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Prioritization of Ecologically Sensitive Regions at Disaggregated Levels in Dakshina Kannada District, Central Western Ghats

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Ecological sensitivity refers to the permanent and irreversible damage of existing biotic and abiotic components of an ecosystem with a considerable erosion in the functional aspects of progression and speciation with the alterations in the ecological integrity of a region. The comprehensive knowledge of the ecological fragility of a region will aid in evolving strategies of conservation. This entails understanding factors responsible for ecological sensitivity, including landscape dynamics, to visualize future transitions to mitigate the problems of haphazard and uncontrolled development approaches. Ecological sensitive regions at disaggregated levels were identified in Dakshina Kannada district, Karnataka State, India. The 33% (24 grids) of the area corresponding to 54 villages represents ESR 1, 20% (15 grids) of the area is demarcated as ESR 2 covering 81 villages, 28% (20 grids) of the area encompassing 145 villages shows ESR 3, and 19% area (14 grids) covering 100 villages ESR 4. Regions ESR 1 and ESR 2 indicate high ecological sensitiveness that needs to be protected with stringent conservation measures. ESR 3 denotes a zone of moderate conservation, with scope for structured developmental activities. ESR 4 represents a zone of the least diverse space, with the potential for developmental activities in accordance with the local requirements under stringent regulatory monitoring with vigilance.

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1. Introduction

Forest ecosystems cover 1.7 million ha globally and face major loss in the spatial extent with a reduction of 2% per annum from 2.5 million ha compared with 1990-2010 (FAO, 2010). Forests are the unique warehouses of carbon and aid in sequestering carbon from the atmosphere, which is crucial to mitigate global warming and fluctuations in the climate. Forest ecosystems provide diverse goods and services, including protection from natural hazards, regulation of ecological and hydrologic processes for the well-being of society (Pramova et al., 2012). The natural environment is complex, and anthropogenic influence has a profound impact and a long history. Establishing a uniform assessment system by considering relative factors that reflect distinct ecological characteristics is crucial (Chen et al., 2018).

Forest transitions encompass changes in stand structure, species composition, and interactions with disturbance and environment over various spatial and temporal scales. Landscape refers to an ecological space with a mosaic of heterogeneous elements, and structure (composition and configuration) determines ecosystem functions and resource availability. Alteration in the landscape structure with fragmentation would lead to habitat loss and biodiversity decline. Either natural or humans by induced drive landscape dynamics with changes occurring in the physical space. Landscape dynamics operating along with a broad range of temporal and spatial scales change the stability, persistence, resistance, resilience, and recovery properties.

Understanding landscape dynamics is crucial for natural resources (land, food, fodder, water, etc.) management and conservation. Landscape dynamics are vital in ecological processes to sustain social, economic, and ecological health. However, unregulated developmental plans have altered the availability and quality of natural resources evident from the barren hilltops, conversion of perennial streams to the seasonal streams threatening water security, loss of topsoil threatening food security, etc. (Ramachandra et al., 2016a). Landscape dynamics are ascertained by analyzing land use land cover (LULC) changes using temporal remote sensing data.

The natural and physical cover of the landscape refers to land cover (LC), while land use (LU) indicates the anthropogenic alterations in land cover for numerous purposes (Ramachandra & Bharath, 2018). LULC changes lead to the landscape alterations either due to natural or anthropogenically induced over a period. Drivers of LULC changes are categorized into (i) proximate drivers, with alterations in landscape composition such as agriculture expansion, infrastructure, settlements, etc., and (ii) underlying driver influencing indirectly through a set of existing drivers such as population dynamics, agricultural policies, markets, etc., (Plieninger et al., 2016). LULC changes have a distinguishable impact on the landscape at a regional scale, inducing environmental complications such as biodiversity loss, alterations in the hydrologic regime, the release of greenhouse gases (GHG) with changes in the climate (Lambin et al., 2003; Hersperger et al., 2010; Vinay et al., 2013; Ramachandra et al., 2018a; Chen et al., 2020; Ramachandra et al., 2020).

Large-scale LULC changes lead to the fragmentation of forest ecosystems by breaking the contiguity of forests into fragments with modifications in the structure and composition of forests (Ramachandra et al., 2016b). Fragmentation has been a greater threat to the forest ecosystems (decline in contiguity and quality of the natural patch, enhanced isolation, a higher proportion of patches with more prominent edges). It affects forest habitats' natural resilience and connectivity, posing challenges for adapting to climate changes. The consequences of expanding non-forest LU are habitat degradation, reduced pollinators, hydrological alterations, higher soil erosion, increases in invasive plants, the dominance of sturdy pests and pathogens, etc. (Wilson et al., 2016). The increased exploitation of biological resources and landscape transformations leads to the degradation of the ecosystem. Escalation in the fragmentation of forests will result in loss of the forest biomass and carbon sequestration potential (Puhlick et al., 2017) and increase carbon emissions (Ramachandra & Bharath, 2021), necessitating a comprehensive understanding of the landscape structure for an optimal natural resource management. Understanding the ecological and hydrologic importance of intact ecosystems would provide insights into the conservation-based decision-making towards the sustenance of natural resources to meet the present as well as the future needs (Ramachandra et al., 2017a).

A comprehensive understanding of the functioning of social-ecological systems and their interactions is required to mitigate abrupt LULC changes in forest landscapes, which facilitates formulating effective policy strategies for viable natural resource usage and management. Geoinformatics with Geographical Information System (GIS) and accessibility of multi-resolution spatial data since the 1970s acquired through space-borne sensors (Remote Sensing (RS) data) have been useful in understanding LULC changes with drivers of changes. Availability of the multi-resolution (spectral, spatial, and temporal resolutions) remote sensing data have been useful in assessing the landscape dynamics aiding planners, land managers to efficiently evaluate landscape changes over micro and macro scales (Bharath et al., 2021; Lambin et al., 2003; Ramachandra et al., 2014; Wu et al., 2006). The quantification of LULC changes and visualization of likely changes has been carried out through various statistical approaches, such as linear, logistic regression models, multivariate analyses, empirical and non-statistical techniques across the globe (Bharath et al., 2014; Bieling et al., 2013; Egli et al., 2019; Hersperger et al., 2010; Hietel et al., 2007; Ramachandra et al., 2017b; Wheeler & Calder, 2007). The modeling and visualization of LULC in a region assists in identifying ecologically significant areas, which helps in framing policies and regulating activities toward prudent management of land resources through active participation of the stakeholders (Ramachandra et al., 2018b).

The ecological sensitivity or fragility refers to unique ecosystems with the predominant natural ecological interactions affected by anthropogenic activities due to mismanagement (Nilsson & Grelsson, 1995). A congregation of unique landscape elements or regions vital for the sustenance of biological diversity, soil, water, or other natural resources at the local and regional context is often referred to as Ecological Sensitive regions (ESRs) or Ecologically Fragile regions (EFRs). Mismanagement of ESR/EFR leads to water scarcity, recurring instances of floods and droughts, loss of crop productivity, the decline of goods and services with the loss of livelihood. This necessitates mapping ecologically sensitive or fragile regions (ESRs) at disaggregated levels by integrating bio-geo-climatic-hydrologic-ecologic parameters with the social aspects, which provides a comprehensive understanding and reliable data support for conservation (Ramachandra et al., 2018a).

EPA- Environmental Protection Act, 1986 (3rd and 5th Sections), MoEFCC, GoI prescribes measures to protect forests and prohibit or restrict the developmental activities (location of industries or carry out certain operations) based on the ecological sensitivity of a region. Subsequently, Pronab Sen Committee (2000), constituted by MoEFCC, GoI, identified parameters for designating ESRs to mitigate deterioration of ecosystems and the environment (MOEF, 2000). The identification process of ESR considers social and ecosystem processes to prioritize specific regions for conservation and framing allowable developments. The current study attempts to identify ecologically fragile regions at disaggregated levels in Dakshina Kannada district at the Western Coast, Karnataka, using temporal RS and collateral data (bio-geo-climatic hydrologic regime, ecological and social aspects).

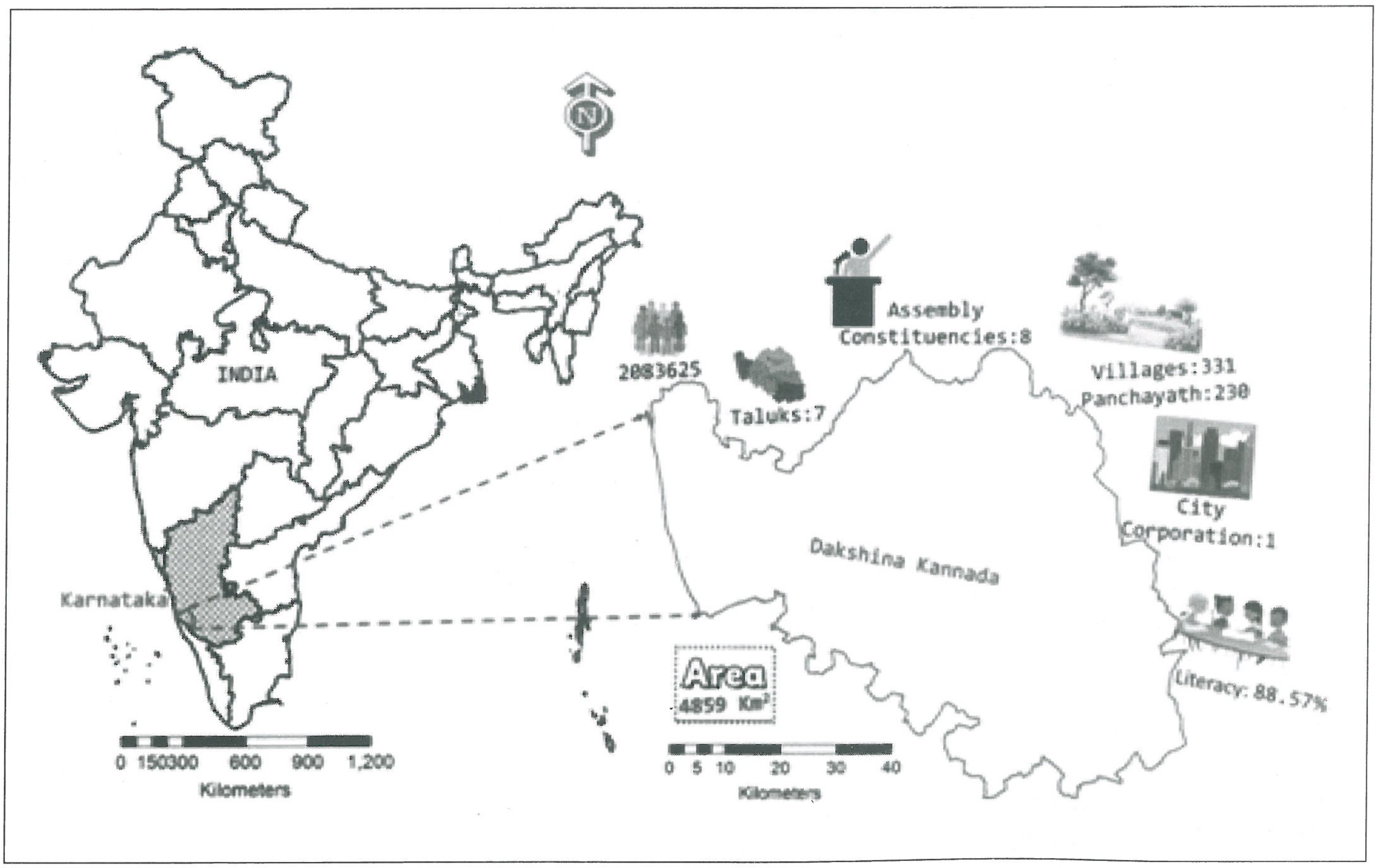
2. Materials and Method

2.1. Study Area

Dakshina Kannada, or South Canara district with a spatial extent of 4866 km^2, is located in the west coast of Karnataka state, India. The study region is bounded by the Arabian Sea in the west and the biodiverse rich Western Ghats in the East, Udupi district in the north, and Kerala state in the south (Figure 1). Mangaluru city is the district capital, which is an economic and educational hub. The Dharmasthala, Kukke Subramanya, Mangalore, Moodabidri (Jain Kashi), Kateel, and Ullal are major pilgrimage centres in the district famous for their beaches. Rituals such as Bhuta kola, Kambala, Cockfight are performed. Yakshagana is popular folk art. Hulivesha and Karadivesha are performed during Dasara. Traditional Hindu festivals like Deepavali, Yugadi, Ganesha Chaturthi, Navaratri are also celebrated. Climatic conditions are characterized by excessive humidity (78%).

There are four distinct seasons such as (i) four wet months of June-September with strong wind and high humidity; (ii) two damp and warm months of October and

Figure 1: Study area- Dakshina Kannada district, Karnataka State, India, with salient features



November; (iii) three cool months of December- February; (iv) three hot months of March-May. The district is drained by rivers such as Netravathi, Kumaradhara, Gurupura, Shambhavi, Nandini, Suvarnanadi. The population in the year 2001 is 18,97,730 persons, whereas it has increased to 20,89,649 (2011). Population density across the taluks per sq. km. depicts Mangalore taluk with a high density (Figure A1) as compared to Puttur (least density).

The district contributes ₹142.9 billion to GDP and contributes 4.8% to state GSDP. The major food crops and horticulture crops are Paddy, Black gram, Green Gram, Sugarcane, Mango, Banana, Pineapple Areca nut, Coconut, Cashew, and Pepper. The region has 23 large to medium scale industries and 21986 Micro, small and medium enterprises supported by agriculture, banking, education, information technology (IT), petrochemicals, port activities, fisheries, food, and marine processing sectors.

Forest types in the district are tropical wet evergreen rain forests, semi-evergreen forests, shola forests, tropical moist and dry deciduous, dispersed scrub jungles, grasslands. The endemic trees are *Artocarpus hirsutus, Hopea parviflora, Myristica malabarica, Prioria pinnata, Syzygium travancoricum, Madhuca insignis, Vateria indica, Pandanus mangalorensis, Knema attenuata,* etc. The relic evergreen forest patches are endowed with the endangered Myristica swamps as habitat for Critically Endangered species *Gymnacranthera canarica* and *Syzygium travancoricum*. Myristica swamps are undergoing anthropogenic pressures with the expansion of horticulture, and expansion of roads, etc. Forests support local livelihood evident from the extraction of medicinal plants (herbs), non-timber forest products, etc.

2.2. Method

The protocol for identifying ecologically sensitive regions is outlined in Figure 2, which has been implemented by adopting the grid-based approach of the National Environmental Survey [NES] of MoEFCC, GoI. The work involved (i) evaluation of ecosystem extent (through LU changes) and condition (fragmentation of forests) using remote sensing data of 1973 to 2019, (ii) prediction of likely LU, and (iii) collating diverse information for prioritization of the ecologically sensitive regions at disaggregated levels in the district.

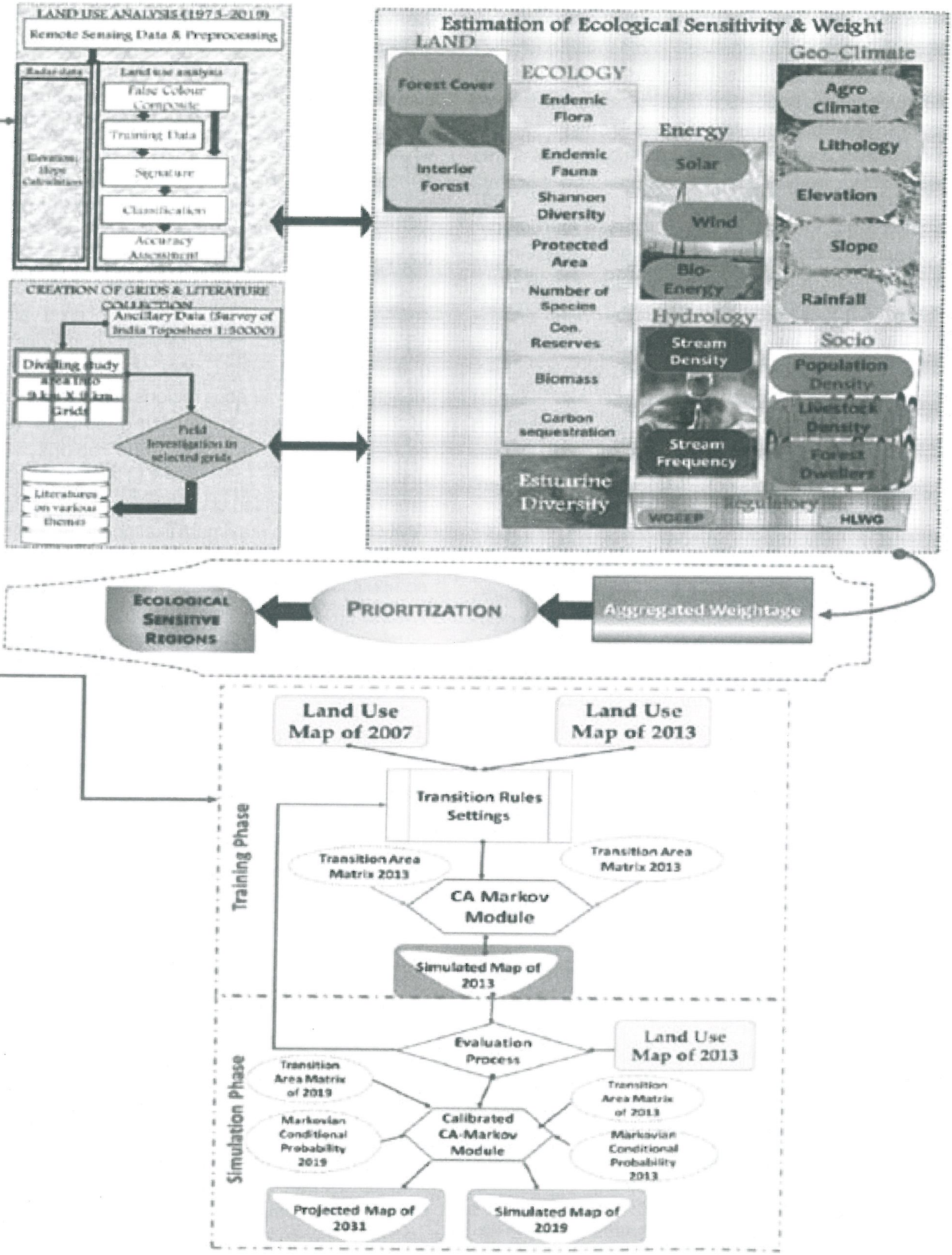
2.2.1. Quantifying Landscape Dynamics

The temporal RS data available in the public domain was downloaded from the Earth Observatory portal. Training data and GCP (ground control points) were compiled from the field across the representative ecosystems of the district through a pre-calibrated Global Positioning System (GPS) for geometric correction and supervised classification of RS data. This was supplemented with the collateral data collected from the secondary sources, which include vegetation maps of south India (Pascal, 1986), topographic maps of 1:50,000 (from the Survey of India-SOI), virtual portal for biodiversity, and earth information (Google Earth, Bhuvan). Data Preprocessing was implemented through geo-registration (geo-referencing or assigning coordinates with projection) and radiometric correction (calibration and correction of pixel values). The RS data classification for quantifying LU categories involved (i) the creation of False Color Composite, which aided in identifying heterogeneous regions in a scene, (ii) selection of training sites or digitizing sample polygons corresponding to heterogeneous regions, which are uniformly distributed and covers at least 15% of the study region, (iii) supervised classification of RS data based on GMLC (Gaussian maximum likelihood classifier) and (iv) accuracy assessment using training data through computation of kappa statistics and confusion matrix (error matrix). The field investigation, along with the help of virtual data portals such as Google Earth and Bhuvan, helped to collect attribute information of these sample polygons for classifying RS data (supervised classification approach).

GMLC is adopted for the classification under six different LU categories using GRASS GIS (Geographical Analysis Support System) and the technique is one of the best and most commonly used classification approaches, which accounts the training data (Bharath et al., 2013; Ramachandra et al., 2016a; Ramachandra et al., 2018d; Ramachandra et al., 2019). GRASS GIS provides functional support for vector and raster data processing. Training polygons with attribute information (60%) were used for classification, and the rest (40%) were used for validating classification through assessment of accuracies (overall, user and producer) and kappa (k) statistics (Lillesand et al., 2015). Forest information was extracted from LU, which is used for computing fragmentation metrics.

Fragmentation of forests is estimated through the standard protocol (Ramachandra et al., 2016a; Riitters et al., 2002) by computing metrics P_f (as per equation 1) and P_{ff} (equation 2) using spatial layers of forests (Kuèas et al., 2011; Ramachandra et al., 2016a; Riitters et al., 2002)

Figure 2: The method used for LU analyses and identification of ESR



through a moving kernel of 5×5 to maintain a fair representation of the proportion (P_f) of pixels (Kuèas et al., 2011; Riitters et al., 2000, 2002; Wickham et al., 2007).

Details of the spatial extent of forest fragmentation were mapped based on the indices P_f and P_{ff} with classification criteria as presented in Table B1.

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

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

2.2.2. Modeling and Visualization of Landscape Dynamics

Markovian Chain (MC) is a random process that integrates temporal LU data as an input to evaluate spatial dynamics. MC defines the site suitability across LU categories by estimating the state through accounting various influencing factors as a weighted linear sum, normalized at 0-1 range. Neighbourhood influence on each pixel, which results in a transitional potential map based on neighbourhood interactions across the LU categories, is evaluated. Transition rules were described by weighing each LU category's demands based on factors such as population growth, etc. The property of non-transition for urban, water classes have been included in the analysis, and the area of LU transformation is estimated considering two time period spatial LU data.

Transition probability matrices (spatial map and area quantity) were developed based on a probability distribution by accounting pixel's next state as per the current state without assessing its previous state (Equations 3 and 4). The likelihood of each pixel transitioning from one LU category to another from time 1 to 2 was reported by generating a transition probability matrix. The cross-tabulation method was employed by including two time period LU maps and adjusted by a proportional error and is interpreted into a collection of probability maps specific to each LU class, which reports the expected number of cells or pixels that would change over the next time period.

Two former LU maps provide the original transition probability matrix (denoted by E) of LU type.

$$E(N) = E(N) - 1) * E \quad (3)$$

where $E_{(N)}$ is the state probability at any time, and $E_{(N-1)}$ is the prior state probability.

The area of transition can be obtained by,

$$Z = [\ Z_{11}\ Z_{12}\ Z_{13} : : : Z_{N1}\ AZ_{N2}\ Z_{NN}\ ] \quad (4)$$

where Z is the transition area matrix; Z_{ij} is the sum of areas from the i[th] LU category to the j[th] category during the years from a start point to target simulation periods; n is the various LU types considered in the analysis. The transition area matrix be obliged to meet the subsequent requirement

i. $0 \leq E_{ij} \leq 1$

ii. $\sum_{i,j=0}^{n} E_{ij} = 1$

For example, the LU maps of Dakshina Kannada district for the years 1990, 2007, 2013, 2019 were given as input for the Markov process. The transition probability and area matrices have been generated to evaluate persistence and transition from one LU to another from time 1 to 2, i.e., 2001-2013; 2013-2019. The constraints such as protected areas, water bodies are exempted from the change.

2.2.3. Prioritization of Ecological Sensitive Regions (ESR)

The process of identifying ESRs involved 4 steps: (i) identifying the significant factors that elucidate the ecological/environmental status or resources (Liu et al., 2015; Zhang et al., 2011); (ii) assigning the weights based on the extent and condition and generating thematic spatial layers based on the environmental weights; (iii) generating aggregated weight by combining individual spatial layers (corresponding to bio-geo-climatic, hydrologic and ecological factors) by applying combination methods; (iv) prioritization of sensitivity of regions, based on the aggregate values (frequency distribution) into groups such as (a) highly sensitive and extremely sensitive, (b) moderately sensitive, (c) marginally sensitive and (d) not sensitive (Leman et al., 2016; Ramachandra et al., 2018a);

and (v) assessing the integrated map, identifying ESRs and suggesting specific recommendations for prudent management towards sustenance of natural resources in the region (Gadgil et al., 2011; Ramachandra et al., 2019).

The study area was divided into 9 × 9 km^2 or 5' × 5' (comparable to a grid size in 1: 50000 scale, the SOI topographic map) uniform area grids (73) to account for variabilities at disaggregated levels/micro-scale. The spatial information of various themes (bio, ego-climatic, ecological, etc.) was compiled based on literature, government documents, unpublished datasets, and ground-based surveys (in the select representative grids). A detailed database of various themes with maps covering bio-geo-climatic, ecological, hydrologic, and social aspects for the district is developed through a grid-based environment survey. The weightage metric score is computed for each grid capturing various themes (Equation 5). Developing a weight-based metric score necessitates integrating information from broad disciplines (Termorshuizen and Opdam, 2009), aids in regional planning by vigorously integrating the current and future landscape demands (Ramachandra et al., 2018d,e; Ramachandra et al., 2017b, c). The procedure adopted from the framework (Beinat, 1997) and enhanced to identify eco-sensitive regions considering chosen parameter's weights. It offers an objective and transparent scheme for uniting various data sets to imply significance. The aggregated weightage per grid is given by equation 5,

$$Weightage = \sum_{i=1}^{n} W_i V_i \quad (5)$$

where, n: variables, Vi: value of i^{th} variable, and Wi: weight assigned (normalized between 10 (high priority) to 1 (least)) based on the condition of i^{th} variable. Values 7, 5, and 3 indicate high, moderate, and low levels of conditions of considered variables for conservation. Weights of variables are aggregated for each grid and grid are grouped, according to the frequency distribution of aggregated scores into four categories as ESR 1-4 (ESR 1(aggregated scores > $\mu+2\sigma$), ESR 2 (for grids within $\mu+2\sigma$ and $\mu+\sigma$), ESR 3 (for grids with $\mu+\sigma$ and μ) and ESR 4 (grids with values < μ)). In particular, the weights are as per specific surrogate values, and the analyses are based on overlay and aggregation techniques in GIS. The final ESR information would guide the local biodiversity management committees (BMC) in the decision-making at disaggregated/ decentralized levels (panchayat levels) as per the goals of the Biodiversity Act, 2002, GoI for optimal management towards the conservation of ecologically fragile regions.

3. Results

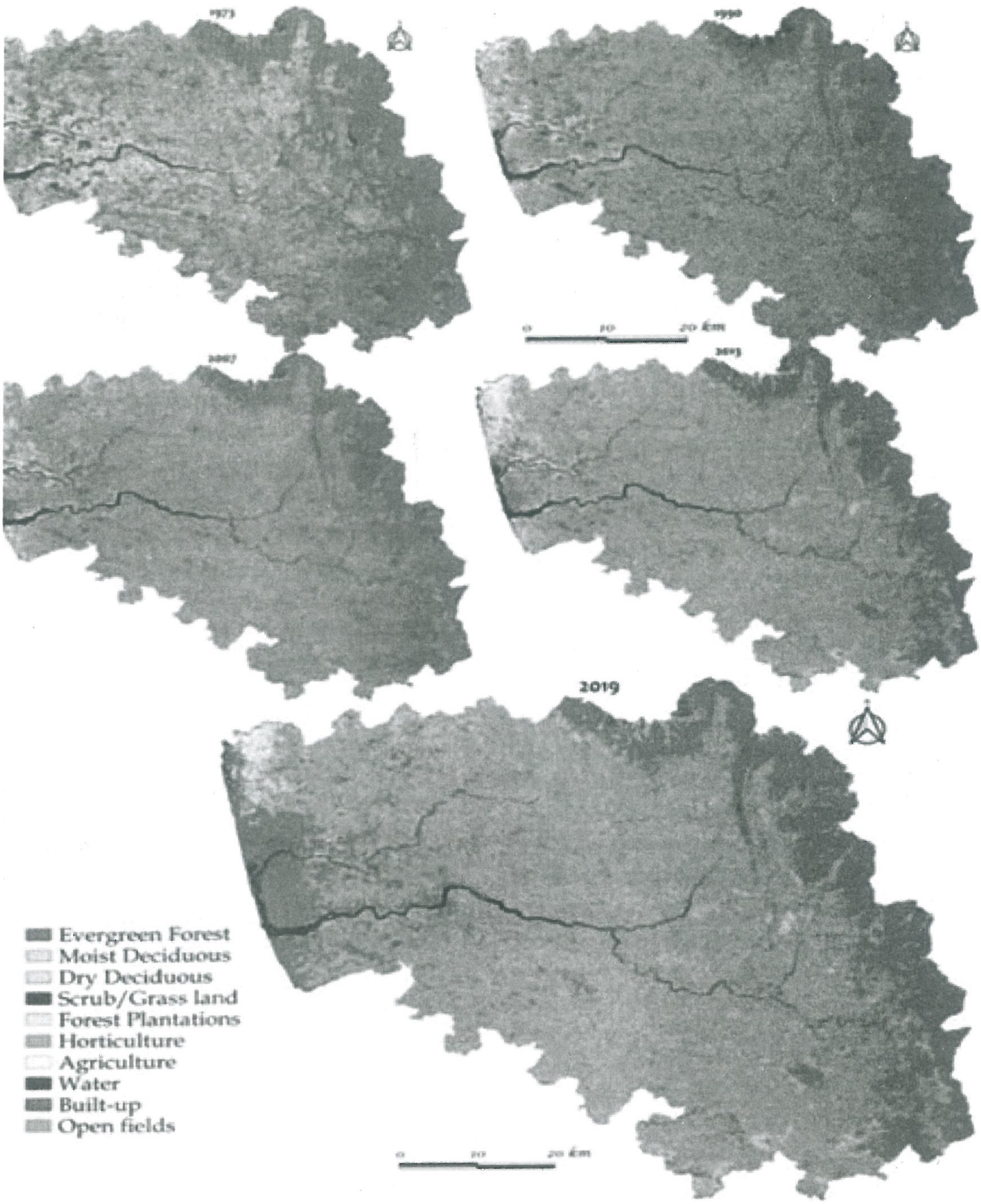
3.1. Assessment of Landscape Dynamics and Fragmentation Analyses

The spatiotemporal changes in the Dakshina Kannada landscape are assessed using temporal RS data through GMLC, during 1973-2019 to understand the anthropogenic pressure and the current status of forest cover. Figure 3 depicts the LU changes of Dakshina Kannada district, highlighting that the region has lost major evergreen forest cover with increased horticulture and built-up areas. Evergreen forest cover declined from 35.07% (1973) to 21.91% (2019), with an increase of horticulture from 32.3 to 51.14 %, and built-up from 0.49 to 5.95%. Mangalore has witnessed rapid urbanization to cater to the land demand of increasing population, resulting in peri-urban growth with more sprawl. The industrial activities in and around Mangalore metropolitan area, petrochemical processing industries, special economic zones (SEZ) in the peri-urban regions resulted in the loss of fertile paddy fields. Mangalore taluk has witnessed large-scale LU changes during the post-1990. The accuracy of the analysis is listed category-wise in Table B2.

The total loss of forest cover in the district over five decades is about 796 km^2, highlighting the largescale mismanagement of the forest ecosystem in the district. The declining forest extent and fragmentation have eroded carbon sequestration potential and increased emissions in the region due to the intense industrial activities (Ramachandra & Bharath, 2021). Figure A2 depicts the current forest cover of 1479 km^2 (2019) as against forest cover of 2276 km^2 in 1973, highlighting the forest decline.

Ecosystem condition is assessed through fragmentation of forests using temporal forest LU to understand the health of the forests. The district had 27% interior forest cover with the least edge and patch forest types in 1973 (Figure A3). The degradation of the forest ecosystem is evident with the decline of interior or contiguous forests with an increase in the patch, edge forest, and non-forest cover. The intact and undisturbed forests are now restricted to the mountainous portions of the district and protected areas such as Kudremukh national park, and Pushpagiri wildlife sanctuary. The non-forest cover increased from 52% to 68% during the past five decades. The loss of interior forest cover has altered the hydrologic regime and led to higher soil erosion, inducing landscape instability resulting in frequent landslides and higher instances of human-animal conflicts.

Figure 3: LU changes from 1973 to 2019



3.2. *Modeling and Visualization of Landscape Dynamics*

The LU analyses provided insights into the transition of forest cover from 1973 to 2019. Modeling of the landscape was been carried out to understand the impact of the current rate of LULC transitions in the near future with the help of Markov and Cellular Automata techniques. Transitions across LU types were computed to understand the level of transition from 2007 to 2013 and 2013 to 2019 (Table B3 and B4). LU transitions from 2007 to 2013 were been used for simulating LU of 2019, which was compared with the actual LU map of 2019 for validation. Kappa statistic was computed to verify the persistency of simulated LU classes with actual LU (2019). After validating the accuracy of simulation, projected LU for the year 2031 was been generated to understand the future state of forests and other LU classes (Table B5). LU transition of 2013 to 2019 has been accounted for projecting LU of 2031. The water bodies and protected areas were considered as constraints for LU changes. The projected LU shows evergreen forests are likely to remain 18.65%, whereas horticulture might reach 55%, followed by the built-up cover of 8% (Table B6). An increase in built-up cover was noticed in Mangalore and Karkala taluks due to the expansion of commercial establishments and their influence. Forests are now confined to high-altitude mountain ranges and protected areas. The abrupt LU changes would impact the hydrologic regime impairing food availability in the region (Figure 4).

3.3. Ecological Sensitive Regions of Dakshina Kannada

Prioritization of Ecological Sensitive regions (ESR) in the Dakshina Kannada region was been carried out using bio-geo climatic, hydrologic regime, ecological, environmental, and social variables at grid levels. The integration of diverse information of various themes helped in prioritizing regions for conservation and effective management. Table B7 provides the range of values theme-wise used to assign weights.

3.3.1. Land

The forest cover changes were assessed through temporal LU analyses. The LU of 2019 is considered for ESR prioritization. The forest cover analysis highlights that the eastern grids corresponding to the Western Ghats region have a decent forest cover (> 60%). The larger spatial extent of forests is in Pushpagiri hills' grids (Kumara Parvatha), Gundia basin, Kudremukha National Park (KNP) regions. The weights of forest cover (Figure A4a, b) depict a higher and moderate ranking in eastern grids. The grids consisting of intact forests, i.e., KNP, Gundia basin region, were assigned higher weights (Figure A4c, d).

3.3.2. Geoclimatic Regime

Variables such as elevation, slope, agro-climatic zones, and rainfall are considered for assessing ecological conditions based on geo-climatic aspects. Figure A5a presents the elevation profile indicating the Kudremukh region with the highest elevation. Undulating regions with poor vegetation cover are susceptible to landslides or mudslides with high-intensity rain under extreme weather conditions. The weight is assigned accordingly by considering elevation > 750 m as higher priority regions for preservation, and 500-750m is modest, and regions < 500 m are of least concern (Figure A5b). Figure A5c depicts slopes that aid in identifying the susceptible regions, and alteration of slopes would significantly affect the ecology. Grids with a slope > 15° are highly vulnerable, and alterations of topography would lead to instability with higher instances of landslides, soil erosion, secondary plant succession, and ultimately land abandonment. Figure A5d indicates weights based on slopes and degree of sensitivity. Geologically, gneiss rocks dominate the district. Lateritic rocks dominate Mangalore, Karkala, and Bantwala taluks. Charnokites and Dharwars are found in the transition zones in the taluks of Puttur and Beltangadi. Alluvial types are predominantly in the Coastal regions. Figure A6a depicts the lithological map; these bedrocks influence the subsurface and baseflow through infiltration. Figure A6b presents the assigned weights based on the porosity, considering infiltration capability.

The clayey soils are the predominant type across the district except in the Coast, which has gravel-sandy soils (Figure A6c). Parameters such as soil depth and texture were evaluated to account for the water-holding capability of the district. The district soils are very deep to moderate, and are responsible for good groundwater recharge. The Western Ghats region has deeper soils with clayey matter responsible for a greater water-holding capability in the forest and ensuring post-monsoons and summer flows in the streams. The weights are assigned based on the distinct characteristics of water infiltration and soil depth, as shown in Figure A6d. The district has distinct agroclimatic zones (Figure A7a) based on its climate, rainfall pattern, and soil groups, which also play a significant role in growing appropriate crops. Agro-climatic zones in the district are (i) West Coast Plain, Hot-Humid, and (ii) The Western Ghats, Hot Moist Sub Humid. Figure A7b indicates the weights assigned based on agroclimatic zones and higher values to grids of Sahyadri with a rich resource base.

The rainfall data from 1901 to 2020 compiled from the Directorate of Economics and Statistics, Government of Karnataka, was pre-processed to correct missing/erroneous rainfall records considering rainfall in neighboring rain gauge stations. The southwest monsoon (June to mid-October) contributes 87 %, pre-monsoon showers fetch 3 to 4 %, and northwest monsoon contributes 8 to 10% of the annual rainfall. The quantum of rainfall increases from the Coast towards the Western Ghats (west to the district's east boundary). The heaviest rainfall occurs during July.

The average rainfall in the district is 3,975 mm. The least is observed in Mangalore taluk with 3672 mm and highest in Beltangadi taluk with 4412 mm. Most parts of the district (Figure A7c) are in the high rainfall zone (> 3500 mm), except the northern parts of Mangalore, weights were assigned by considering the rainfall gradient (Figure A7d).

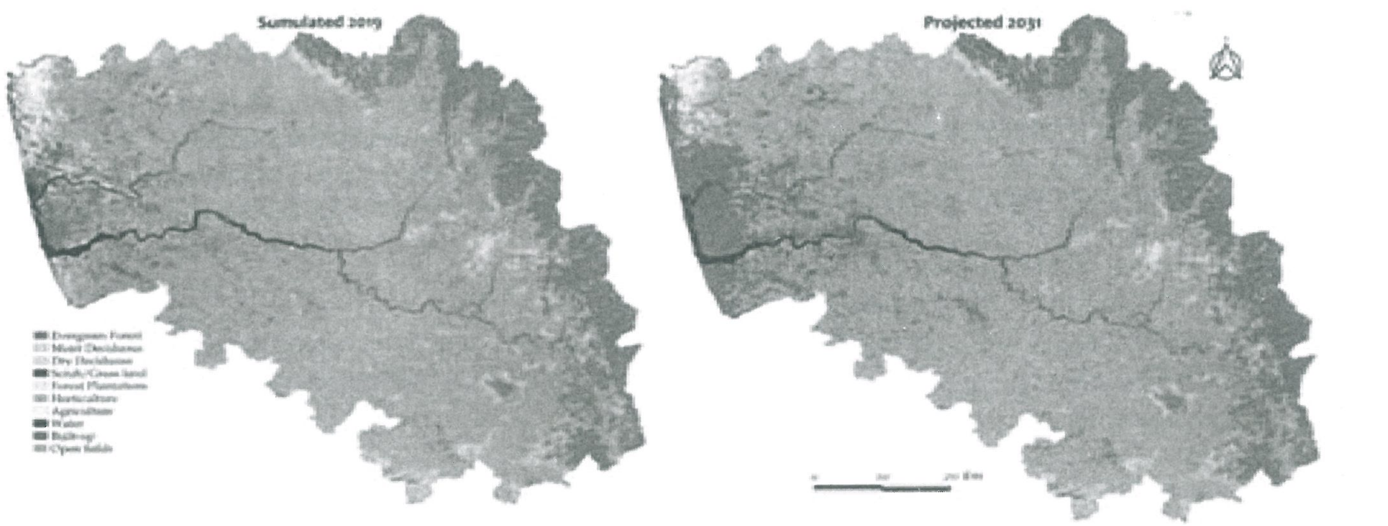
3.3.3. Hydrologic Regime

The hydrologic regime assessment aided in demarcating the regions based on the water flow (perennial and seasonal flows) in water bodies, and weights were assigned considering hydrologic variables such as stream density, and streamflow (duration of water flow and quantity). Stream density is characterized as the ratio of stream length and the stream area occupied in a grid. Figure A8a, b indicates higher drainage density in the Western Ghats, and lower density is in the Coast and plains. Grids in the Ghats indicated higher stream density due to Netravathi and Gurupura catchment areas, as against the coastal plains, and were assigned higher weights. The ghats with rich native forest cover have rich water retention capacity, which are responsible for perennial flows, compared to coastal and plain regions, and weights were assigned as per flow dynamics (Figure A8c, d).

3.3.4. Ecology

The district has diverse ecological features, and respective weights were assigned based on their diversity. The ecological diversity was been analyzed using variables such as endemic flora, fauna, protected areas, elephant movement path, biomass, carbon sequestration potential, etc. Details (biomass, etc.) were compiled from field-based measurements and supplemented with the literature review. The Sahyadri region of the district has an excellent biomass accumulation of > 1200 Gg (Giga Gram). The coastal region has the least biomass < 300 Gg. Grids were assigned weights based on forest biomass potential. The carbon sequestration by forests depicts that grids in the Sahyadri region have > 600 Gg carbon in the forests, and weights were assigned accordingly (Figure A9a-d). A detailed database of flora and fauna (with latitude, the longitude of various places, species name, family name, habitat, IUCN protection status, document source, uses, etc.) is developed and presented spatially of flora and fauna details with habitat. The flora database consists of 290 species of 80 families and the forest ecosystem consists of (i) critically endangered species such as *Elaeocarpus gaussenii, Pandanus mangalorensis, Santapaua madurensis, Syzygium travancoricum, Utleria salicifolia, Vateria indica,* and (ii) vulnerable species such as *Aglaia talbotii, Calamus nagbettai, Chloroxylon swietenia, Cinnamomum sulphuratum, Cleistanthus collinus, Cryptocarya beddomei, Dalbergia latifolia, Diospyros candolleana, Diospyros paniculata, Embelia tsjeriam-cotta, Erythroxylum obtusifolium, Garcinia indica, Glochidion johnstonei, Grewia salviflora, Griffithella hookeriana, Mitrephora grandiflora, Murdannia koenigii, Myristica malabarica, Ochreinauclea missionis, Santalum*

Figure 4: Simulated and projected LU for Dakshina Kannada district



album, Saraca asoca and endangered species such as Bulbophyllum neilgherrense, Cinnamomum wightii, Cynometra bourdillonii, Dimeria hohenackeri, Diospyros crumenata, Dipterocarpus indicus, Dysoxylum malabaricum, Glochidion tomentosum, Hopea parviflora, Hopea ponga, Kingiodendron pinnatum, Shorea roxburghii, Syzygium caryophyllatum.

The district consists of a rare, endemic, and endangered fauna of 664 species under 135 families. Major predators are *Panthera tigris* (tiger), *Melursus ursinus* (sloth bear), *Cuon alpinus* (Asiatic wild dog), and *Panthera pardus* (leopard), etc. Abundantly occurring prey animals are *Axis axis* (spotted deer), *Cervus unicolor* (sambar deer), *Muntiacus muntjak* (barking deer), Sus scrofa (wild boar), *Bos gaurus* (gaur). The region acts as a primary territory for sensitive species such as *Macaca silenus* (Lion-Tailed Macaque), *Ratufa indica* (Malabar giant squirrel), *Loris lydekkerianus* (Slender Loris), *Indotestudo travancoria* (Travancore Tortoise), varieties of vultures (*Gyps bengalensis, Gyps indicus, Sarcogyps calvus*), different kind hornbills (Indian Grey Hornbill, Malabar Pied Hornbill, Malabar Grey Hornbill, Great Indian Hornbill), different snake species such as *Ophiophagus Hannah* (The king cobra), *Naja naja* (cobra), *Craspedocephalus malabaricus* (Malabar Pit Viper), *Python molurus* (Indian Rock Python), sensitive frog species such as *Philautus amboli* (Amboli Bush Frog), *Hylarana aurantiaca* (Golden Backed Frog), *Indirana leithii* (Leiths Indian Frog), *Nyctibatrachus major* (Malabar Night Frog), attractive birds such as *Psittacula columboides* (Blue-winged Malabar parakeet), *Harpactes fasciatus* (Malabar Trogon), T*erpsiphone paradisi* (Indian paradise flycatcher), etc.

Figure A10a, b provides the spatial distribution of fauna species and corresponding weight. Shannon Diversity shows the grids of the southern portion have higher diversity, which is depicted in Figures A10c, d respectively. Figure A11a, b illustrates the distribution of endemic flora and respective weight across the district. Grids corresponding to KNP and Pushpagiri regions depict a higher number of species. Weights of 10 are assigned to grids (Figure A11c, d) with the endemic, critically endangered, threatened species, and least concern fauna category.

Figure A12a (Appendix 2) illustrates KNP, Pushpagiri Wildlife Sanctuary (PWLS) regions, which occupy large tracts of forests, protected under conservation tag. These protected areas identified as per wildlife act 1972, GoI for conservation, have been considered for ESR mapping. KNP has been aiding as a rich biodiversity reserve with several endangered and globally significant wildlife species like tigers (*Panthera tigris*), Malabar civet (*Viverra civettina*), Leopard (*Panthera pardus*), Wild dog (*Cuon alpinus*), Sloth bear (*Melurus ursinus*) Flying Lizard (*Draco dussumieri*), Flying Snake (*Chrysopelea ornata*), King Cobra (*Ophiophagus hannah*), Shield Tail Snakes (Uropeltidae spp.), Travancore Tortoise (*Indotestudo jorsteni*), Forest Cane Turtle (*Geoemyda silvatic*) and majority are endemic to the area. There are about 200 species of birds, 30 species of reptiles, 100 species of butterflies and moths, and 50 species of fish. The region comes under the Global Tiger Conservation Priority-I, as per Wildlife Conservation Society (WCS) and World Wide Fund-USA.

Pushpagiri Wildlife Sanctuary (PWLS) lies at the junction of the southern and northern ranges of Western Ghats and forms a part of the wildlife migration corridor to Wayanad Tiger Reserve (Kerala) via Nagarhole and Bandipur tiger reserves. In the north, 12 contiguous reserve forests act as vital corridors, connecting Kudremukh and two other tiger reserves in the state. Figure A12b depicts grids with higher weights covering protected areas.

The Bisle Reserve Forest forms a part of a vital elephant corridor - Mysore Elephant Reserve, which forms connectivity to the Western Ghats and the Eastern Ghats, covering many wildlife sanctuaries, National Parks, etc (Figure A12c, d).

3.3.5. Energy

Renewable energy resources such as solar, wind, and bioenergy have been analyzed to understand prospects in the district to minimize environmental hazards associated with fossil fuel-based energy systems. The district has solar insolation of > 6 kW/h and is suitable for harvesting solar energy at disaggregated levels. Figure A13a, b highlights the solar potential in the region. Wind velocity of 1.5 m/s wind flow across the district highlights the scope for hybrid renewable energy generation by integrating solar and wind options to meet the regional energy demand (Figure A13c, d). The district has rich bioresources availability, and Figure A13e, f highlights the significance of bioenergy in meeting the domestic (cooking and water heating) energy demand.

3.3.6. Social Aspects

The forest-dwelling communities being, directly and indirectly, being contingent on forest resources of the region have been considered for ESR prioritization. There are 32 tribal groups distributed across all taluks of the district (3.7% of the total), and major groups are Gowdlu, Koragas, Malekudiya, Jenukuruba, Marati Naiks, Kadukuruba, and Yeravas (Lalitha, 2015). The spatial distribution of these communities at villages was assessed, and a weight of 10 is assigned to those grids considering the role of communities in the conservation (Figure A14a, b). Figure A14c, d depicts the population density computed based on population census 2011 data and grids assigned weights of 1 (high density) and 10 for grids with low population density. Figure A14e, f depicts livestock density as per livestock Census 2012; the district has a livestock population of 0.43 million, including cattle, buffaloes, sheep, goats, pigs, rabbits, and dogs. The district has indigenous cattle breed Malnad Gidda with endurance, resistance to disease, and socio-cultural significance. The weight is assigned as per the density.

3.3.7. Estuarine Diversity

Estuarine ecosystems are a tiny ribbon of land, but the emissions from their destruction are nearly one-fifth of those attributed to deforestation of mangroves, etc., worldwide (Pendleton et al., 2012). The major mangrove species present are *Acanthus ilicifolius, Avicennia alba, A. officinalis, Kandelia candel, Porteresia coarctata, Rhizophora apiculata, R. mucronata, Sonneratia alba, S. caseolaris, Excoecaria agallocha, Bruguiera gymnorrhiza* (Reddy et al., 2015; Suma, 2013). The district has eight dominant true mangrove species belonging to six families: Avicenniacea, Rhizophoraceae, Lythraceae, Euphorbiaceae, Poaceae, and Acanthaceae of which six trees, one herb, and one grass category. The mangrove ecosystem needs suitable conservation considering the crucial ecosystem (carbon sequestration, mitigation of impacts due to cyclones or tsunami, etc.) services (Murugan & Anandhi, 2016). The annual provisioning services provided by Mulki – Pavanje estuary is 187 million Rs, Netravathi estuary is 425 million, Udyavara estuary is 186 million Rs, Sita estuary is 365 million Rs/ year, Chakra – Haladi - Kollur estuary is 572 million Rs, which highlights the ecological productivities in sustaining local livelihood and accordingly weights are assigned (Figures A15a, b).

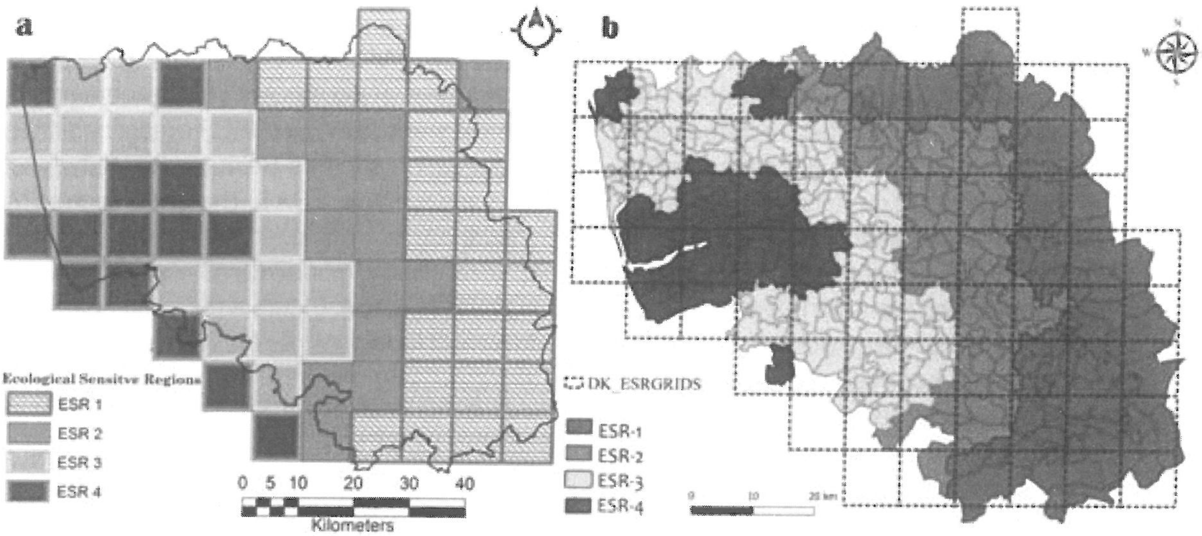
3.3.8. Regulatory Framework

Environmental Protection Act, 1986 (Sections 3 and 5), Government of India (GoI) prescribes graded measures based on ecological sensitivity to protect forests by regulating or permitting specific activities or operations. In this regard, The Ministry of Environment, Forests and Climate Change, GoI constituted Western Ghats Ecology Expert Panel (WGEEP), to formulate guidelines for prudent management of ecosystems by delineating ecologically sensitive areas (ESA). WGEEP prescribed three levels of categorization such as Belthangadi, Sulya, Karkala, as ESA 1 and Puttur as ESA 3. The taluks such as Mangalore, Bantwal are not assigned any status. Subsequently, a high-level working group (HLWG) was constituted to validate the WGEEP report. Figure A15c, d comparatively assess eco-sensitiveness as per the regulatory framework.

3.3.9. Ecological Sensitive Regions (ESR)

ESR are delineated at disaggregated levels through a qualitative and quantitative assessment of the relevant ecological, environmental, and social variables essential for sustaining natural resources to support people's livelihood. The weights are assigned to variables based on the ecosystem extent, condition, and relative strengths. The composite metric is computed by aggregating scores (of bio-geo-climatic, ecological, environmental, and social variables) per grid and assessed statistically (frequency distribution considering mean $\pm$ *i* standard deviation, where *i* ranges from 1 to 2) to group grids based on the composite metric into four groups (Figure 5a) to designate as ecologically sensitive regions (ESR-1, ESR-2, ESR-3, and ESR-4). The spatial analyses reveal that the district has 33% (24 grids) as ESR1, 20% (15 grids) as ESR 2, 28% (20 grids) as ESR 3, and the rest 19% (14 grids) as ESR 4. Figure 5b lists the ecologically sensitive region at village levels. ESR 1 represents the zone of highest conservation, where the stringent norms are to be implemented without allowing any degradation. Grids in ESR 1 are susceptible (or highly sensitive), requiring stringent protection through an inclusive approach involving VFCs (Village Forest committees), BMC (Biodiversity Management Committee at Panchayath). Grids in ESR 2 are higher conservation (with a potential to be in ESR1 with conservation). The regulated developmental activities are allowed in ESR 3, a moderate conservation region. Developmental activities may be allowed in ESR 4 as per the requirement of local people with strict vigilance. It is recommended that afforestation of degraded landscapes in ESR 3 with the native species would enhance the job opportunities for local youth. In ESR 2 and ESR 3 further developments are allowed only after critical review by the regulatory authorities in consultation with the local stakeholders.

Figure 5: Ecological Sensitive Regions of Dakshina Kannada



Small-scale tourism such as homestay (without any large-scale construction activities), spice farms, eco-friendly boating, etc., could be encouraged by adopting a benefit-sharing approach with local communities. The unregulated development, including infrastructure projects, needs to be restricted in and around water bodies (lentic and lotic) and natural forests. Cluster approaches in the development path at the panchayat level would aid in the optimal use of local resources, with the least effects on the ecosystem. The overlay of village boundaries on the eco-sensitive map depicts that ESR1 has 54 villages, ESR 2 has 81 villages, 145 in ESR 3, and 100 in ESR 4. Forest ecosystems in these villages need to be protected through a participatory approach involving local people in the maintenance and management that would help in arresting degradation. Table B8 lists a prudent policy framework of the eco-sensitive region-wise permissible and regulated activities.

4. Conclusion

Prioritization of Ecological Sensitive Regions (ESR) is done through composite metrics by integrating the district's distinct bio, geo, hydro, climatic, and ecological characteristics at disaggregated levels. Identifying ESR has provided a new policy dimension in planning at disaggregated levels. LU analysis indicates the loss of 13% evergreen forest cover owing to human-induced disturbances. The unregulated urbanization and industrialization in Mangalore city and its suburbs are responsible for the loss of largescale productive paddy fields. ESR is prioritized at disaggregated levels by dividing the study region into equal grids of 9 × 9 km^2 or 5' × 5' as per NES, which indicates 33% (24 grids; 54 villages) of the district area is under ESR1, 20% (15 grids; 81 villages) in ESR2, 28% (20 grids; 145 villages) in ESR3, and rest 19 % (14 grids; 100 villages) area are in ESR 4. The current research recommends stringent protection measures for high ecologically sensitive regions such as ESR 1 and 2. Regulated activities with the scrutiny of environmental impacts and implementation of the environmental management plans are allowed in ESR 3.

Developmental activities may be permitted in ESR 4 as per the requirement of local stakeholders under the strict vigilance of regulatory authorities. The region-specific development (cluster-based approaches in the development path to enhance job opportunities and optimization of local resources use) can be carried out at every panchayat, with the least impact on the ecosystem. The comprehensive assessment and delineation into distinct ESRs by accounting for ecology, climate, topography, and social factors will aid the government and regional managers in framing environmental policies crucial for sustaining ecosystem services to support the livelihood of people.

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Conflicts of interest

The authors declare no conflict of interest.

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"He who has health, has hope; and he who has hope, has everything"

– Thomas Carlyle

Appendix A - Figures

Prioritisation of Ecological Sensitive Regions at disaggregated levels in Dakshina Kannada District, Central Western Ghats

Figure A1: Population density of Dakshina Kannada

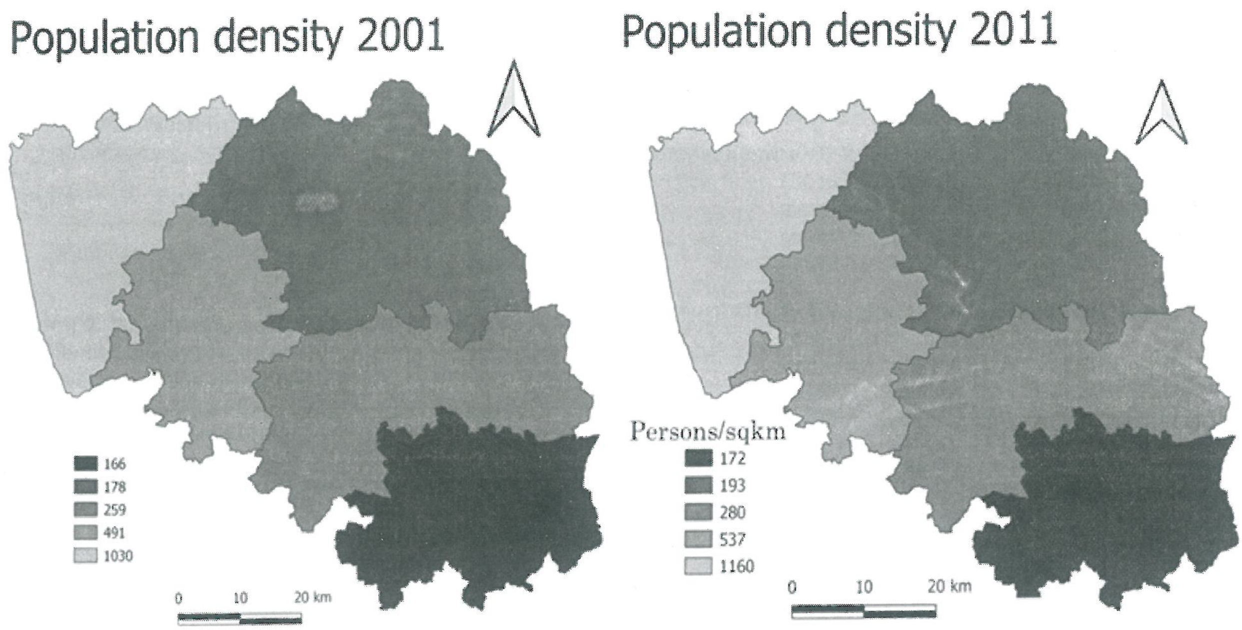


Figure A2: Spatiotemporal changes in LU and forest cover loss from 1973 to 2019

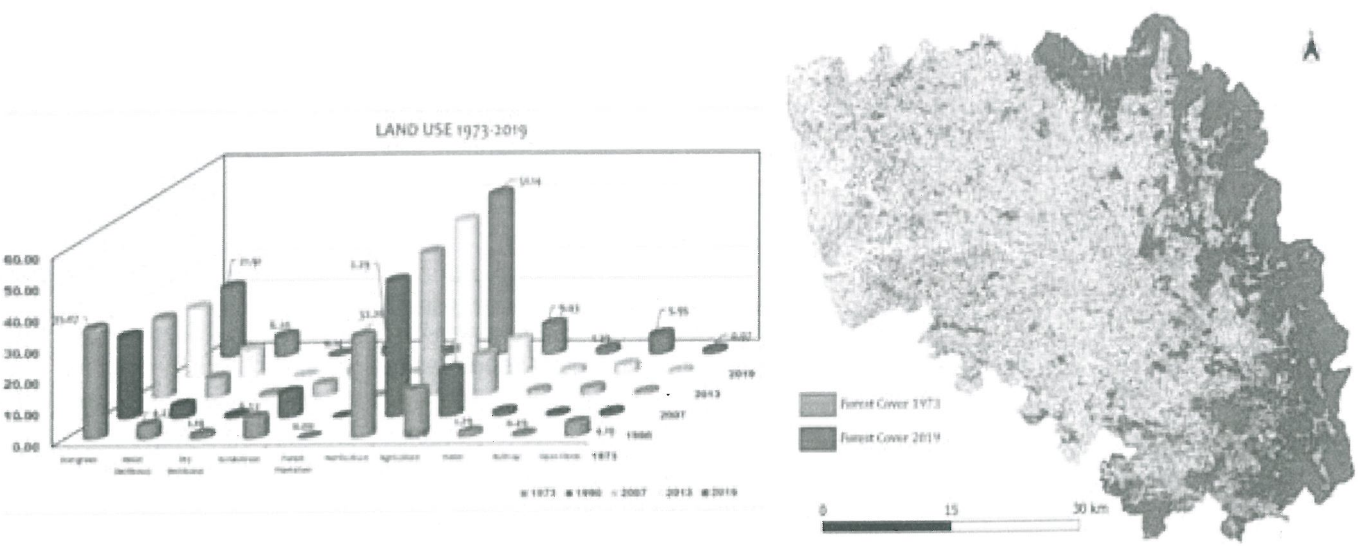


Figure A3: Spatio temporal fragmentation of forests from 1973 to 2019

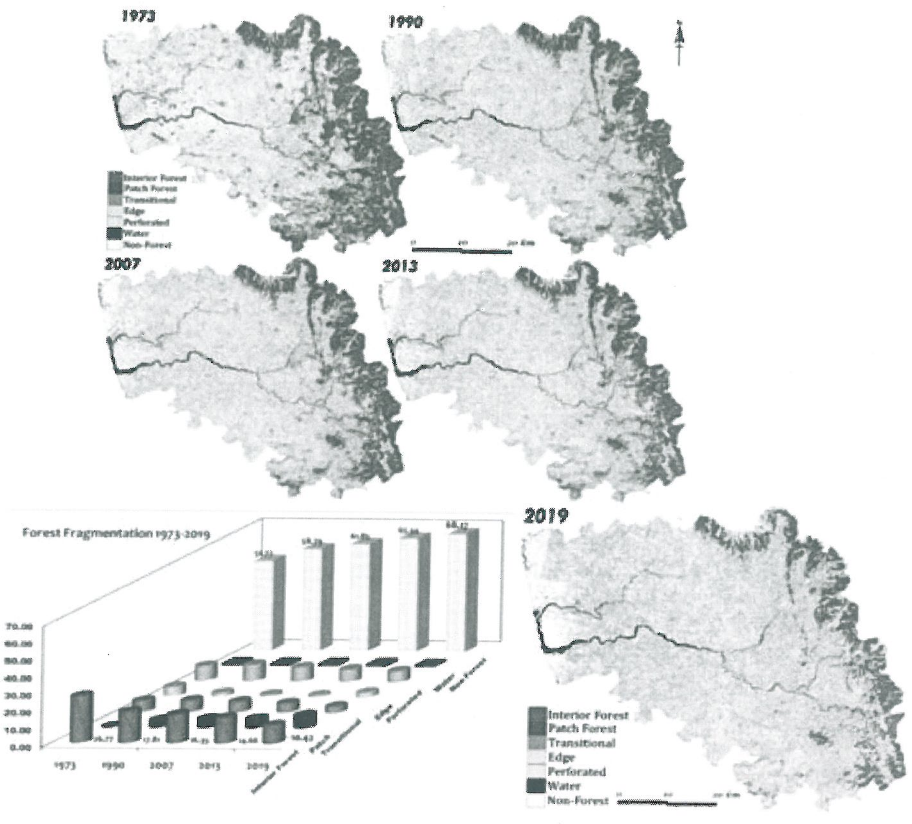


Figure A4: Forest cover, Interior forest cover in Dakshina Kannada and corresponding weight

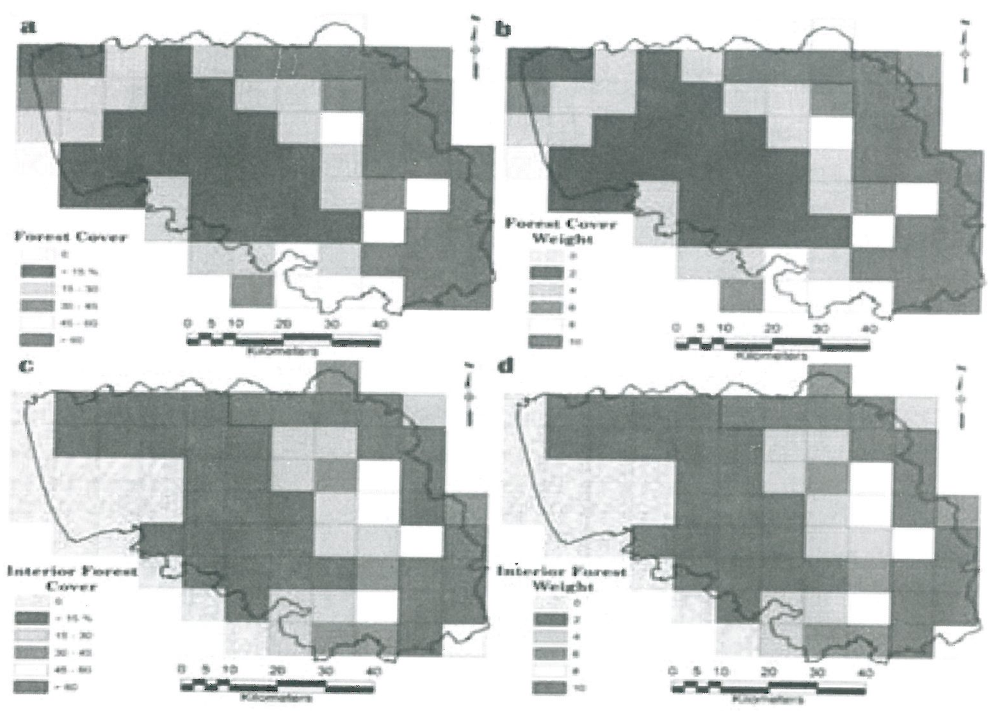


Figure A5: Elevation profile, Slope (degree) of Dakshina Kannada and corresponding weight

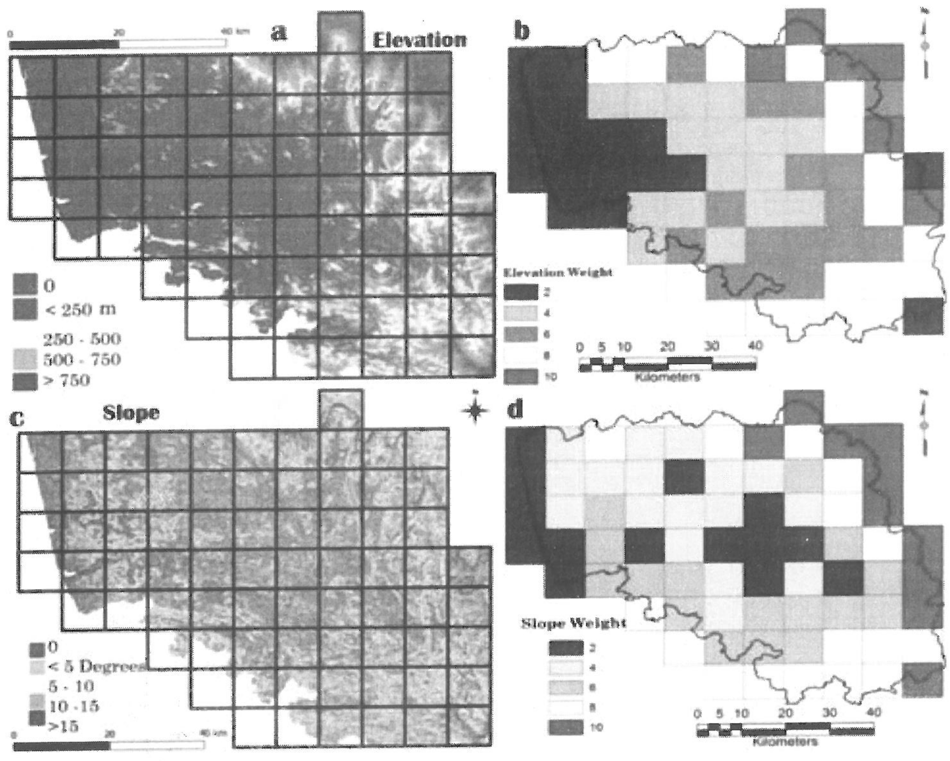


Figure A6: Lithology, distinct soil types of Dakshina Kannada and corresponding weight

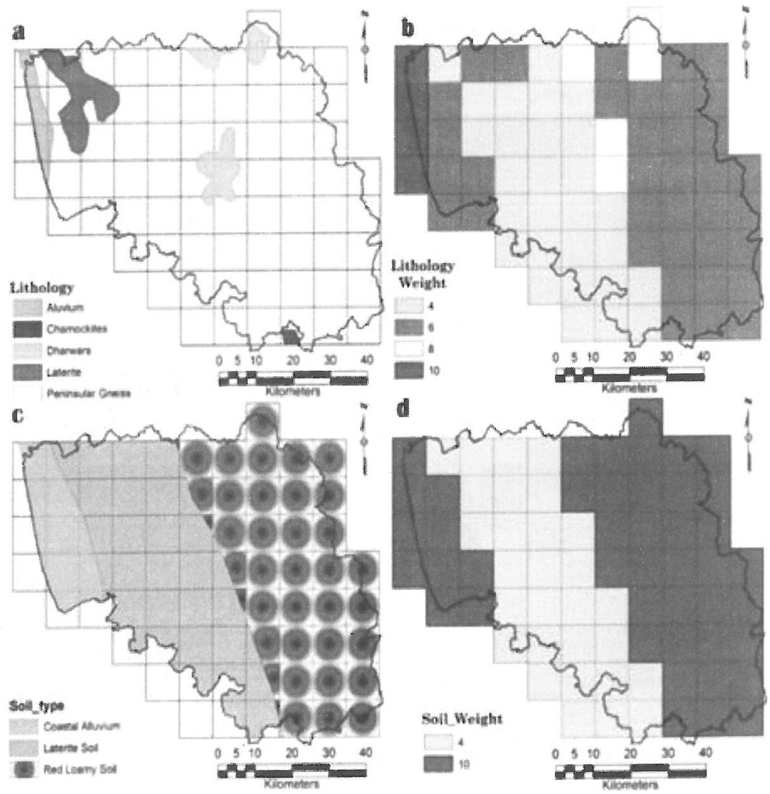


Figure A7: Agro-climatic zones, Rainfall variation in the district and corresponding weight

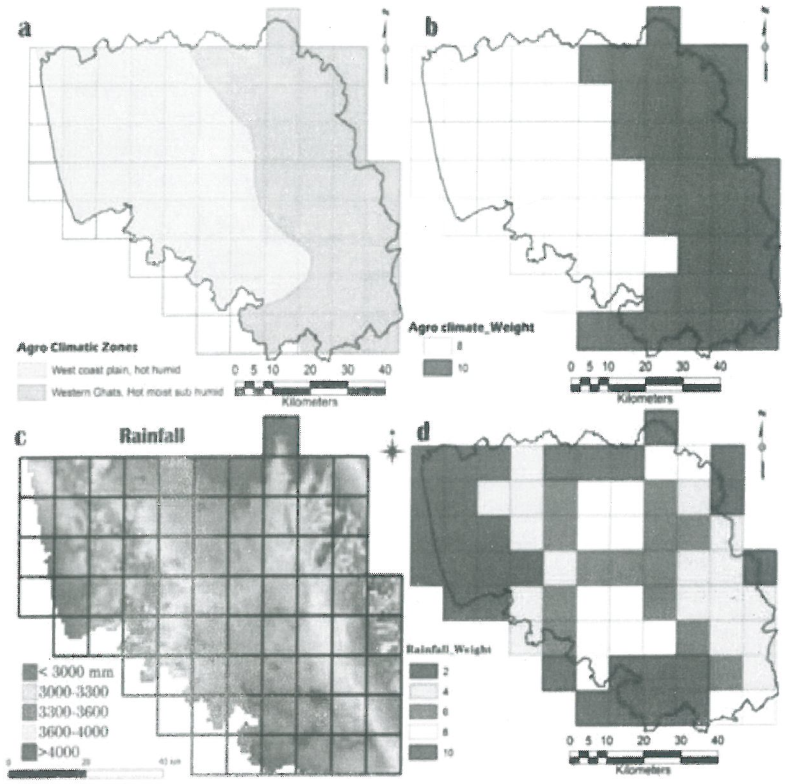


Figure A8: Stream Density, Streamflow of Dakshina Kannada and weight assigned as per flow

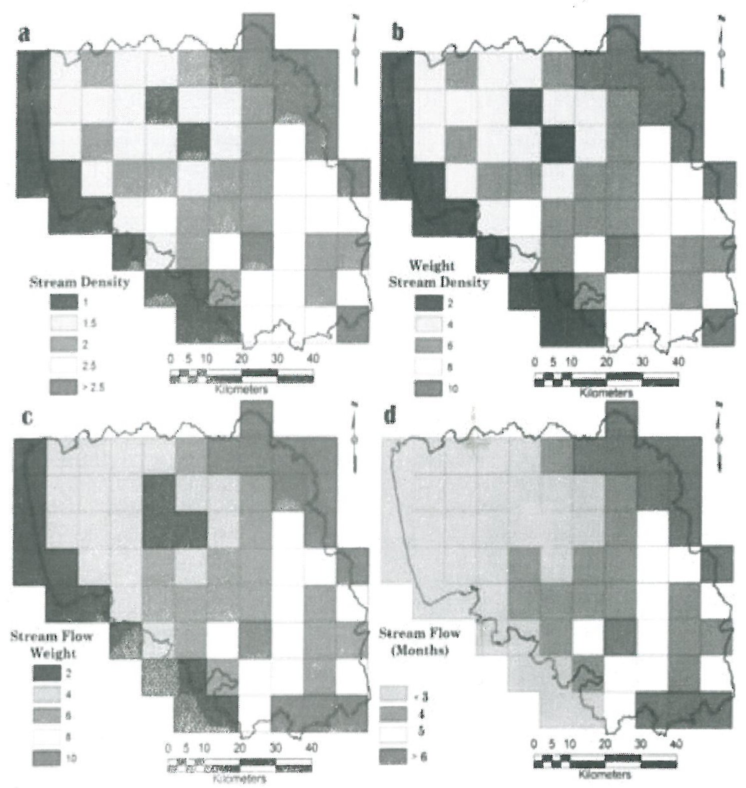


Figure A9: Biomass, Carbon sequestration by forests of the district and weight assigned

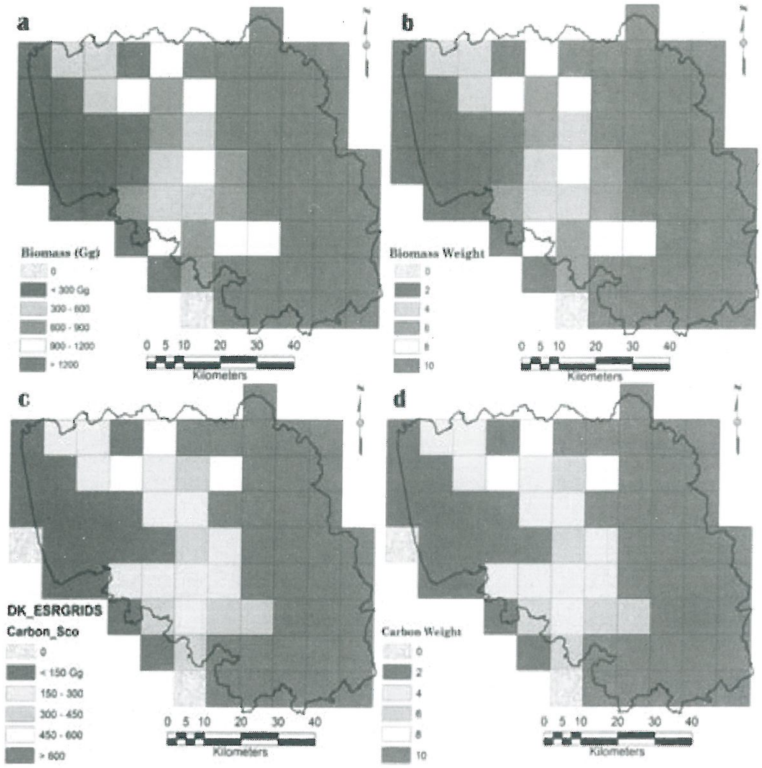


Figure A10: Number of species, Shannon Diversity of the district and weight assigned

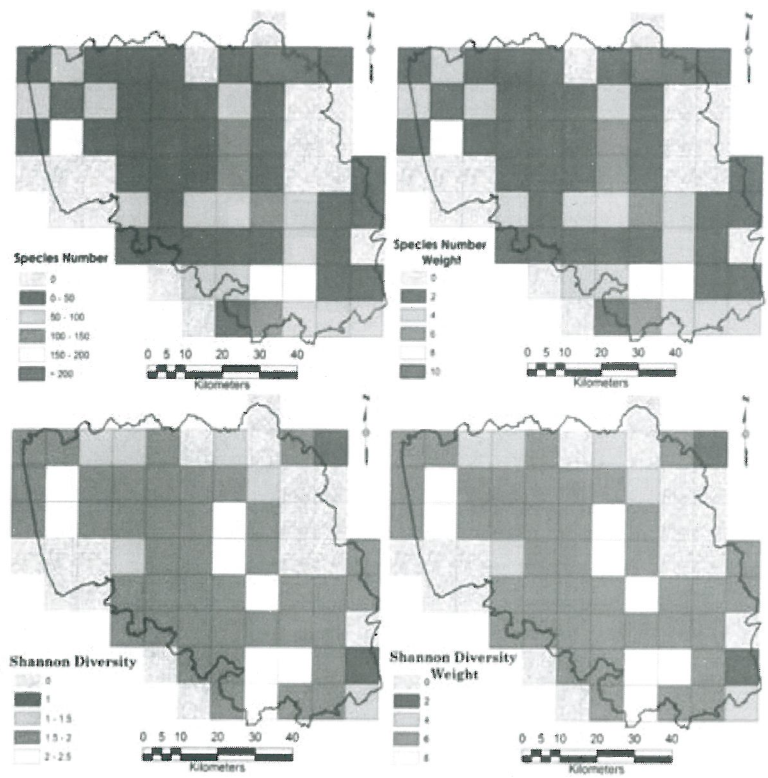


Figure A11: Diverse flora, and fauna of the district with weight

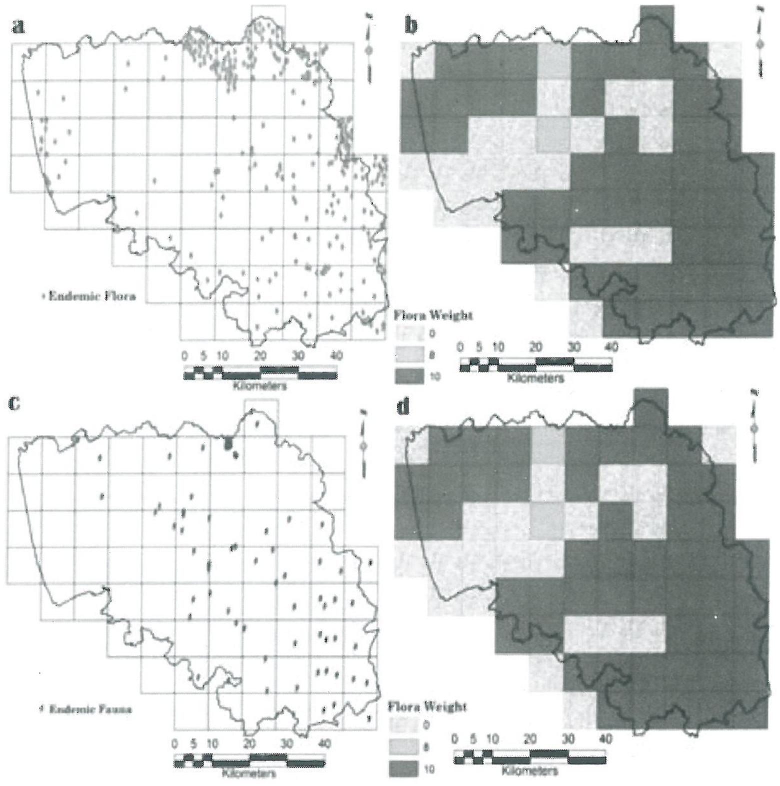


Figure A12: Protected areas, Mysore Elephant reserve portions of the district and weight

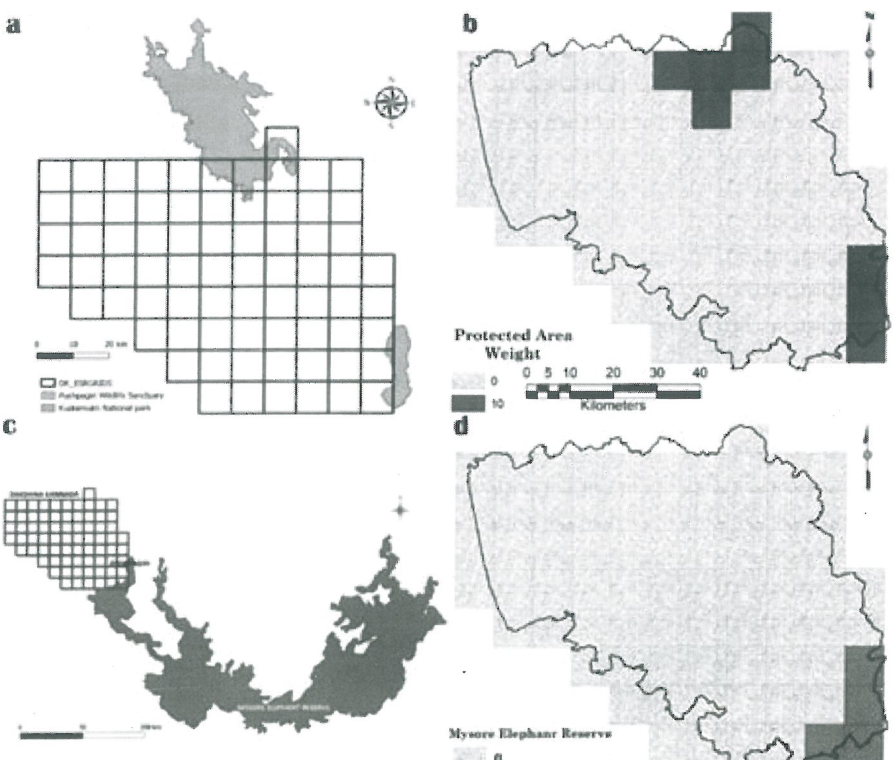


Figure A13: Energy prospects of the district and weight

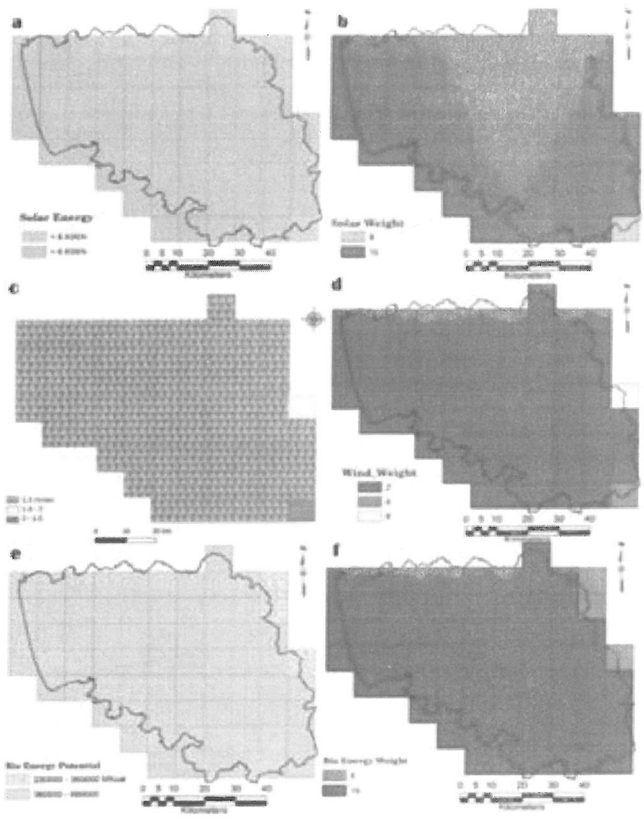


Figure A14: Tribal population; Population density; Livestock density and corresponding weight

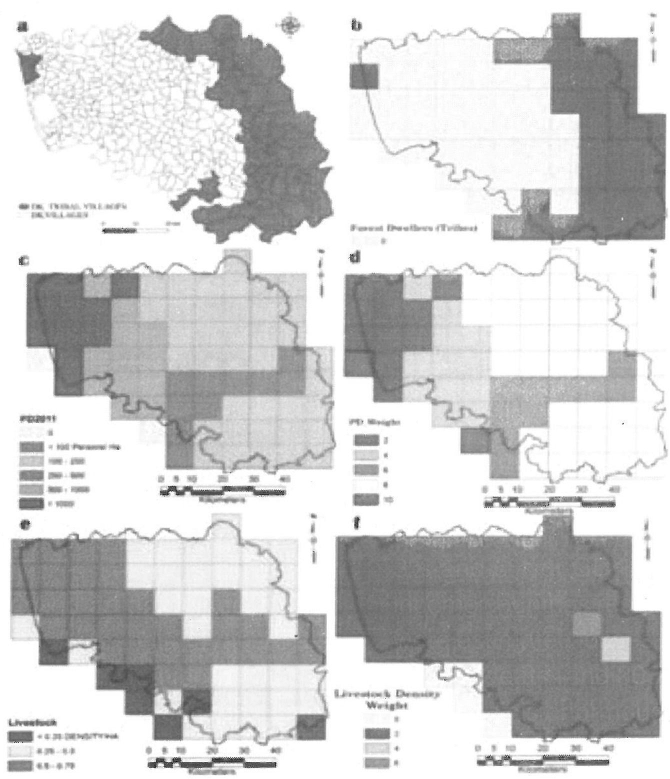
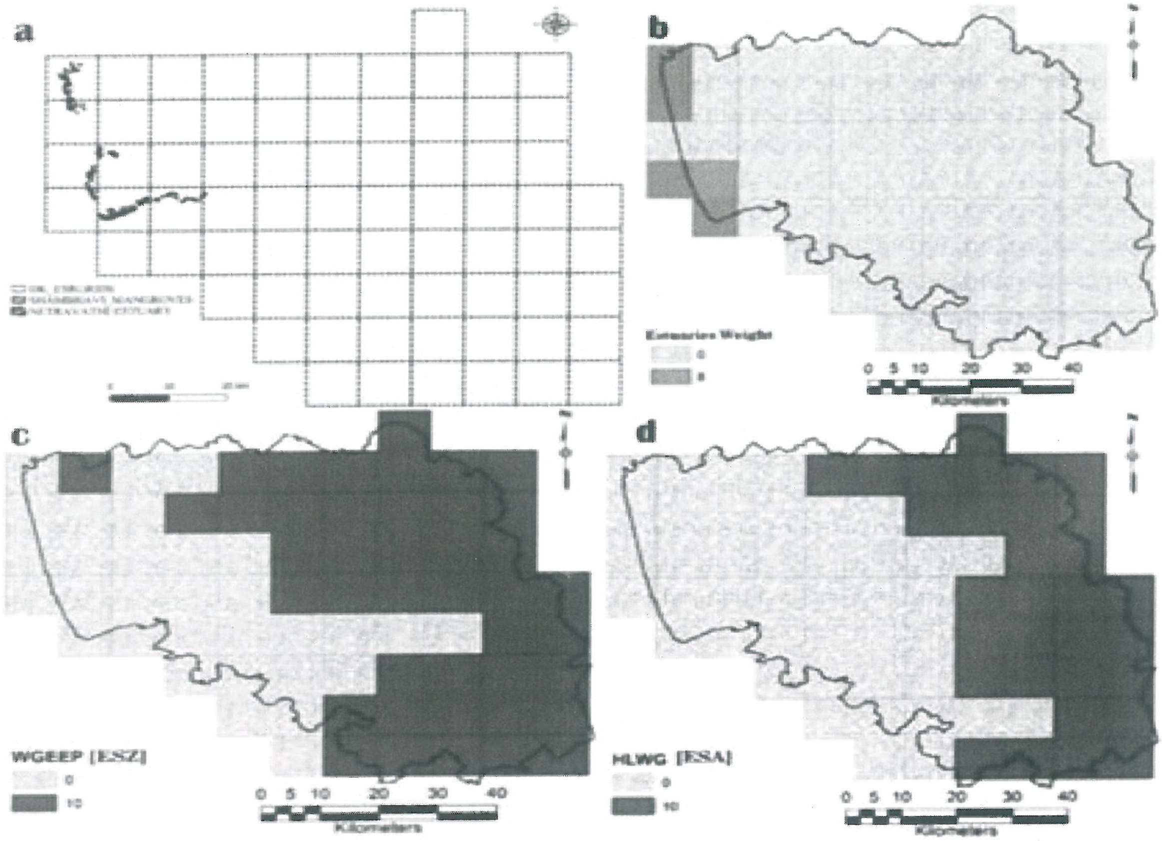


Figure A15: Estuaries of Dakshina Kannada and weight; weight assigned as per ESZ of WGEEP and weight assigned as per ESA of HLWG



Appendix B - Tables

Prioritisation of Ecological Sensitive Regions at disaggregated levels in Dakshina Kannada District, Central Western Ghats

Table B.1: Fragmentation components and their description

Fragmentation Component	Description	Computation
Interior	Forest pixels are far away from the forest-non forest boundary. Interior forested areas are surrounded by thicker forested areas.	($P_f = 1$). All pixels surrounding the center pixel are forest.
Patch	Forest pixels comprise small forested areas surrounded by non-forested land cover.	($P_f < 0.4$). A pixel is part of a forest patch on a non-forest background, such as a small wooded lot within a built-up area.
Perforated	Forest pixels forming the boundary between an interior forest and relatively small clearings (perforations) within the forested landscape.	($P_f > 0.6$ and P_f $P_{ff} > 0$). Most pixels in the surrounding area are forested, but the center pixel appears to be part of the inside edge of a forest patch. This would occur if small clearings were made within a patch of forest.
Edge	Forest pixels define the boundary between interior forest and large non-forested land cover features.	($P_f > 0.6$ and P_f $P_{ff} < 0$). Most pixels in the surrounding area are forested, but the center pixel appears to be part of the outside edge of a forest. This would occur along the boundary of a large built-up area or agricultural field.
Transitional	Areas between edge type and non-forest types. If higher pixels are non-forest, they will tend to non-forest cover with a higher degree of edge.	($0.4 < P_f < 0.6$). About half of the cells in the surrounding area are forested and the center forest pixel may appear to be part of a patch, edge, or perforation depending on the local forest pattern.
Non-Forest	Areas covered by anthropogenic landscape elements (such as buildings, roads, agricultural field, and barren land) other than natural vegetation	Depicts the intensity of disturbances.
Water	Streams, Rivers, Ponds, Lakes	Considered as non-fragmenting features which form the natural corridors in a forested landscape and support biodiversity

Table B.2: Accuracy assessment of temporal remote sensing data

Year	Accuracy	Evergreen	Moist Decidous	Dry Decidous	Scrub/ Grass	Forest Plantation	Horticulture	Agriculture	Water	Built-up	Open fields
1973	PA	57.81	86.50	96.45	85.60	...	87.80	89.00	75.50	89.00	98.67
	UA	98.90	69.42	72.33	84.05	...	92.33	85.52	97.88	88.85	92.98
	Estimated Kappa	0.79	0.81	0.84	0.85	...	0.90	0.89	0.87	0.89	0.96
1990	PA	98.31	99.89	98.70	100.00	...	60.26	93.96	49.95	99.20	98.50
	UA	97.38	84.77	98.90	65.71	...	92.23	65.65	89.27	87.49	73.68
	Estimated Kappa	0.98	0.92	0.99	0.83	...	0.76	0.80	0.70	0.94	0.86
2007	PA	98.66	74.65	75.58	88.17	...	91.98	83.20	98.90	68.91	97.59
	UA	98.66	100.00	72.31	100.00	...	72.29	77.16	98.53	80.43	99.79
	Estimated Kappa	0.98	0.71	0.75	0.87	...	0.90	0.81	0.99	0.68	0.97
2013	PA	67.81	98.70	98.90	99.50	98.80	98.80	99.00	97.80	98.90	98.90
	UA	100.00	69.42	72.33	84.05	95.76	92.33	95.52	97.88	88.85	92.98
	Estimated Kappa	0.83	0.84	0.86	0.92	0.97	0.96	0.97	0.98	0.94	0.96
2019	PA	98.67	97.67	85.58	87.50	91.45	96.70	98.90	98.30	59.78	90.69
	UA	100	100	82.31	93.31	99.72	97.91	79.73	100	93.58	90.28
	Estimated Kappa	0.99	0.99	0.84	0.90	0.96	0.97	0.89	1.00	0.77	0.90

Year	Overall Accuracy	Kappa
1973	89.23	0.86
1990	86.32	0.85
2007	90.46	0.89
2013	89.23	0.86
2019	95.47	0.93

Table B.3: LU transitions during 2007 - 2013

2013		Ever green	Moist Deci dous	Dry Deci-dous	Scrub/ Grass	Forest Planta-tion	Horti-culture	Agri-culture	Water Water	Built-up	Open fields
2007	Evergreen	0.859	0.093	0.000	0.000	0.000	0.046	0.000	0.001	0.001	0.000
	Moist Deciduous	0.000	0.756	0.001	0.000	0.017	0.205	0.011	0.002	0.005	0.003
	Dry deciduous	0.001	0.334	0.029	0.000	0.032	0.419	0.075	0.015	0.053	0.042
	Scrub/Grass	0.000	0.042	0.011	0.570	0.020	0.233	0.057	0.003	0.020	0.044
	Forest Plantation	0.111	0.111	0.111	0.111	0.000	0.111	0.111	0.111	0.111	0.111
	Horticulture	0.000	0.026	0.001	0.000	0.009	0.945	0.014	0.000	0.003	0.004
	Agriculture	0.001	0.006	0.004	0.000	0.009	0.157	0.772	0.000	0.020	0.031
	Water	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.982	0.000	0.000
	Built-up	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.986	0.000
	Open fields	0.001	0.018	0.021	0.000	0.005	0.163	0.344	0.003	0.226	0.219

Table B.4: LU transitions during 2013 - 2019

2019		Ever green	Moist Deci dous	Dry Deci-dous	Scrub/ Grass	Forest Planta-tion	Horti-culture	Agri-culture	Water Water	Built-up	Open fields
2013	Evergreen	**0.977**	0.000	0.000	0.001	0.000	0.003	0.001	0.001	0.017	0.000
	Moist Deciduous	0.000	**0.518**	0.000	0.000	0.000	0.471	0.000	0.000	0.008	0.003
	Dry deciduous	0.000	0.002	**0.466**	0.020	0.002	0.045	0.040	0.000	0.419	0.005
	Scrub/Grass	0.000	0.001	0.001	**0.797**	0.001	0.016	0.014	0.000	0.169	0.002
	Forest Plantation	0.000	0.000	0.000	0.001	**0.983**	0.001	0.001	0.000	0.014	0.000
	Horticulture	0.000	0.000	0.000	0.002	0.000	**0.949**	0.004	0.000	0.045	0.001
	Agriculture	0.000	0.001	0.002	0.013	0.001	0.029	**0.659**	0.000	0.292	0.003
	Water	0.001	0.016	0.005	0.018	0.001	0.107	0.029	**0.658**	0.135	0.030
	Built-up	0.000	0.007	0.011	0.095	0.011	0.033	0.182	0.001	**0.635**	0.026
	Open fields	0.009	0.001	0.001	0.005	0.001	0.012	0.011	0.000	0.135	**0.825**

Table B.5: Accuracy of the simulation

Categories	Consistency %
Evergreen Forest	82.89
Moist Deciduous	97.27
Dry Deciduous	88.43
Scrub / Grass	83.48
Forest Plantation	92.33
Horticulture	88.24
Agriculture	88.00
Water	99.22
Built-up	93.31
Open Fields	89.93
Total Observations	5381483
No of Consistent Observations	4999478
Overall Accuracy	92.90
Kappa	0.90

Table B.6: Simulated and projected LU in Dakshina Kannada

Year	Simulated 2019		Projected 2031	
Categories	**Ha**	**%**	**Ha**	**%**
Evergreen Forest	102478.40	21.16	90322.75	18.65
Moist Deciduous	38927.74	8.04	34830.81	7.19
Dry deciduous	959.69	0.20	1047.35	0.22
Scrub/Grass	6843.40	1.41	8257.42	1.70
Forest Plantation	3551.75	0.73	3920.22	0.81
Horticulture	242258.22	50.02	261883.67	54.07
Agriculture	48630.92	10.04	38299.13	7.91
Water	7954.56	1.64	5133.36	1.06
Built-up	28091.86	5.80	35542.82	7.34
Open Fields	4648.16	0.96	5107.17	1.05

Table B.7: Theme-wise allocation of weights

S. No.	Theme	Variable	Weight				
			2	4	6	8	10
1	Land	Forest Cover	<15%	15-30%	30-45%	45-60%	>60%
		Interior Forests	<15%	15-30%	30-45%	45-60%	>60%
2	Geo- climatic	Agro-Climatic Zone	-	-	-	West Coast Plain, Hot Humid	The Western Ghats, Hot Moist Sub Humid
		Elevation	-	<250m	250-500m	500-750m	>750m
		Slope	-	N.A	N.A	>15^0	>30^0
		Rainfall	<600 mm	600-1200	1200-1800	1800-2400	>2400 mm
		Soil	Coarse Loamy	Sandy or Sandy Skeletal	Fragmental or Rocky	Clayey Loamy or Clayey Skeletal	Loamy or Clayey
		Lithology	-	Charnokitesi or Kalaadgi	Peninsular Gneiss	Dharwars or Granite	Deccan Trap
3	Ecology	Flora	Non-endemic		-		Endemic/ Threatened flora
		Fauna	Non-endemic		-		Endemic/ Threatened fauna
		Protected Area (PA)		0 was assigned to grids outside PA			10 was assigned to the grids within PA
		Mysore Elephant Conservation Reserve		0 was assigned to grids outside			10 was assigned to the grids
		Shannon Diversity	<1	1-1.5	1.5-2	2-2.5	>2.5
		Species Number	<50	50-100	100-150	150-200	>200
		Biomass (Gg)	<300	300-600	600-900	900-1200	>1200
		Carbon Sequestration	<150	150-300	300-450	450-600	>600
4	Hydrology	Stream Density	<1	1-1.5	1.5-2	2-2.5	>2.5
		Stream Flow		3 months	4	5	>6
5	Energy	Solar	-	-	-	< 6 KW/h	>6 KW/h
		Wind	1.5	1.5-2	2-2.5	2.5-4	>4 meters/ second
		Bio	-	230000	230000-360000	360000-660000	>660000
6	Estuaries	Diversity	-	-	-	Moderate	Rich Diversity
7	Social	Population Density	>1000	500-1000	250-500	100-250	<100 (persons per ha)
		Livestock Density	<0.75	0.75-1.5	1.5-2.25	2.25-3	>3 animals per ha
		Forest Dwellers	-	-	-	-	Presence of tribal population in forest grids
8	Regulatory Framework	Western Ghats	-	-	-	-	ESZ-1 mapped by WGEEP
		HLWG (High Level Working Group	-	-	-	-	ESA-1 mapped by HLWG

Table B. 8: Regulated activities and recommendations for enriching ESRs

S. NO.	ACTIVITIES	ECOLOGICALLY SENSITIVE REGIONS			
		ESR-1	ESR-2	ESR-3	ESR-4
1	**ENERGY**	√	√	√	√
	(A) Solar (Rooftop)				
	(B) Wind power	×	√	√	√
	(C) Bio energy	×	√	√	√
	(D) Coal based (Thermal power)	×	×	×	×
	(E) Gas or liquid fuel based	×	×	×	√
	(F) Hydro power (Major)	×	×	×	×
	(G) Hydro power (Micro)	×	×	×	√
	(H) Nuclear power	×	×	×	×
2	**FORESTS**	×	×	×	×
	(A) Land use change (Forest to non-forest usages)				
	(B) Monoculture plantations	×	×	×	×
	(C) Extraction of medicinal plants (with strict regulations)	×	×		
	(D) Forest improvement through VFCs	√	√	√	√
	(E) NTFP collection	(Strict regulation by department)			
	(F) River Diversion	×	×	×	×
	(G) Construction of Dams & Reservoirs (under drinking water project Schemes)	×	×	√ (Allowed only after EIA & involving local stakeholders and experts)	√
3	**AGRICULTURE**	√	√	√	√
	(A) Agroforestry				
	(B) Organic farming	√	√	√	√
	(C) Land use change / Encroachments	×	×	×	×
	(D) Genetically modified crops	×	×	×	×
	(E) Animal Husbandry	√	√	√	√
4	**HORTICULTURE**	√	√	√	√
	(A) Organic farming				
	(B) Nitrogen and Phosphorus (N&P) fertilizers	×	×	×	√ Dosage as prescribed by Agriculture department
	(C) Endosulfan	×	×	×	×
	(D) Pesticide	×	×	×	√
	(E) Watermelon & Muskmelon farming	×	√	√	√
5	**INDUSTRIES (Larger scale)**	√	√	√	√
	(A) Agro-processing industries				
	(B) Information Technology industries (IT)	×	×	√	√
	(C) Red category (Polluting) industries	×	×	×	×
	(D) Garment industries	×	×	√	√

	(E) New establishment of Industries	×	×	×	(Allowed only after critical review by local stakeholders and experts)
	(F) Non Polluting (Green) Industries	×	×	√	√
6	**INDUSTRIES (Small scale)**	×	√	√	√
	(A) Garment industries				
	(B) Domestic (Home based) industries	√	√	√	√
	a. Papad				
	b. Mango processing	√	√	√	√
	c. Areca nut processing & Coir industries	×	√	√	√
	d. Milk products and processing	√	√	√	√
	e. Dry fruits & Spices	√	√	√	√
	f. Fruit processing (Ex: Kokum Juice *(Garcinia indica)*)	√	√	√	√
	g. Fish products processing	√	√	√	√
	h. Bee keeping and bee nurseries	√	√	√	√
	i. Pongamia plantations for biofuel (in private lands)	×	√	√	√
	j. Bio pesticides manufacturing	×	√	√	√
	k. Poultry farms and powdered eggs	×	√	√	√
	l. Vegetable dyes; fruits and vegetables preservation	√	√	√	√
	m. Medicinal plants cultivation and processing	√	√	√	√
	n. Aromatic plants and essential oil distillation; orchids and cut flowers harvesting industries	×	√	√	√
7	**TOURISM INDUSTRY**	×	√	√	√
	(A) Ecotourism				
	(B) Organic village and homestay	√	√	√	√
	(C) VFC managed tourism	√	√	√	√
	(D) VFC managed homestay tourism in higher	×	√	√	√
	forest cover regions and protected areas				
	(E) Arts and handicrafts museum and trade center	√	√	√	√
8	**MINING AND MINERAL EXTRACTION**	×	×	×	×
	(A) Iron ore				
	(B) Manganese	×	×	×	×
	(C) Bauxite	×	×	×	×
	(D) Limestone	×	×	×	√
	(E) Quartz	×	×	×	√
	(F) Sand extraction (on sustainable basis byBan on exporting)	×	×	×	√
9	**WASTE DISPOSAL**	×	×	×	×
	(A) Hazardous waste processing units				
	(B) Solid waste disposal manure preparation)	×	×	×	√(For composting and manure preparation)

(C) Liquid waste discharge	×	×	×	(Treatment plants (STP) for processing)
(D) Recycling and waste processing and units	×	×	×	(Complaint with PCB)
10 **TRANSPORTATION**	×	×	×	Allowed only after strict (EIA)
(A) Roads and expressways				
(B) Rail and freight corridors	**Subject to EIA; Strict regulation and social audit**			
(C) Up gradation of existing infrastructure	×	×	√Subject to EIAs, strict regulation and social audit)	√

Remarks

- The ESR_1 represents a zone of highest conservation, no further degradation allowed. ESR-2 has the potentiality to become as ESR-1 provided with strict regulations and improvement of forests and its environs by more protection. A small change in ESR-2 will have more adverse effects in ESR-1.
- Forest Rights Act to be implemented scientifically considering genuine forest dwelling communities.
- Monoculture plantations are not allowed, existing exotics should be replaced by planting native species.
- Promote decentralized electricity, through harvesting locally available 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 decision making and environmental monitoring.
- No new major roads, railway lines are allowed in ESR 1 and ESR 2, and when highly essential in ESR 3 and ESR 4 subject to EIA, by imposing strict regulation and social audit.
- Tourism Master Plan should be based on MoEFCC regulations (after taking into account social and environmental costs).
- Controlled activities are permitted based on socio-economic importance and activities such as depriving wetlands, natural forests, and the introduction of alien invasive species are not permitted.