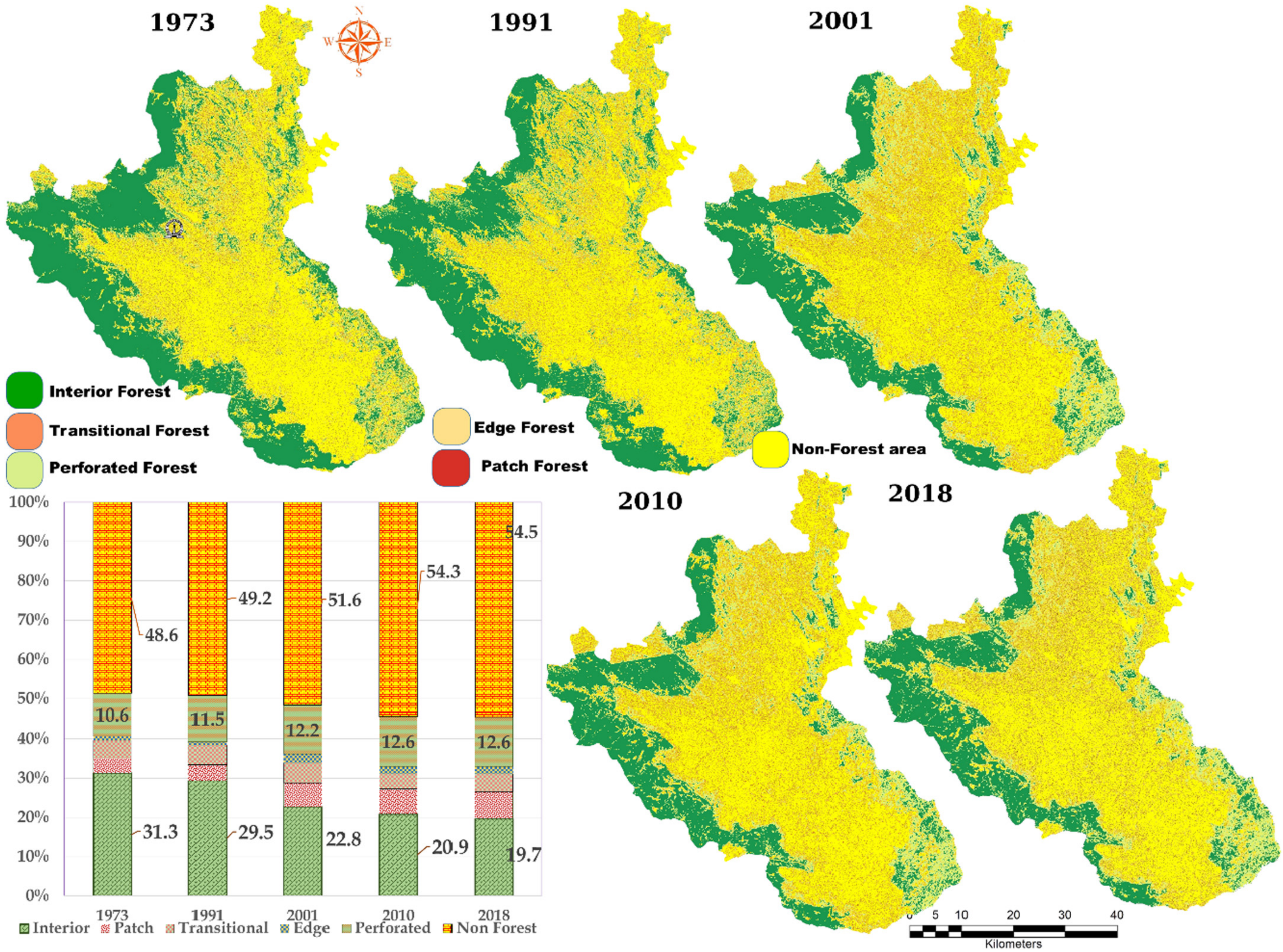

Fig. 4. Fragmentation of Kodagu forest (1973–2018).

3.2. Spatial distribution of biodiversity

Kodagu district is endowed with the diverse forest cover types as well as rich biodiversity habitats. A detailed account of the biodiversity considering flora (trees, shrubs, herbs) and fauna (amphibians, birds, reptiles, fish, butterfly, mammals) has been developed through the review of published literature and field data analysis. The current endeavor has documented 925 flora species and 3990 fauna species (Fig. 5a). The flora of the district includes 436 tree species under 92 families. There are 68 species that are endemic to the Western Ghats and 56 species are confined to Southern Western Ghats. The prime endemic species include *Actinodaphne malabarica, Blachia umbellate, Casearia wynadensis, Cinnamomum travancoricum, Diospyros ghatensis, Ficus beddomei, Garcinia gummi-gutta, Holigarna ferruginea, Homalium travancoricum, Hopea parviflora, Knema attenuate, Myristica dactyloides, Pinanga dicksonii, Semecarpus anacardium, Syzygium laetum, Syzygium mundagam* and *Vateria indica,* etc. Fig. 5b shows the conservation status of the species based on IUCN categories. There are 16 species Critically Endangered, 18 species are Endangered, 37 are Vulnerable, 13 are Near Threatened, 66 Least Concern, 13 are Data Deficient and 762 shows Not Evaluated status. The many biotic species possess anti-microbial properties, medicinal and economic values across the world. The region supports faunal diversity, which also supports the regional economy through tourism. The region has 800 faunal species under 170 families as shown in Fig. 5c. The district has 19 amphibian species, 464 birds, 101 reptiles, 129 fishes, 79 mammals and 8 butterfly species. The IUCN conservation status (Fig. 5d) shows 2 Extinct species, 13 Critically Endangered, 37 Endangered, 45 Vulnerable, 75 Threatened, 14 Data Deficient, 560 Least Concern and 51 species are in the Not Evaluated category. The region is home for many critically endangered species such as *Ardeotis nigriceps, Barbodes bovanicus, Hypselobarbus pulchellus, Ompok malabaricus, Petinomys fuscocapillus, Barbodes wynaadensis, Indirana gundia, Viverria civettina, Sarcogyps calvus, Gyps bengalensis and Gyps indicus*. The current study reports of 90 species in the district that are endemic to the Western Ghats region.

3.3. Modelling of LU changes under various scenarios

Existing and Predicted land use dynamics of Kodagu are presented in Fig. 6 and LU details are listed in Table 2. Between 2010 and 2018 Kodagu has lost about 3% of the forest area i.e., from 53 to 50%, due to the escalation in the monoculture activities such as forest plantations, horticulture and agriculture. Built-up areas are concentrated in and around the major cities such as Madikeri, Somvarpet, Kushalnagar, Siddapur, Virajpet, Ponnampet, Gonikoppa and in small towns of Ammatti, Shanivarasante. Land use modelling for the year 2026 considering the current growth patterns of 2010 to 2018 (SC 1) shows that the forest cover would further degrade to 45.18%, mainly in the regions of

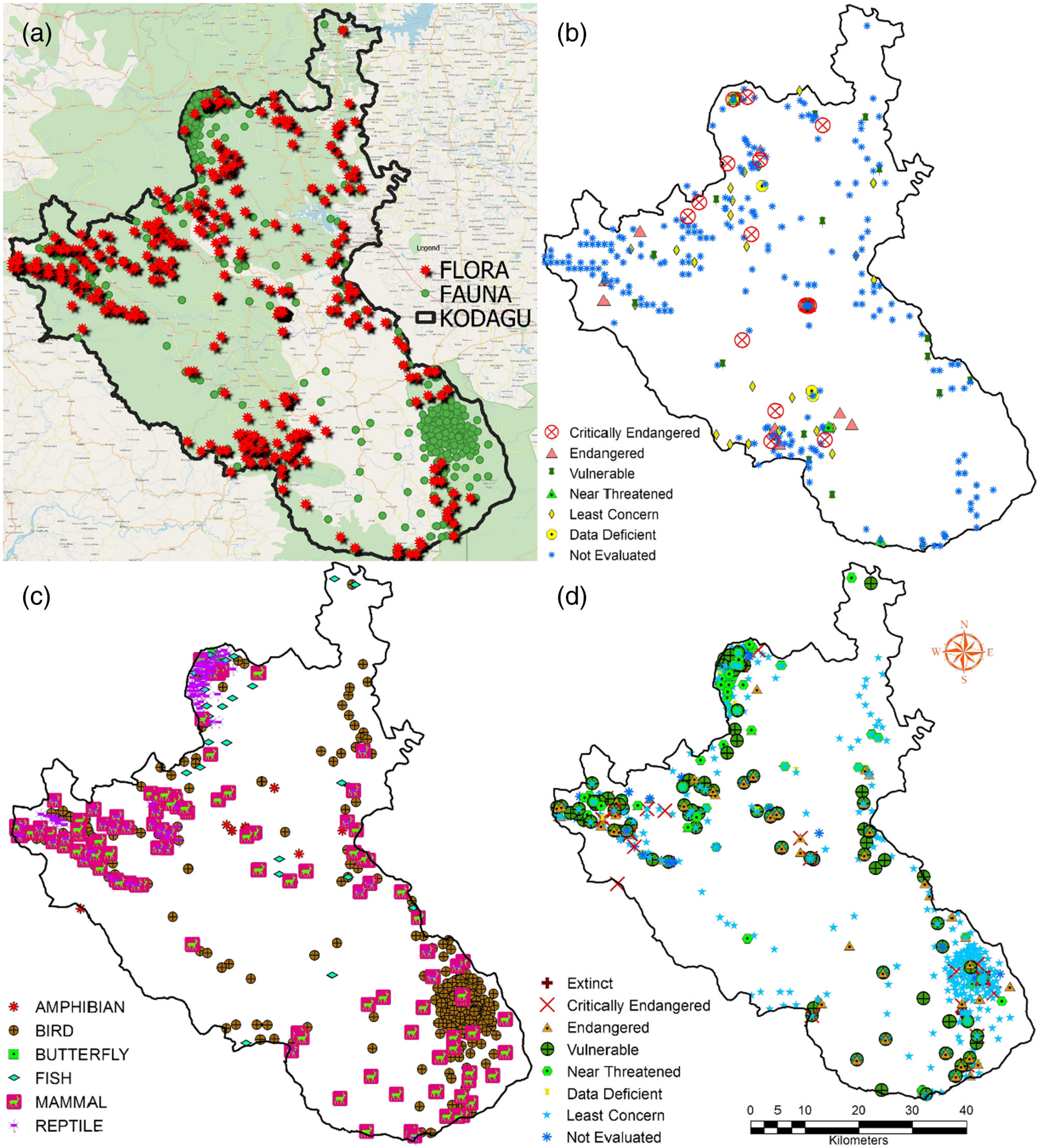

Fig. 5. Biodiversity of Kodagu district and IUCN conservation status.

Bhagamandala, Titimatti, Makutta and closer to major city centers wherein forests are converted to horticulture, forest plantation (i.e., horticulture would increase to 38.63%.) and agricultural activities (to 10.31%) mostly towards the transition zones and plain region of Kushalnagara and north, Bhagamandala, Virajpet, Gonikoppa, Ponnampet and surroundings (Fig. 6, Table 2). The forest landscapes other than the protected areas (either by forest department or at local levels in the form of sacred groves) would retreat to cater the growing human needs, reducing the area under forests to 42.63% with an increase in agriculture of 11.4% and built-up areas to 4.13% with the urban sprawl - leapfrog, ingrowth, edge growth, ribbon development. The concentration of urban areas would be more at Madikeri, Virajpet, Gonikoppa, Ponnampet, Somvarpet, Kushlnagara, Shanivarasante, and many smaller urban pockets without proper infrastructure and basic amenities.

The forest fragmentation analyses depict disturbing divergent pictures for SC1 and SC2. The interior cover is likely to decline in both scenarios. The SC1 depicts a loss of interior cover from 20 (2018) to 17.5% with an increase in non-forest and perforated patches. SC2 shows the loss of interior forest cover (by about 5%) as compared to 2018. The

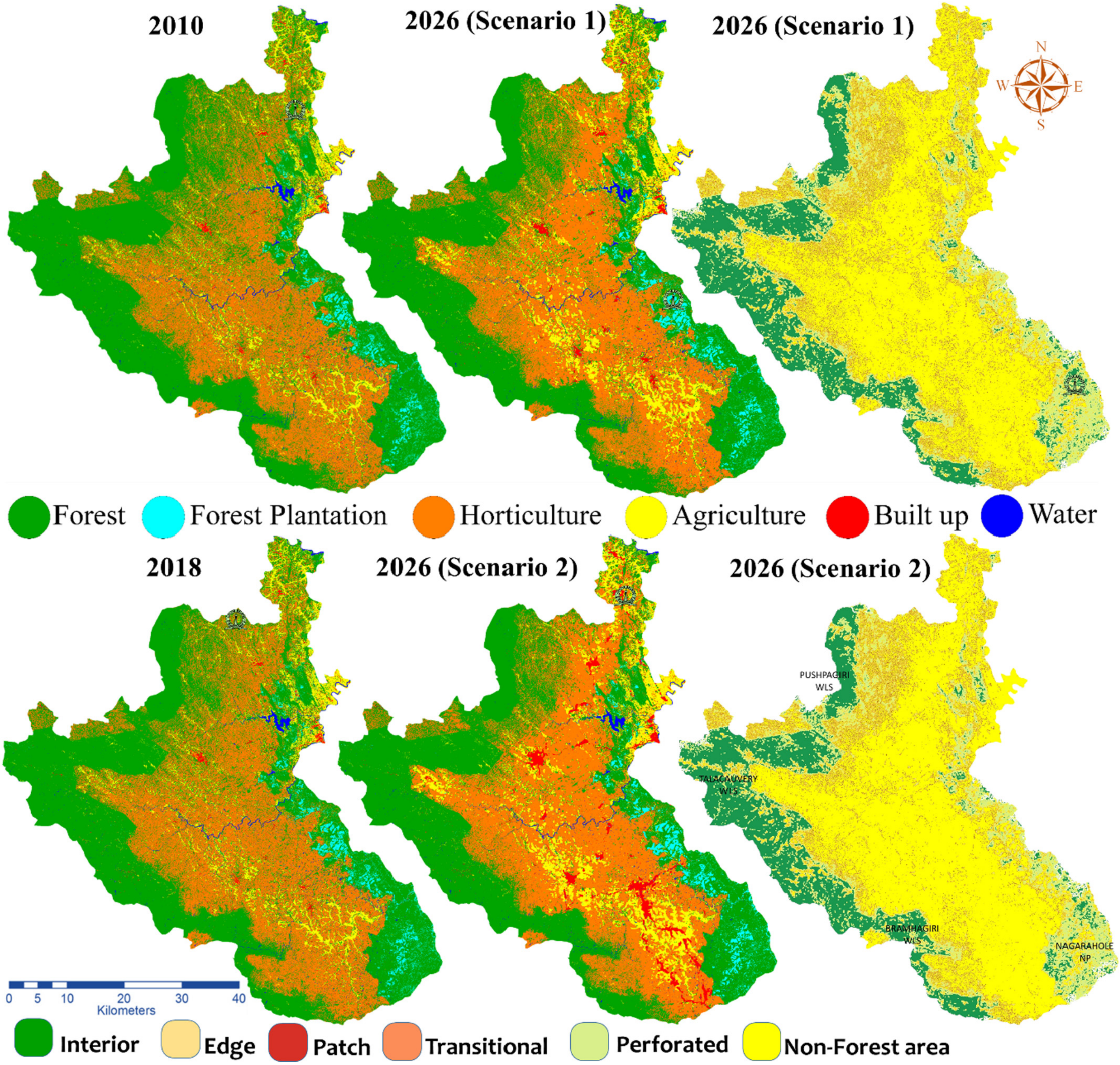

Fig. 6. Simulated, likely land use changes and likely fragmentation in Kodagu.

interior forest cover will confine to all protected areas as shown in Fig. 6. The likely loss of forest cover would be 8194.04 ha with the implementation of road expansion projects and new railway line in the district. This will aggravate existing human-animal conflicts and threatens water security with alterations in the hydrologic regime. The district is already facing acute crisis of human-elephant conflicts due to forest fragmentations with encroachments in the elephant movement path and also habitat degradation. The high instances of elephants riding

Table 2
Simulated and likely LU and fragmentation statistics of Kodagu.

LU (%)	Simulated 2010	Simulated 2018	2026_SC1	2026_SC2	Type	2026_SC1	2026_SC2
Forest	**53.17**	50.28	**45.18**	**42.63**	Interior	**17.52**	**16.53**
Forest plantation	1.84	1.99	2.25	2.31	Patch	4.52	3.58
Horticulture	**35.29**	36.59	**38.63**	**38.51**	Transitional	3.81	3.64
Agriculture	7.02	7.78	10.31	11.39	Edge	2.48	2.57
Built up	1.66	2.34	2.61	4.13	Perforated	13.00	13.00
Water	1.02	1.02	1.02	1.02	Non forest	58.68	60.67

coffee plantations have been reported during the recent decade [1]. The implementation of road expansions and railway project in the ecologically fragile regions would only result in further fragmentations of habitats and escalation in human–animal conflicts with the decline of fodder and water.

4. Discussion

Spatial analyses of landscape dynamics with the proposed linear projects (road expansions and railway projects) reveal of large scale land use changes in the district, posing serious challenges to the forest ecosystem, biodiversity and hydrology. The biophysical, socioeconomic factors and terrain conditions will witness transitions with the LULC changes. Road expansions will have long term consequences for the society as well as to the fragile ecosystems sustaining biodiversity and hydrologic regime. The ecological implications of road expansion projects are loss of habitat, fragmentation of forests, the barriers to animal dispersal and gene flow, alteration in the habitat structure, increase in greenhouse gas (GHG) footprint, loss of water retention capability of the catchment, occurrence of flash floods, enhanced accidental mortalities, etc. These effects are incremental and cumulative, which may vary across biomes, habitats and scales, and eventually would threaten biodiversity richness and species composition [12]. Planning and impact assessment processes as an integral part of the developmental activities must account all costs, benefits, social and environmental impacts to ensure that the future endeavors are socially acceptable and environmentally sustainable. Unplanned large scale LU alterations will have consequences of excess overland flow generated along impermeable and non-vegetated road surfaces, interception of overland or subsurface flows from upslope areas, altered stream flows and initiating new channel formation [15,27]. The implementation of the road expansion and rail network without carrying capacity assessment of ecologically fragile regions would enhance the environmental consequences threatening the sustainability of natural resources as well as social security. The implications of irrational land use changes would be (i) alterations in hydrologic regime with the catchment losing the ability to retain the water, (ii) instances of floods and droughts (as happened recently – during the second week of August 2018), (iii) landslides and mudslides leading to the loss of life and property, (iv) conversion of perennial streams to seasonal streams with the water scarcity during non-monsoon seasons, (v) loss of people's livelihood due to the lowered crop (agriculture and horticulture) productivity with the water scarcity and also decline of pollinators, (vi) enhanced instances of human-animal conflicts, (vii) water deficit in the major rivers leading to intra and interstate social conflicts, etc. Road construction by altering streams have shown dramatically reduce riparian and streams habitat complexity and function, and to impact the biodiversity and community composition of fish and benthic macro invertebrate communities across the world [59]. This emphasizes the need for restraint on the part of decision makers to ensure minimal land use changes in the ecologically fragile region and inevitable changes are accompanied with the appropriate location specific environmental mitigation measures for ensuring the sustenance of livelihood and biodiversity. The detailed recommendations are provided in Appendix 1. The changes in Kodagu landscape leading to the decline of native forests in the catchment of important rivers will have serious implications on water availability for three states namely Karnataka, Tamilnadu and Kerala. The cascading effect of implementation of projects would be the escalation of interstate conflicts, loss of biodiversity and alterations in the hydrologic regime threatening the water and food security with erosion in the sustainability of natural resources.

5. Conclusion

Insights of landscape dynamics through temporal LU analyses would help in evolving appropriate management strategies to ensure the conservation of biodiversity and sustenance of natural resources. Kodagu is the hottest hotspot of biodiversity in the Western Ghats with rich biodiversity (925 flora species and 3990 fauna species). The modelling and visualization of likely changes has provided the crucial information of environmental, economic, and social drivers responsible for change in Kodagu. The temporal LU analyses highlight the loss of evergreen forest cover from 40 (1973) to 24% (2018) with the increase in other LU. The reduction of contiguous or intact/interior forest cover from 31 to 19% (2018) highlight the seriousness of the prevailing LU transitions. The native forests are being replaced with the monoculture plantations (of exotic species) are responsible for micro-climate alterations threatening the sustenance of horticulture crops. The emissions due to deforestation and loss of carbon sequestration potential of the landscape will enhance global warming with the consequences of changes in the climate. The scenario based analyses highlight the likely loss of forest cover from 53 to 42% (2010–2026) with the implementation of the proposed linear projects, whereas, business as usual scenario shows forest cover of 45% (2026). Mushrooming of built-up would be intense in towns (Madikeri, Virajpet, Gonikoppa, Ponnampet, Somvarpet, Kushlnagara, Shanivarasante) with urban sprawl in the *peri* urban regions (of the current towns) and these regions would be devoid of proper infrastructure and basic amenities. Further interventions will worsen the ecology and hydrology as well as livelihood with the increase in the instances of human induced calamities-landslides, mudslides, floods, droughts, etc. This necessitates the intervention form policymakers and managers to frame strategies to arrest the degradation and enrichment of forest cover of native species. The study recommends engaging local stakeholders, village level forest committees VFCs (Village forest committee), and women self-help groups in forest protection activities. The creation of water bodies, growing fodder crops, restrictions on inappropriate crops and eviction of unauthorized occupation of forest lands are the initiatives recommended for the conservation of the region and improvement in the ecology.

Data and accessibility

Data used in the analyses are compiled from the field. Data is analysed 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/.

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Research ethics

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

Animal ethics

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

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.

Declaration of competing interest

We have no competing interests either financial or non-financial.

Appendix 1

All the proposed expansions are passing through sensitive habitats of wild life, passing through buffer or running parallel to the protected area boundary of Kodagu district (Tables A1 and A2). The implementation of such projects will aggravate existing human-wild life conflict. The coffee predation by elephants will accentuate due to fragmentation as well as loss of connectivity.

Table A1
Description of linear alignments.

S. no.	Alignment	Parameter	Description
1	Bantwala – Bangalore Road Expansion	Origin and destination	Bantwala (Dakshina Kannada District) to Bengaluru
		Route	Passes through Sampaje, Madikeri, Kushalnagar, Hebbale, Hassan, Channarayapattana, Kunigal, and reaches Bengaluru
		Distance covered in Kodagu	77 km
		Remarks	Passes through the evergreen forests, which is a sensitive habitat for endemic flora and fauna.
2	Halebeedu - Kutta	Origin and destination	Halebeedu (Chickmagaluru) to Kutta (Kodagu – Virajpet (T))
		Route	Passes through Hassan, Arakalgud, Piriyapattana, Gonikoppa, Kanoor and reaches Kutta
		Distance covered in Kodagu	54 km
		Remarks	Runs parallel to Nagaraholé NP
3	Channarayapattana -Madikeri	Origin and destination	Halebeedu (Chickmagaluru) to Kutta (Kodagu – Virajpet (T))
		Route	Passes through Holenarasipura, Arakalgudu, Shanivarasante, Somvarpet and then joins Madikeri
		Distance covered in Kodagu	64 km –for road expansion
		Remarks	The expansion will impact lot of coffee plantations and forest patches
4	Madikeri - Hosdurg	Origin and destination	Madikeri (Karnataka – Kodagu(D)) to Hosdurg (Kerala – Kasargord(D))
		Route	Passes through Bhagamandala, Panthur and join Hosdurg
		Distance covered in Kodagu	61 km
		Remarks	Passes through buffer of Talacauvery WLS and thick evergreen patches. It will aggravate fragmentation with in and surrounding WLS.
5	Madikeri - Tellicherry	Origin and destination	Madikeri (Karnataka – Kodagu (D)) to Tellicherry (Kerala – Kannur (D))
		Route	Passes through Virajpet, Makutta, Vilamana, Mattannur (Airport close to this place), and joins coastal city of Tellicherry.
		Distance covered in Kodagu	58 km
		Remarks	Touches the boundary of Bramhagiri WLS and passes through buffer of WLS before entering Kerala.
6	Mysore - Tellicherry	Origin and destination	Mysore (Karnataka – Mysore (D)) to Tellicherry (Kerala – Kannur (D))
		Route	Passes through Hunsur, Thithimathi, Gonikoppa, Virajpet, Makutta, Vilamana, Mattannur (Airport close to this place), and joins coastal city of Tellicherry.
		Distance covered in Kodagu	56 km
		Remarks	Touches the boundary of Bramhagiri WLS as well as Nagaraholé NP and passes through sensitive evergreen and deciduous patches impacting wildlife.
7	Sakalsehpura - Tellicherry	Origin and destination	Sakaleshpura (Karnataka – Hassan (D)) to Tellicherry (Kerala – Kannur (D))
		Route	Passes via Kodalipete, Shanivarasante, Hebbale, Kudige, Kushalnagara, Siddapura, Ammatti, Virajpet, Makutta, Vilamana, Mattannur (Airport close to this place), and joins coastal city of Tellicherry.
		Distance covered in Kodagu	122.3 km
		Remarks	Passes through sensitive habitat of evergreen forest cover in the west and touches the boundary of Nagaraholé NP
8	Mysore - Tellicherry Railway line	Origin and destination	Mysore (Karnataka – Mysore (D)) Tellicherry (Kerala- Kannur (D))
		Route	Passes through Hunsur, Thithimathi, Balele, Kanoor, Kutta, Mananthavady an joins Tellicherry
		Distance covered in Kodagu	42 km
		Remarks	Passes through buffer region (touches the borders) of Nagaraholé National Park and might have serious impact on wildlife movement.

The region has rivers such as Cauvery (Harangi, Lakshmanathirtha, Taraka, Cauvery, Hemavathi, Kabini), Aralampuzha, Kuppanam, Payaswini, Valapattanam, Netravathi (Kumaradhara). These rivers are acting as a lifeline for Karnataka, Tamilnadu, Kerala states. The rivers support large biota as well as irrigating larger area. Table B shows catchment area of each river with in Kodagu district. The rivers Harangi, Lakshamanthirtha, Taraka, Cauvery, Hemavathy, Kabini are east flowing and joining Bay of Bengal. Aralampuza, Kuppanm, Kumaradhara, Payasawini, Valarpattanam are west flowing and joins Arabian Sea. With increase in connectivity, immense land use changes occur in the regions altering the topography of the terrain. Changes in land use and alterations in topography would alter the catchments hydrological properties such as the water holding capacity, drainage network, etc. which would cause recurring floods and drought conditions in the post monsoons. Road networks and railway networks, in order to be constructed would change the topography and diver the streams through construction of bunds, culverts, affecting the natural flow path, this would influence the downstream users (both human and other depended floral and faunal diversity). Fig. A1 shows the catchment with the river and stream network likely to be affected with the proposed linear projects.

Table A2
Details of rivers of Kodagu.

Watershed	Basin	Area (hectare)
Aralampuza	Aralampuza	3418
Harangi	Cauvery	67,260
Lakshamanthirtha	Cauvery	68,179
Taraka	Cauvery	14,910
Upper Cauvery	Cauvery	106,827
Upper Hemavathy	Cauvery	19,048
Upper Kabini	Cauvery	1720
Kuppanm2	Kuppanm	20,434
Kuppanm1	Kuppanm	10,745
Kumaradhara	Netravathi	17,628
Payasawini	Payaswini	33,508
Valarpattanam	Valarpattanam	46,264
Total area		409,941

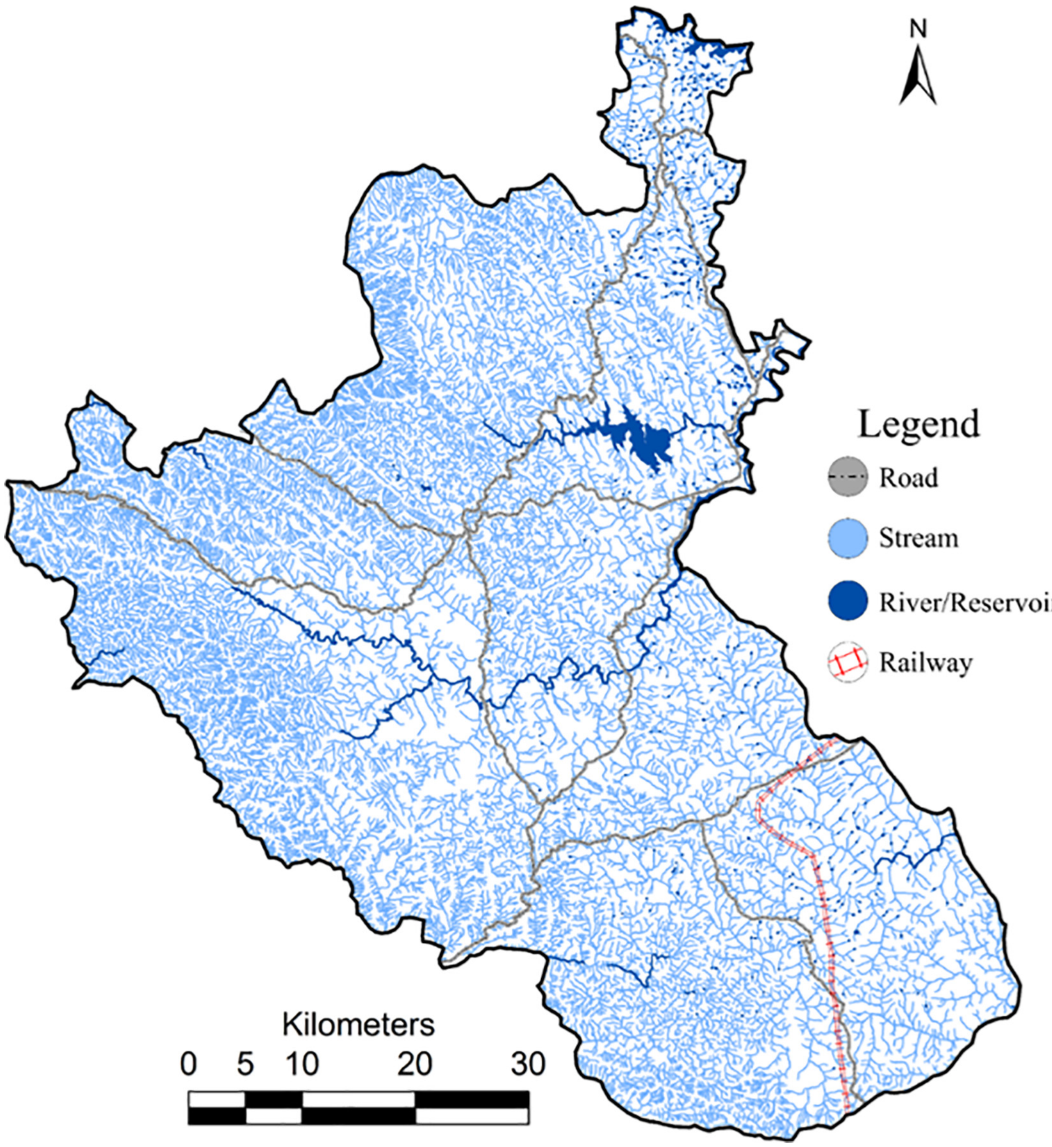

Fig. A1. Drainage network and proposed alignments.

Recommendations

Kodagu forests sustain water and forms lifeline for Karnataka, Tamilnadu, Kerala states. Drastic land use changes will threaten the water security and people's livelihood. The region is part of the central Western Ghats with the exceptional biodiversity. The expansion or new construction of liner alignments would result in irreversible ecological degradation. The recent floods and landslides are certainly the warning to the decision makers of likely implications with the drastic changes in the land cover eroding the native forest ecosystems. Further interventions will worsen the ecology and hydrology as well as livelihood with the increase in the instances of human induced calamities – landslides, mudslides, floods, droughts, etc. Hence following some are the recommendations for conservation and management of these forests.

- Linear projects such as major roads, railway lines shouldn't be allowed, even if they are essential from the perspective of highly influential section of the society. The region is intrinsically fragile with steep slopes and sharp gradients; small disturbances will lead to catastrophe. Deforestation need to be arrested immediately through strict regulation and social audit.
- Forest Rights Act to be implemented scientifically (using spatio-temporal data) in its true spirit and reaching out to people.
- Tourism is creating ecological and environmental disaster in Kodagu, so strict regulations are required to regulate tourism activities as well as the number of tourists per season. Tourism Master Plan should be based on MoEFCC (the Ministry of Environment, Forests and Climate Change, Government of India) regulations (after taking into account social and environmental costs). Strict ban on plastics as well as solid waste dumping in forest areas and ecological fragile riverine ecosystems should be imposed with higher fines.
- Unscientific land use changes should not be allowed as the region is prone to landslides with incessant rain. The government needs to impose strict regulations on construction of resort, villas, etc.
- The physical and chemical integrity of water bodies to be ensured through the implementation of stringent regulatory norms. River diversion (currently clandestinely pushed by the lobby under the guise of drinking water projects) should not be allowed in the district. All river diversions projects pushed (with the sole motive to exploit forest resources

indiscriminately) as drinking water scheme to subvert the environmental norms and also to misguide judiciary. Lake or stream alterations should not be allowed.

- Large, medium and micro scale hydroelectric projects should not be allowed.
- The quarries (existing even in steep slopes) and uncontrolled illegal sand mining are to be regulated for protecting streams, natural resources in the district.
- The district administration should restrict the unauthorized occupation of forest areas by the illegal immigrants as well as commercial farming (ginger cultivation).
- The ban on ginger cultivation need to be imposed as commercial farming of ginger with replacement of coffee plantations are noticed in recent time. The land becomes infertile for at least 2–3 years after growing ginger, requires chemical treatment to get back faming land.
- Rubber plantation is another major driving force distressing this unique biodiversity rich landscape. The unethical plantations in the heart of evergreen forest cover would enhance human animal conflicts.
- Monoculture plantations are not allowed, existing exotics should be replaced by planting endemic species both in evergreen and deciduous forest. Teak monoculture planting in Nagarholé has to be stopped by promoting native species planting.
- Due to scarcity of food and fodder trees and plants, wild animals including elephants more often end up spending more time in coffee plantations and croplands escalating human-animal conflict and loss of crops. Hence, more and more prominence has to be given for planting fruiting trees and fodder plants used by wild animals for their food and fodder requirements instead of non-food trees.
- The large degraded deciduous forest patches have to be compartmentalized block wise and planting with native species, protected from grazing by both cattle and wild animals by laying proper trenches or fences. Heavy collection of firewood, poles and illegal logging has to be immediately curbed.
- Many fragments of forests and sacred groves etc., has to be linked for establishing animal corridors and linked to many larger tracts of forests and wild life areas for easy movement of wild animals and preventing them from entering human habitations and croplands.
- As large track of Kodagu district is under coffee plantations; prominence has to be given for promoting native trees as shade plants. More and more coffee plantations have lost earlier native trees and many coffee plantations are filled with exotic silver oak trees. These regions are devoid of regeneration of native species as well as diverse pollinators. Hence, the coffee planters have to be given special incentives for promoting native species in their lands.
- There should be effective village wise VFCs (Village forest committee) not only for safeguarding but also for promoting the quality of forests. Presently many of the sacred groves are in various stages of encroachment by coffee planters and other farmers or have been totally neglected with the forest being filled with weeds, thorns and exotic plants. Many have only namesake board as ‘Devarakadu’ with original sacred grove completely lost for other human land use.
- Village Forest Committees (VFCs) and co-operative societies need to be involved to regulate tourism activities and mitigating impacts. Women self-help groups, youth and tribes should be engaged for creating nurseries and afforestation programs. The schools, colleges and local people should be involved in forest enrichment with native species and awareness workshops.
- Many biodiversity rich areas such as *Myristica* swamps have to be studied, mapped and earmarked for conservation. Presently these areas have been lost in the sea of secondary forests and many have even been planted with teak plantations.
- The eviction of forest encroachments to be executed ignoring political and social pressures to bring back the balance in ecosystem.
- The government needs to take appropriate mitigation measures in the animal movement paths and PAs by (i) creating water bodies, (ii) growing fodder crops, (iii) restrictions on inappropriate crops and (iv) eviction of unauthorized occupation of forest lands.
- Proper training and awareness has to be given for the forest department personals such as watchers and guards to identify trees and plants for effecting conservation.
- Improved connectivity and reduced fragmentation will aid species conservation, so the connectivity between forest patches should be established by enriching native forest cover (biological corridors) that allow species to move, and genes to flow, from one patch to other.
- Enrich the grass lands, grassy patches by native grass varieties (e.g., *Cynodon dactylon, Oplismenus burmanii, Arundinella leptochloa, Panicum* auritum etc.) to improve herbivorous population.
- Regulated traffic movement in the night should be bring in to existence in order to lower the high instances of wildlife road kill.
- Promote decentralized electricity, use of renewable energy sources such as (solar, wind power). The local bio resource based industry should be promoted. All should be strictly regulated and be subject to social audit.
- Adapt development projects which will have a least environmental impact by involving local community members in the decision making and environmental monitoring. The uncontrolled development should be discouraged in and around of pristine lakes, primeval forest patches, perennial water bodies. The site-specific (clustered base) sustainable developments can be taken up at each panchayat, which least effects on the ecosystem.

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