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ORIGINAL PAPER

Global Warming Mitigation Through Carbon Sequestrations in the Central Western Ghats

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Abstract

Global warming with the escalation in greenhouse gas (GHG) footprint (400 ppm from 280 ppm CO_2 emissions of the pre-industrial era) and consequent changes in the climate have been affecting the livelihood of people with the erosion of ecosystem productivity. The anthropogenic activities such as power generation (burning of fossil fuels), agriculture (livestock, farming, rice cultivation and burning of crop residues), polluting water bodies, and industry and urban activities (transport, mismanagement of solid, liquid waste, etc.) have risen substantially CO_2 concentrations to 72% among GHGs. Emissions and sequestration of carbon need to be in balance to sustain ecosystem functions and maintain the environmental conditions. Forests are the major carbon sinks to mitigate global warming. The current research focusses on the carbon budgeting through quantification of emissions and sinks in the Uttara Kannada district, central Western Ghats, Karnataka. This would help in evolving appropriate mitigation strategies towards sustainable management of forests. The study reveals that total carbon stored in vegetation and soils are 56,911.79 Gg and 59,693.44 Gg, respectively. The annual carbon increment in forests is about 975.81 Gg. Carbon uptake by the natural forest is about 2416.69 Gg/year and by the forest plantations is 963.28 Gg/year amounting to the total of 3379.97 Gg/year. Sector-wise carbon emissions are 87.70 Gg/year (livestock), 101.57 Gg/year (paddy cultivation), 77.20 Gg/year (fuel wood consumption), and 437.87 Gg/year (vehicular transport), respectively. The analysis highlights that forest ecosystems in Uttara Kannada are playing a significant role in the mitigation of regional as well as global carbon emissions. Hence, the premium should be on conservation of the remaining native forests, which are vital for the water security (perennial streams) and food security (sustenance of biodiversity) and mitigation of global warming through carbon sequestration. Sustainable management ecosystem practices involving local stakeholders will further enhance the ability of forests to sequester atmospheric carbon apart from other ecosystem services, such as hydrological services and improvements in soil and water quality.

Keywords Carbon sequestration · Emissions · Forest ecosystems · Carbon budgeting · Sustainable management

1 Introduction

Forests sequester atmospheric carbon [19, 44] and play a pivotal role in mitigating changes in the climate [14, 30]. Atmospheric carbon gets stored in the above- and below-ground biomass and soil organic matter. Mismanagement of forests leading to deforestation and enhanced anthropogenic emissions during postindustrial revolution has increased carbon dioxide concentration in the atmosphere to 400 ppm from 270 ppm during the preindustrial era [35]. The recent estimates of emissions in 30 developing countries (including Brazil, Bolivia, Indonesia, Myanmar, and Zambia) highlight that deforestation and forest degradation are the prime sources of CO_2 imperiling productive ecosystems [15]. Carbon dioxide, nitrous oxide, methane, chlorofluorocarbon, and water vapors are major greenhouse gases (GHGs), which induce greenhouse effect by absorbing and re-emitting infrared radiation in the Earth's atmosphere. This has resulted in the increase of the Earth's ambient temperature, leading to global warming,

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with the consequent changes in the climate impacting the survival of living organisms. Carbon footprint is thus a measure of the impact of human activities on the environment in terms of the amount of greenhouse gases produced and expressed in units of carbon dioxide equivalent (CO_2 Eq). The amount of carbon storage or sequestration is expressed as amounts in metric tons or Gg (gigagram) per hectare, which indicates the amount of carbon uptake by forests. The effective forest management greatly influences the amount of carbon stored in the aboveground biomass, soils, and associated forest products.

Burgeoning population and unplanned urbanization coupled with the increased consumption levels have led to the release of a large amount of carbon from anthropogenic sources. Deforestation and forest degradation accounts to 20–25% of the total anthropogenic carbon emissions [43]. Vegetation stores the carbon in the form of carbohydrate and soil accumulates the carbon in organic and inorganic form. Forest removal leads to the release of stored carbons and the global phenomenon of deforestation have contributed to an increase in atmospheric CO_2. Large-scale land use land cover (LULC) changes leading to deforestation, indiscriminate harvesting of industrial wood, forest fire, etc. are responsible for carbon emissions. LULC changes modify biogeochemical cycles, climate, and hydrology [2, 59, 66], driving biodiversity loss through habitat fragmentation and destruction [62, 63]. Irrational LULC changes have been posing challenges with alterations in the ecosystem integrity leading to the decline of ecosystem services, which is affecting the livelihood of people. India emits nearly 5% of global CO_2 emissions, which is expected to increase by more than 2.5 times by 2030 [29]. This necessitates the quantification of sources and sinks of carbon in order to evolve appropriate mitigation and adaptation strategies. Carbon budgeting of a region provides the spatial and temporal distribution of major pools of carbon sources and sinks that help in assessing the pattern and variability of carbon in the atmosphere. Terrestrial and aquatic plants and soil are major carbon sinks, which accumulate the carbon. Sources of GHG for a region are from livestock, agriculture, fuelwood consumption, industries, transportation, land use changes, etc. The carbon budget of a region (United Nations Framework Convention on Climate Change, UNFCCC) includes emissions from burning fossil fuels, industrial production, direct emissions from heating in households and businesses, transportation, agriculture, waste management, land use, forestry, and emissions arising from other activities.

1.1 Objectives

The objective of the current research is to carry out taluk wise carbon budget for Uttara Kannada district, Central Western Ghats. This involves

1. Source-wise carbon sequestration assessment with the combination of field and remote sensing data
2. Sector wise assessment of carbon emissions
3. Computation of regional level carbon metric (ratio of carbon sink to source)

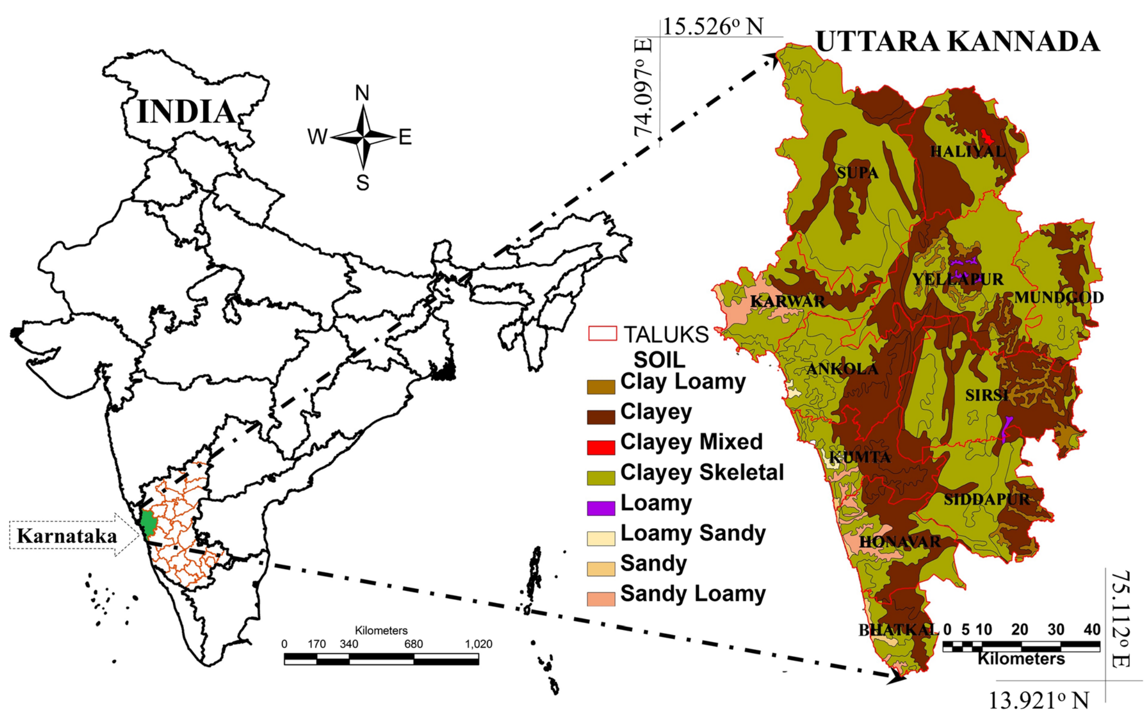


Fig. 1 Study region—Uttara Kannada district, Central Western Ghats

2 Materials and Method

2.1 Study Area

The Western Ghats or "Sahyadri" is a chain of mountain ranges along the western side of India and is one among the global ten "hottest hotspot of biodiversity." Uttara Kannada with an area of 10,291 km^2 (covering 5.37% of Karnataka state) is located between 13.769° to 15.732° north and 74.124° to 75.169° east (Fig. 1) in the central part of the Western Ghats. The district extends to about 328 km north to south, and 160 km east–west is hilly, undulating, and thickly wooded and comprises of 11 taluks (also known as tehsil—an area of land with a city or town that serves as centre local administrative unit in South Asian countries). The region consists of three agro-climatic zones namely coastal, hilly, and plains. The soils of the district are divided into distinct zones based on topography: the alluvial, lateritic, and granitic soils. The soil can be described as derivatives of the most ancient metamorphic rocks in India, which are rich in iron and manganese [46]. Forests of Uttara Kannada are broadly divided into moist and dry types. The moist type may be subdivided into evergreen, semi-evergreen, and moist deciduous. The dry type can be divided into dry deciduous and thorn forest. The central part of Uttara Kannada is of the evergreen type. The total population of the district is 1,436,847 with density as 140 persons per sq. km. The agricultural sector has been playing a prominent role in the economy evident from the production of crop varies such as paddy (182,000 metric tons), sugarcane (45,000 metric tons), groundnut (4695 metric tons), and horticulture crops production accounts to 179,671 metric tons.

2.2 Method

Figure 2 outlines the approach adopted for budgeting carbon in Uttara Kannada. Forest types are mapped using vegetation maps [45, 54] and field data with the remote sensing data. Forest vegetation is sampled using transect-based quadrats (Fig. 3), which is validated and found appropriate especially in surveying undulating forested landscapes of central Western Ghats [9, 52, 53]. Topographic maps of 1:50,000 scales were used to do ground surveys and selection of sample plots. Availability of temporal remote sensing data helped in understanding the vegetation dynamics and in assessing biomass and carbon uptake. Further, the analysis was carried out in two major folds, i.e., spatial mapping of carbon sinks and estimating carbon emissions.

2.3 LU Dynamics

Land use (LU) analysis of a region provides the status of a landscape and its health. Land use changes induced by human activities play a major role at global as well as at regional scale climate and biogeochemistry of the Earth system. These changes

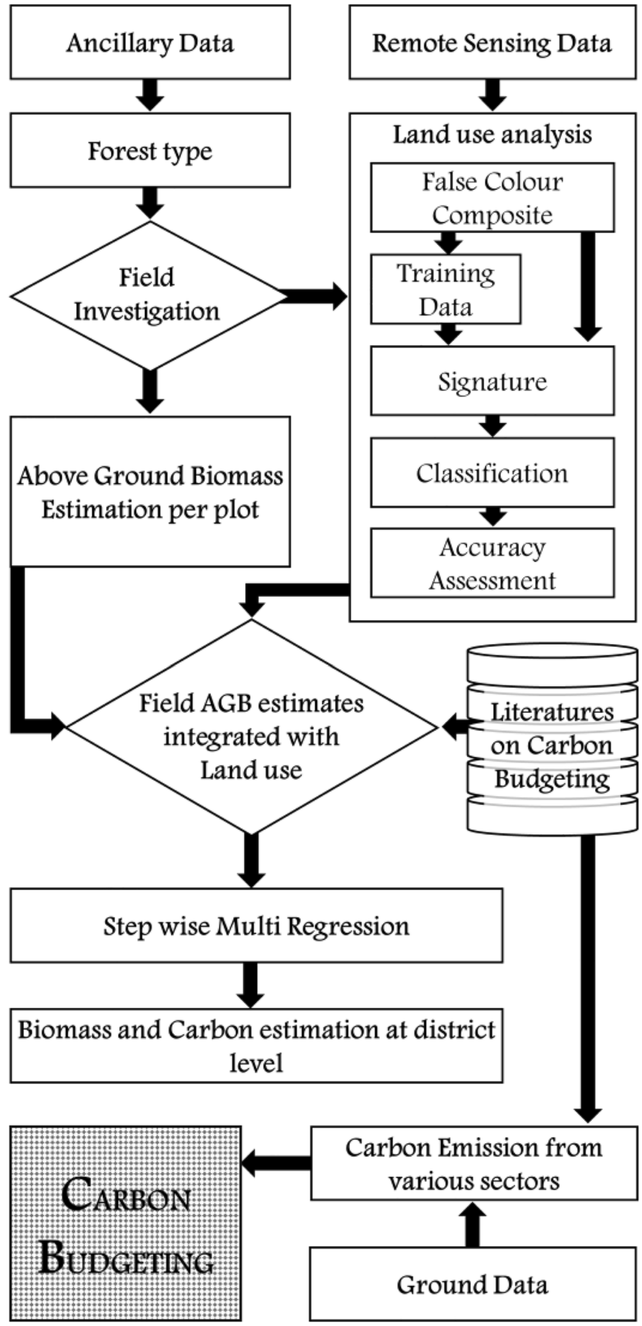


Fig. 2 Method adopted for carbon budgeting

directly impact biodiversity of a region [55], soil degradation, and loss of CO_2 sequestration potential, which induce local climate change [64] as well as global warming [67]. Earlier studies have revealed deforestation and other LU change activities are the prime agents of atmospheric CO_2 increase [11] and consequent global warming. The temporal LU analyses provide insights to the rate of CO_2 emission escalation with deforestation and loss of carbon sequestration potential of the ecosystem [47]. LU combined with "ground-based" in situ data serves as a cost-efficient and reliable source to account carbon emissions [28, 39]. Land use analyses involved (i) generation of false color

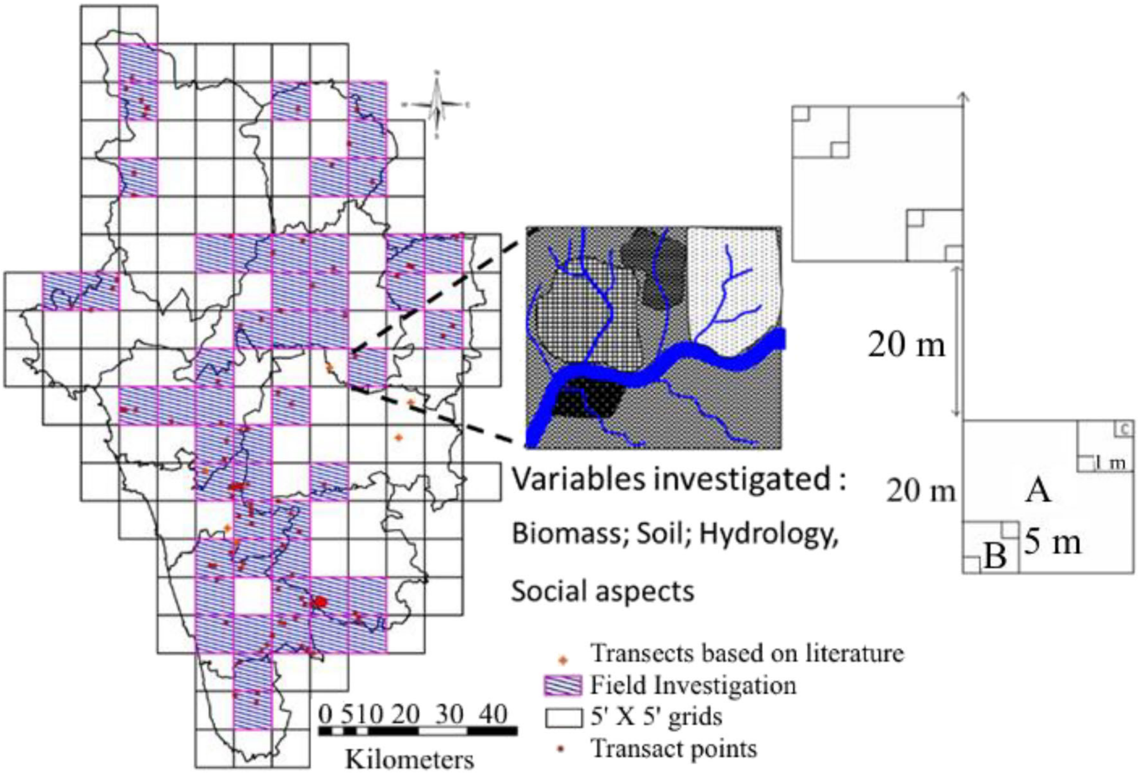


Fig. 3 Study area and distribution of transects cum quadrats for sampling vegetation

composite (FCC) of RS data (bands–green, red, and NIR). This composite image helps in locating heterogeneous patches in the landscape, (ii) selection of training polygons by covering 15% of the study area (polygons are uniformly distributed over the entire

Table 1 Biomass computation for different agro zones [49, 50]

Index	Equation	Significance	Region applied
Basal area (BA) (m^2)	$(DBH)^2/4\pi$	To estimate basal area from DBH values	All
Biomass (T/Ha)	$(2.81 + 6.78 \times BA)$	Effective for semi evergreen, moist deciduous forest cover types and having moderate rainfall	Coastal
Biomass (T/Ha)	$(21.297 - 6.953(DBH)) + 0.740(DBH^2)$	Effective for wet evergreen, semi evergreen forest cover types and having higher rainfall)	Sahyadri interior
Biomass (T/Ha)	$exp\{-1.996 + 2.32 \times \ln(DBH)\}$	Effective for deciduous forest cover types and having lower rainfall	Plains
Carbon stored (T/Ha)	(Estimated biomass) × 0.5	Sequestered carbon content in the region by forests	All
Annual increment in biomass (T/Ha)	(Forest cover) × 6.5	Incremental growth in biomass [49, 50]	Coastal
	(Forest cover) × 13.41		Sahyadri
	(Forest cover) × 7.5		Plains
Annual increment in carbon (T/Ha)	(Annual increment in biomass) × 0.5	Incremental growth in carbon storage	All
Net annual biomass productivity (T/Ha)	(Forest cover) × 3.95	Used to compute the annual availability of woody biomass in the region [49, 50]	Coastal
	(Forest cover) × 5.3		Sahyadri
	(Forest cover) × 3.5		Plains
Carbon sequestration of forest soil (T/Ha)	(Forest cover) × 152.9	Carbon stored in soil [57]	Coastal
	(Forest cover) × 171.75		Sahyadri
	(Forest cover) × 57.99		Plains
Annual increment of soil carbon	(Forest cover) × 2.5	Annual increment of carbon stored in the soil	All

Table 2 Biomass productivities in various types of vegetation

S. no.	Vegetation types	Biomass (t/ha/year)
1	Dense evergreen and semi evergreen	13.41 to 27.0
2	Low evergreen	3.60 to 6.50
3	Secondary evergreen	3.60 to 6.50
4	Dense deciduous forest	3.90 to13.50
5	Savanna woodland	0.50 to 3.50
6	Coastal (scrub to moist deciduous)	0.90 to 1.50

Table 3 Soil carbon storage in different forest types

S. no.	Forest types	Mean soil carbon in top 30 cm (Mg/ha)
1	Tropical wet evergreen forest	132.8
2	Tropical semi evergreen forest	171.7
3	Tropical moist deciduous forest	57.1
4	Littoral and swamp forest	34.9
5	Tropical dry deciduous forest	58
6	Tropical thorn forest	44
7	Tropical dry evergreen forest	33

study area), (iii) loading these training polygons co-ordinates into pre-calibrated GPS, (vi) collection of the corresponding attribute data (land use types) for these polygons from the field, (iv) supplementing this information with Google Earth, and (v) 60% of the training data has been used for classification based on Gaussian maximum likelihood algorithm, while the balance is used for validation or accuracy assessment (ACA). The land use analysis was done using a supervised classification technique based on Gaussian maximum likelihood algorithm with training data. The land use is classified under 11 categories such as Built-up, Water, Cropland, Open fields, Moist deciduous forest, Evergreen to semi evergreen forest, Scrub/grass, Acacia/Eucalyptus/Hardwood plantations, Teak/Bamboo/Softwood plantations, Coconut/Areca nut/Cashew nut plantations, and Dry deciduous forest. GRASS GIS (Geographical Resources Analysis Support System, http://ces.iisc.ernet.in/grass), free and open source software, has been used for analyzing RS data by using available multitemporal "ground truth" information. Earlier time data were classified using the training polygon along with 1 from the historical published topographic maps, vegetation maps, revenue maps, and land records available from local administrative authorities. The Landsat data of 1973 with a spatial resolution of 57.5 m × 57.5 m (nominal resolution) were resampled to 30 m (nominal resolution) to maintain the uniform resolution across temporal (1999–2018) RS data.

3 Spatial Mapping of Carbon Sinks

3.1 Field Investigation

The study area falls in three agro-climatic regions. The district is divided into 5′ × 5′ equal area grids (168) covering approximately 81 km^2 (9 × 9 km) comparable to grids in the Survey of India topographic map (of 1:50,000 scale). Representative grids were chosen in each agro-climatic zone for further field data collections (Fig. 3). The basal area, height, species type, diversity, etc. were computed based on the collected field data through flora sampling in quadrats of 116 transects (distributed across agro-climatic zones). Along a transect of 180 m, 5 quadrats each of 20 m × 20 m were laid alternately on the right and left, for tree study (minimum girth of 30 cm at GBH (girth at breast height or 130 cm height from the ground) and height > 1.5 m), keeping intervals of 20 m length between successive quadrats. Two sub-quadrats of 5 m × 5 m were laid within each tree quadrat, at two diagonal corners, for shrubs and tree saplings (< 30 cm girth). Within each of these, two herb layer quadrats each of 1-m^2 area were laid for documenting herbs and tree seedlings. Standing biomass in forests and plantations is quantified to evaluate carbon sequestration potential of the respective ecosystem. Land use

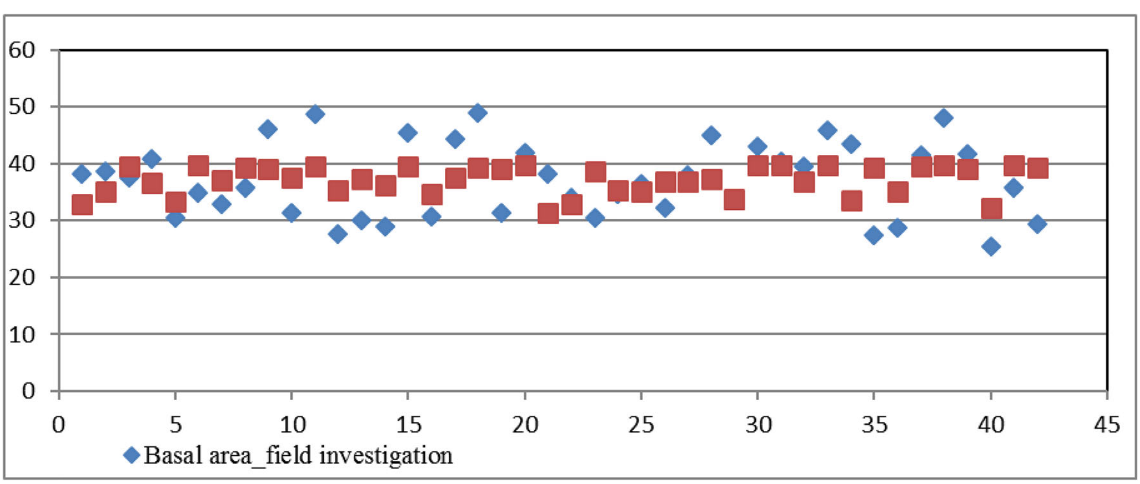
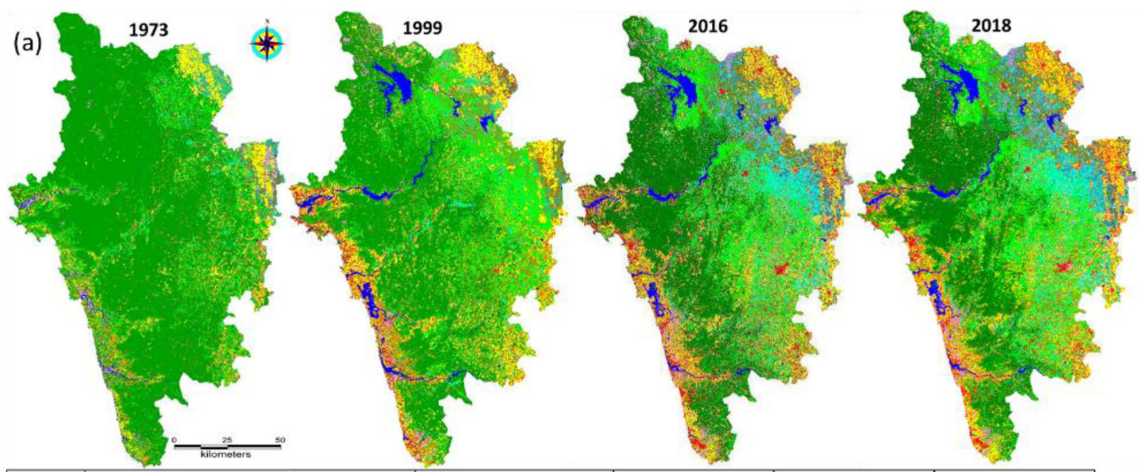


Fig. 4 Comparison of predicted and estimated basal areas

Table 4 Season- and region-wise cooking fuelwood requirement (PCFC)

Agro-climatic Region	Cooking fuelwood (kg/person/day)								Cooking fuelwood (tons/person/year)
	Summer		Monsoon		Winter		Average		
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	
Coastal	1.98	1.40	1.95	1.34	2.11	1.73	2.01	1.49	0.734
Plains	2.02	1.34	2.22	1.38	2.32	1.59	2.19	1.44	0.8
Sahyadri	2.22	1.56	2.23	1.94	2.51	2.77	2.32	2.09	0.85

Source: Ramachandra et al. [49, 50]; Cummings et al. [13]



Legend	Category	1973		1999		2016		2018	
		Ha	%	Ha	%	Ha	%	Ha	%
	Built-up	3886	0.38	21635	2.1	51132	**4.97**	54,023	**5.23**
	Water	7681	0.75	32983	3.21	28228	2.74	28,406	2.73
	Crop land	71990	7	138458	13.45	147109	14.3	149,151	14.59
	Open fields	14071	1.37	21945	2.13	42634	4.15	41,941	4.08
	Moist deciduous forest	95357	9.27	179075	17.4	164239	15.95	163,734	16.07
	Evergreen to semi evergreen forest	696978	**67.73**	423062	41.11	303585	**29.5**	298,015	**29.15**
	Scrub/ Grass lands	38109	3.7	47366	4.6	42083	4.09	41331	3.57
	Acacia/ Eucalyptus plantations	40905	3.97	73977	7.19	110950	10.78	109,705	**10.66**
	Teak/ Bamboo plantations	13997	1.36	38588	3.75	78953	7.67	76,847	7.37
	Coconut/ Areca nut / Cashew nut	20702	2.01	43623	4.24	47135	4.58	52,232	5.17
	Dry deciduous forest	25410	2.47	8374	0.81	13038	1.27	13,701	1.38

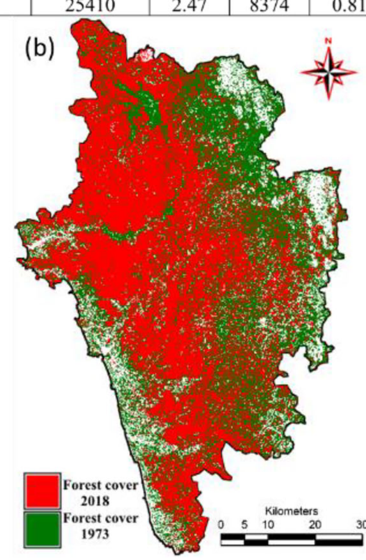


Fig. 5 Land uses and transition of forest cover from 1973 to 2018 in Uttara Kannada

analysis is performed to account grid-wise and at district-level forest cover, which helped in estimating biomass at the district level.

3.2 Quantification of Biomass (Forests)

The aboveground biomass (AGB) of trees refers to the cumulative weight of the tree biomass aboveground, in a given area. The change in standing biomass over a period of time is called productivity (which is assessed based on biomass increment monitoring for 36 months, thrice during the past three decades). AGB is a valuable measure for assessing changes in forest structure [4, 13] and an essential aspect of studies of the carbon cycle. AGB data at a landscape scale can be used to understand changes in forest structure resulting from succession or to differentiate between forest types [7]. AGB was calculated using the basal area equation and belowground biomass calculated from indirect estimation [9, 40, 49, 56]. The region-specific allometric equations (Table 1) have been used to compute biomass [3, 9]. The study area falls in three diverse agro-climatic variations, i.e., coastal, Sahyadri interior, and plains. Probable relationship between basal area (BA), forest cover, and extent of interior forest (Eq. 1) is based on the field data coupled with land use data. The multiple regression analysis is done for estimating the relationship between a dependent (standing biomass) and independent variables (basal area, forest cover, percentage of interior forests computed from land use analysis). The probable relationship as per Eq. 1 was used for predicting the standing biomass and carbon stock in all grids.

$$\text{Standing biomass} = F\{\text{basal area},\ \text{interior forest},\ \text{forest cover}\} \quad (1)$$

Statistically significant equations based on the basal area with land use and interior forest are obtained and given in Eqs. 2, 3, and 4, respectively, for coastal, Sahyadri, and plains. Validation of basal area based on Eqs. 2–4 was done with the known basal area (collected through field sampling) in the respective grids (Fig. 6). Later, basal area (Table 2) for

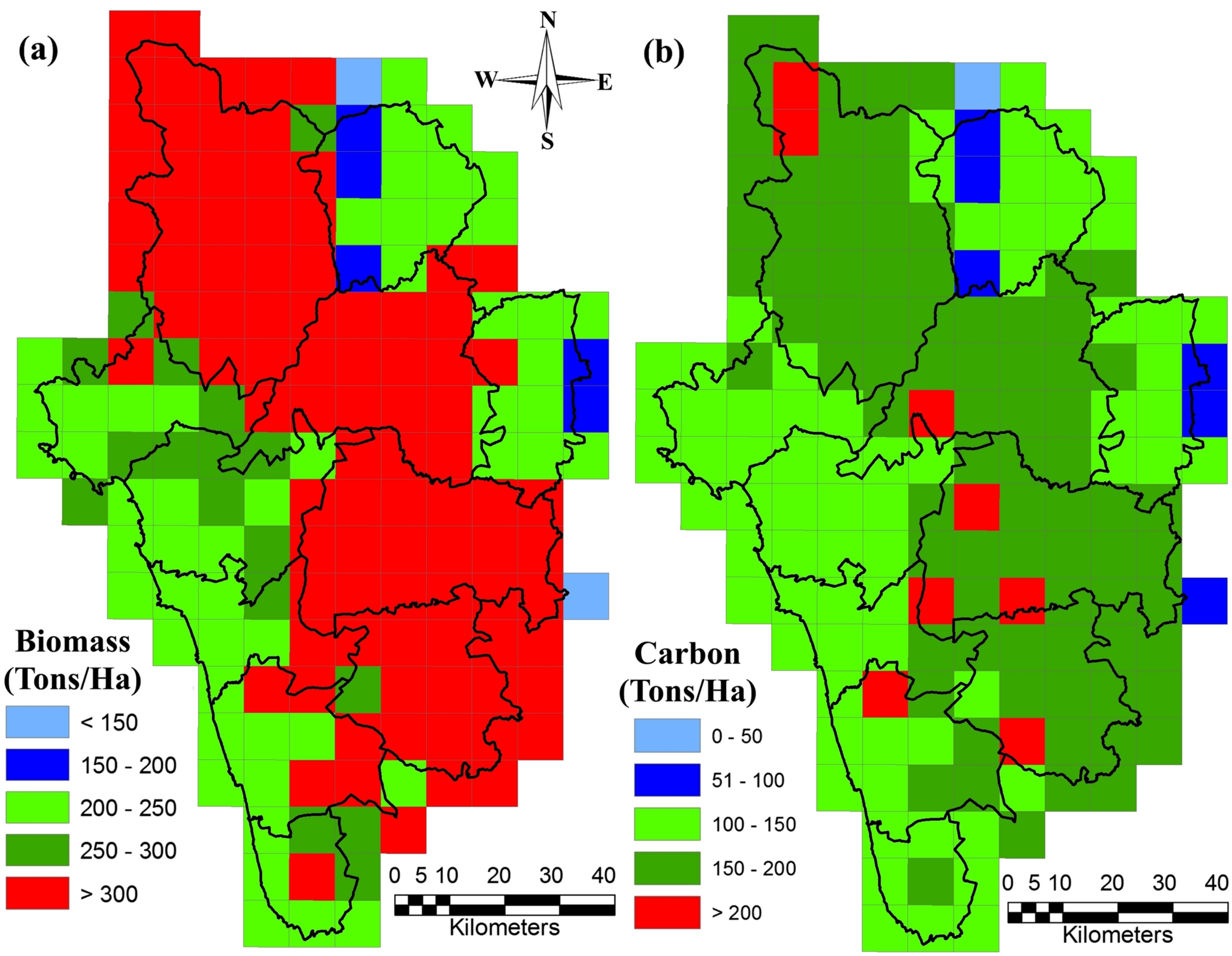


Fig. 6 Biomass estimate and carbon sequestrated per hectare

all grids in the coast, Sahyadri interior, and plains were computed considering forest land use and interior forests (in the respective grids) using Eqs. 2, 3, and 4.

For coastal region,

$$BA = \{30.1 + (0.0414 \times (\text{forest land use}) + 0.053 \times (\text{interior forest))}\}; \quad n = 50, SE = 6.2 \tag{2}$$

For Sahyadri interior region,

$$BA = \{39.1 + (-0.099 \times (\text{forest land use}) + 0.091 \times (\text{interior forest))}\}; \quad n = 55, SE = 6.3 \tag{3}$$

For plain region,

$$BA = \{34.8 + (-0.186 \times (\text{forest land use}) + 0.12 \times (\text{interior forest))}\}; \quad n = 11, SE = 5.5 \tag{4}$$

where n is a number of transects and SE refers to standard error. Comparisons of predicted (as per Eqs. 2, 3, and 4 for different agro-climatic regions) and quantified basal area from the field showed a reasonable agreement with the coefficient of determination (R) of 0.878 and standard error of 11.73 (Fig. 4). Parameters such as annual increment of biomass (standing biomass) and carbon were evaluated based on field measurement and the review of literatures [4, 9, 49, 50]. Carbon storage in forests is estimated by taking 50% of the biomass as carbon.

3.3 Forest Plantations

Afforestation activities are aimed at removal of emissions through improved carbon sequestrations with a green cover. Mitigating the carbon content from the atmosphere through the establishment of forest plantation on wastelands, community lands, and in agricultural land [24] would not only help in fulfilling the target of maintaining the green cover but also mitigation of changes in the climate [6], but unplanned intensified monoculture plantations have impacted the biodiversity [25]. Rapid conversion of forests for timber production, agriculture, and other uses has caused serious consequences on the ecology

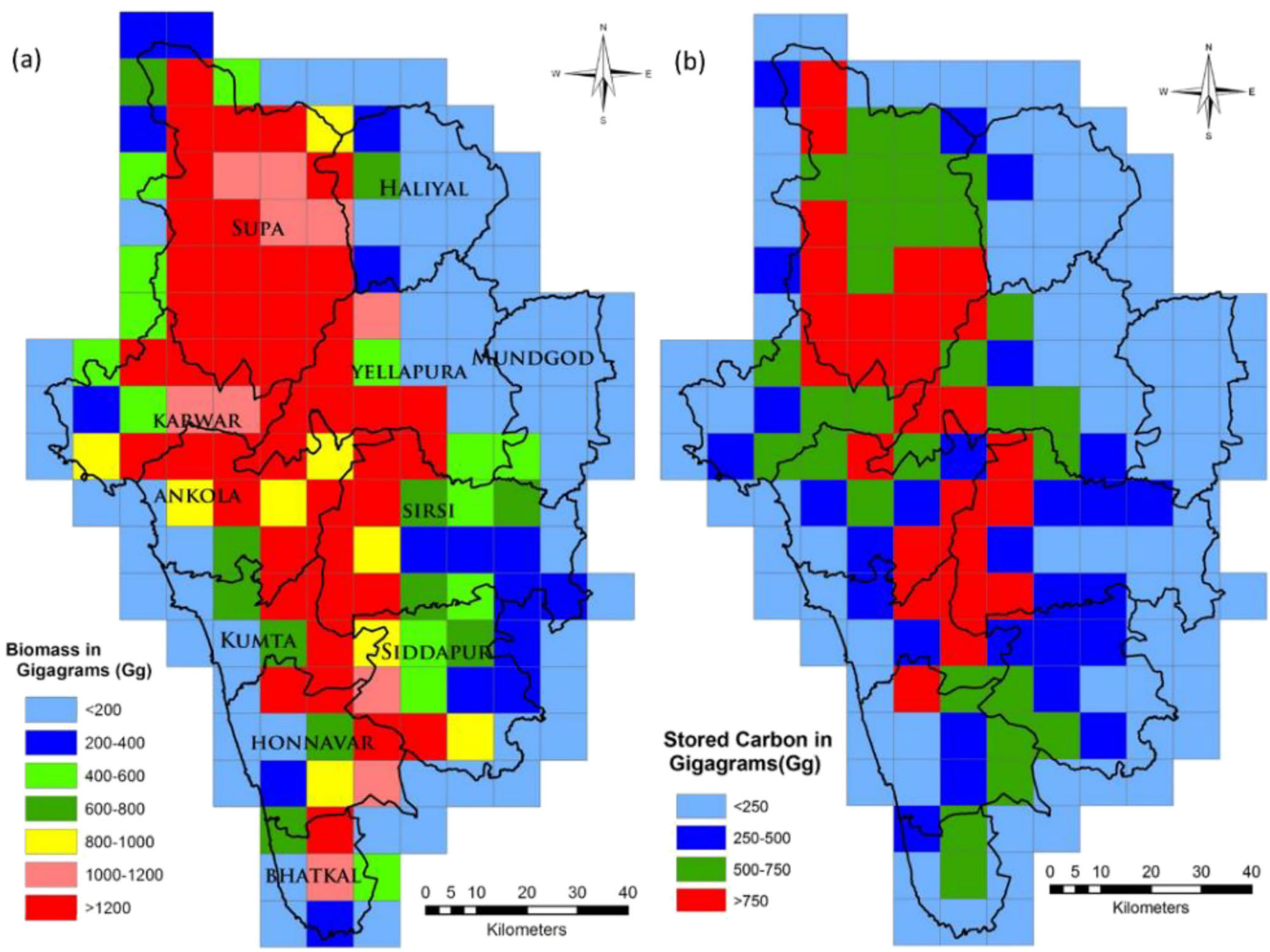


Fig. 7 Biomass estimated and carbon sequestrated in Gg

and biodiversity [34]. Monoculture plantations are associated with relatively low ecological values and may be vulnerable to disturbances caused by anthropogenic activities induced climate change. The expansion of monoculture plantations with the decline of native forest cove has accentuated extinction risk for many forest-dependent taxa [10] and also led to an increase in the acidity of soils, with long-term associated consequences for biodiversity and subsequent land cover [18, 32]. Carbon sequestration by monoculture plantations was estimated based on field measurements as well as published literatures. The comparative analyses of carbon uptake by the native forests with the monoculture plantations highlight the supremacy of natural vegetation in carbon sequestration.

3.4 Forest Soils

Forest soils are major sinks of carbon, approximately 3.1 times larger than the atmospheric pool of 800 GT [41]. The carbon is stored in the soil as soil organic matter (SOM) in both organic and inorganic forms. SOM input is determined by the root biomass and litter [31]. SOM is a complex mixture of carbon compounds, consisting of decomposing plant and animal tissue, microbes (protozoa, nematodes, fungi, and bacteria), and associated soil carbon minerals. SOM improves soil structure and enhances permeability while reducing erosion with bioremediation leads to the improved quality in groundwater and surface waters. Soil disturbance through deforestation also leads to increased erosion and nutrient leaching from soils [5], which have led to eutrophication and resultant algal blooms within inland aquatic and coastal ecosystems, ultimately resulting in dead zones in the ocean [42]. Soil carbon is calculated based on the field estimations in top 30 cm soil for different forests (Table 3) and mean soil carbon reported in literature [57].

4 Estimation of Sector-Wise Carbon Emissions

Carbon budgeting at the district level has been done considering ecosystem-wise carbon sequestration potential and sector-wise emissions using multiple datasets. Sector-wise

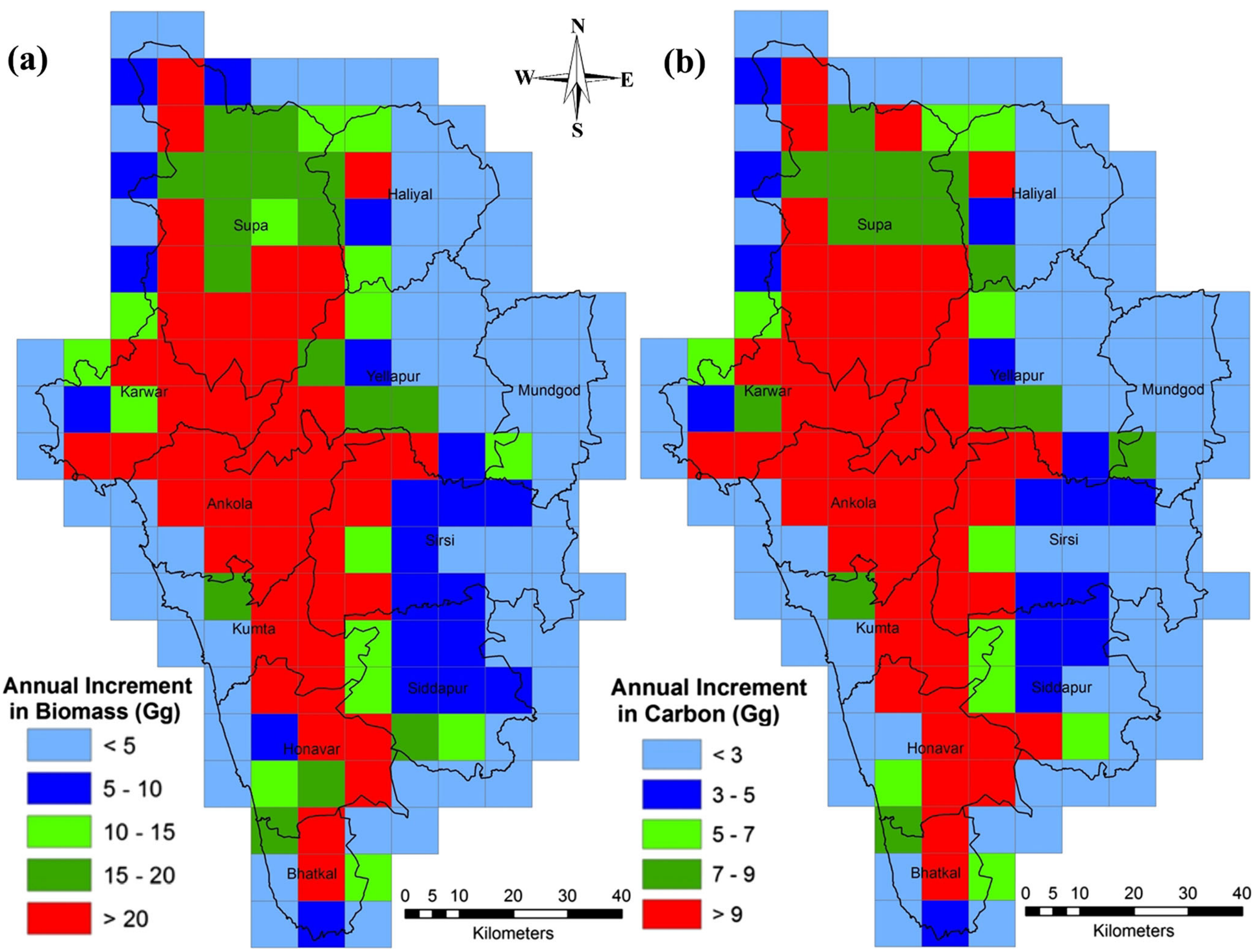


Fig. 8 Annual increment in biomass and carbon (Gg)

carbon emissions were compiled from literature [40, 49, 56, 57] and review of the emission experiments [42].

4.1 Livestock

Livestock is an important component of an agroecosystem, providing the critical energy input to the croplands required for plowing, threshing, and other farm operations. Animal dung used in the manufacture of organic manure provides the essential nutrients that enrich soil fertility and crop yields. Livestock produces methane (CH_4) emissions from enteric fermentation. CH_4 and N_2O (nitrous oxide) emissions are from livestock manure management systems and agriculture sector accounts approximately 20 and 35% of the global GHG emissions. The enteric fermentation in livestock alone accounts for nearly 70% of the global CH_4 emission [17, 23]. Methane emission assessment has been done for the district based on the emission factor details available at Indian emission inventories of GHG [20, 21, 33]. CH_4 emission factors of Indian livestock is based on dry matter intake (DMI) approach for different animal categories, and methane conversion factors were based on the feeding experiments [26, 65]. Methane emissions varied from 0.8 to 3.3 kg CH_4/animal/year, and N_2O emission factors varied from 3 to 11.7 mg/animal/year, which are lower than the IPCC default values. GHG emissions from livestock through enteric fermentation methane emission factor (EF_T) were calculated following IPCC, 2006 chapter 10–11 [17]. Livestock population [8] data was obtained from the State Veterinary Department, Government of Karnataka (Table 10, Appendix). Siddapur, Sirsi, Joida, and Yellapura are the potential regions for dairy development. Livestock density (Eq. 5) is computed village wise as per the Eq. 5.

$$D = {}^{P_i}/_{A} \quad (5)$$

where D is the livestock density, Pi is the livestock population, and A is the area of the region.

Methane emissions due to the enteric fermentation are computed as per Eq. 6, based on Tier 1 [17].

$$CH_4 \text{ enteric} = {}^{\sum_T (EF_T \times N_T)}/_{10^6} \quad (6)$$

where CH_4 enteric is CH_4 emissions from enteric fermentation, Gg CH_4/year; EF_T is the emission factor for the defined livestock category, kg CH_4/animal/year; NT is the number of

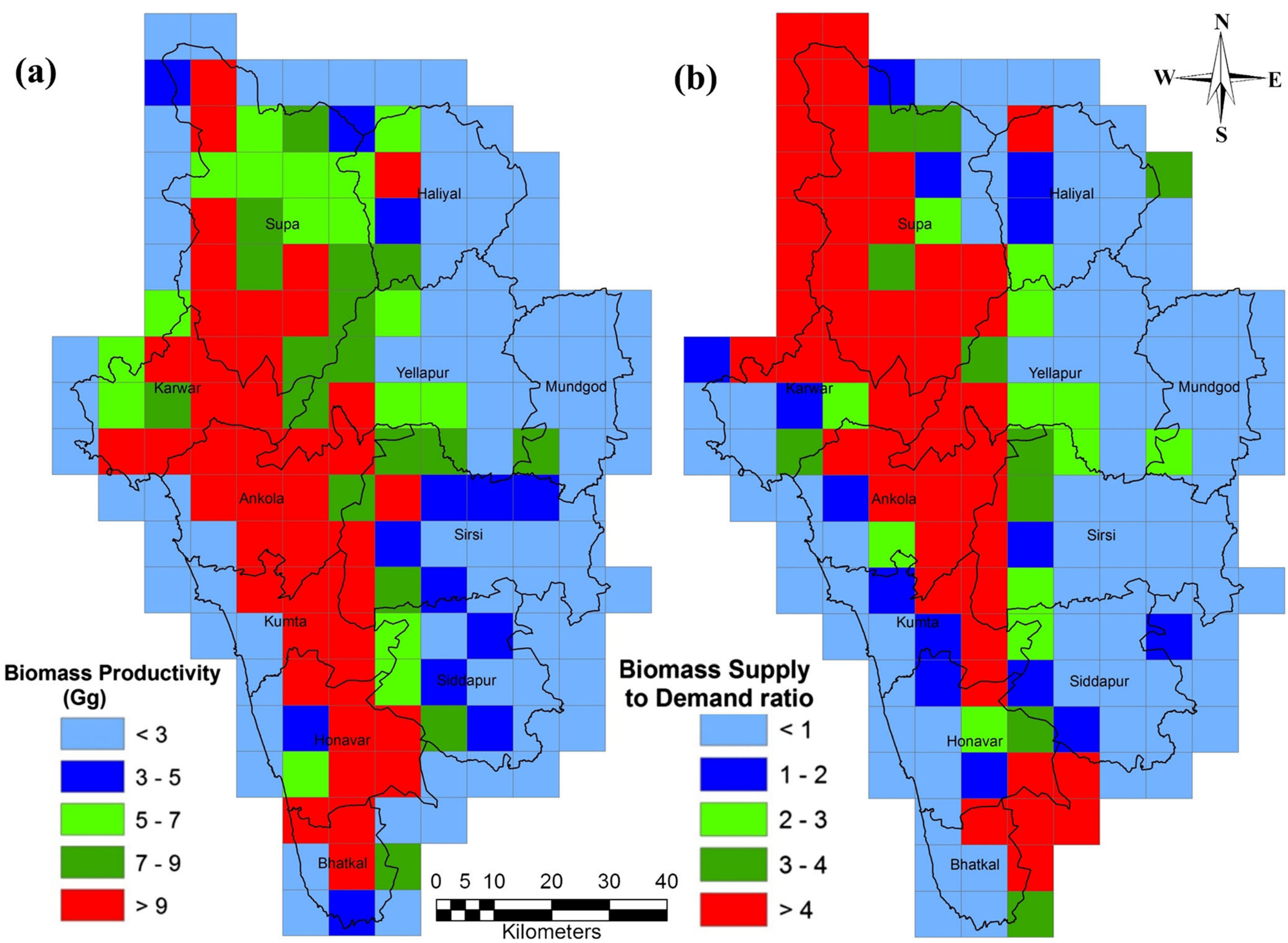


Fig. 9 Annual biomass productivity (deadwood, twigs, fallen branches, etc.) in Uttara Kannada (Gg) and supply to demand ratio based on population

animals of livestock for category T; and T is a category of livestock. EF_T for various livestock categories is listed in Table 11 (Appendix).

Emission factors for manure depend on the manure volatile solid content, temperature, and manure management practices. The emission factors EF_T (for various average annual temperatures) are given by IPCC for the respective livestock categories [49]. Methane emissions due to manure management are estimated using Eq. 7:

$$CH_4 \text{ manure} = {}^{\sum_T (EF_T \times N_T)}/_{10^6} \quad (7)$$

where CH_4 is methane emissions from manure (Gg CH_4/year) by area; EFT is the emission factor for the defined livestock category, kg CH_4/animal/year by region; NT is the number of head of livestock for category T in the region; and T is a category of livestock. Emission factors based on earlier field estimates were used to compute category-wise emission. Emission factor was 2.83 to 76.65 kg CH_4/animal/year (Table 12, Appendix) for enteric fermentation. Emission factor of 0.8 ± 0.04 to 3.3 ± 0.16 kg CH_4/animal/year was considered for manure management of bovines and 0.1 to 6 kg CH_4/animal/year for nonbovines.

4.2 Agriculture (Paddy Cultivation)

Agricultural sources are the largest global source of non-CO_2 emissions. Globally, 70% of methane emission was contributed by six anthropogenic sources and 20% of methane emission was contributed by paddy (*Oryza sativa* or *Oryza glaberrima*) cultivation. Methane is emitted from water stagnant paddy fields due to anaerobic fermentation of organic soil and is transported through rice plants, contributing to around 20% of the global methane budget [68]. CH_4 emissions are estimated by multiplying daily emission factors [17] by cultivation period of rice and annual harvested areas. Rice is a staple food and is grown in almost all villages, which occupies 30% of the total cropped area in the district. Rainfed water logged category of paddy fields constituting 41% of the total harvested area and methane emission is computed using Eq. 8:

$$CH_4 \text{ rice} = (EF \times t \times A) \quad (8)$$

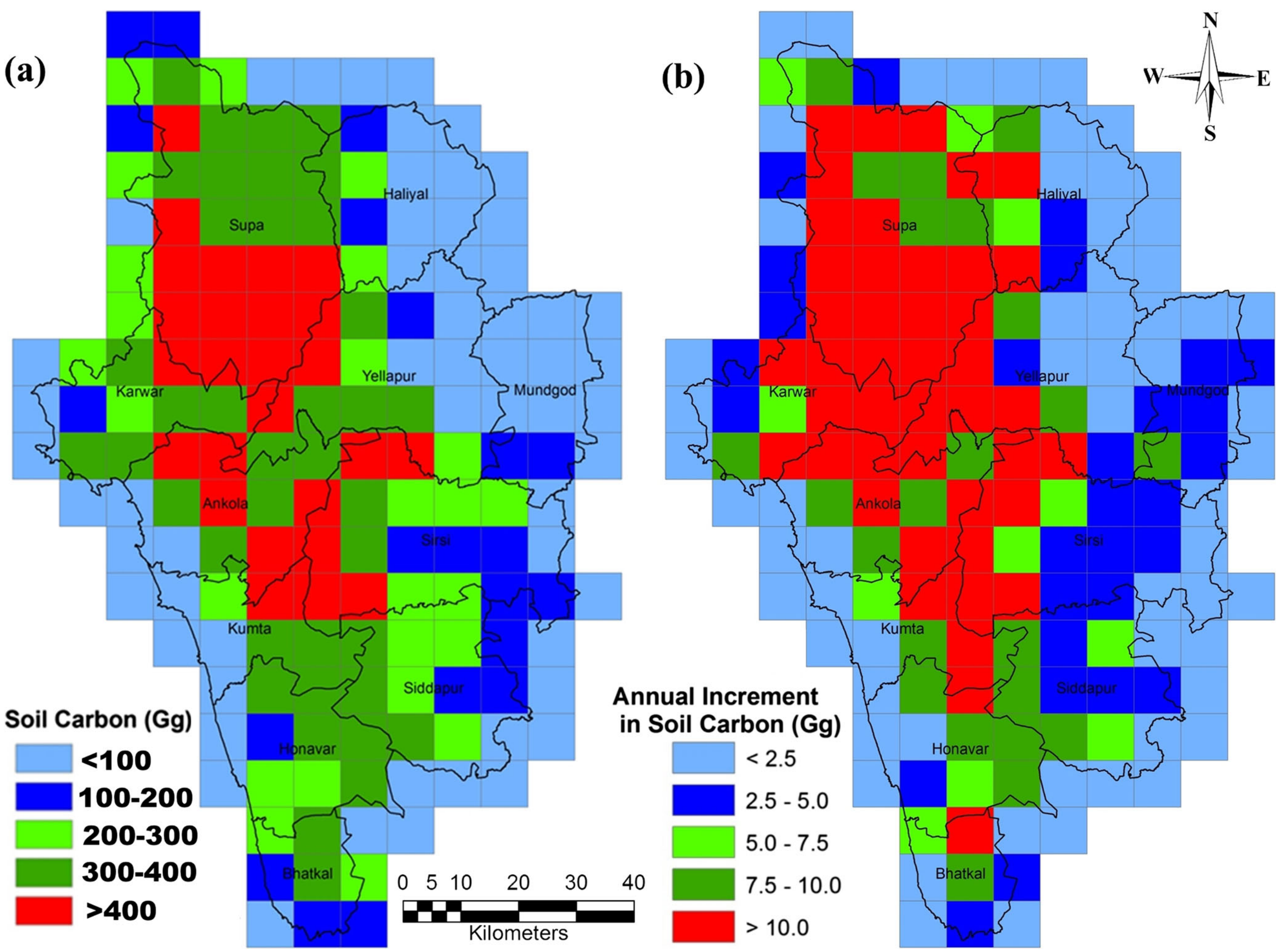


Fig. 10 Annual carbon sequestration and annual increment in soil

where CH_4 rice is the annual methane emissions from rice cultivation, Gg CH_4/year; EF is a daily emission factor for kg CH_4/ha/day; t is the cultivation period of rice; and A is the annual harvested area of rice ha/year. The EF was considered to be 0.45 Tg/year [57].

4.3 Fuelwood Consumption

Energy is a fundamental and strategic tool even to attain the minimum quality of life. The procurement of energy is also responsible in varying degrees for the ongoing deforestation, and loss of vegetation and topsoil [1, 36]. CO_2 release through incineration occurs at a much faster rate than decomposition because burning wood takes a few seconds and decomposition takes years. Inefficient and incomplete combustion of wood can result in elevated levels of greenhouse gases other than CO_2. The energy content of wood ranges from 14.89 to 16.2 megajoules per kilogram (4.5 to 5.2 kWh/kg). Per capita fuel consumption (PCFC) values (Table 4, computed as per Eq. 9) were analyzed to account fuel consumption pattern in various agro-climatic zones of the Uttara Kannada district and determine the carbon emissions due to fuelwood consumption at domestic level.

$$\mathrm{PCFC} = {}^{FC}/_{\sum Ai} \quad (9)$$

where PCFC is per capita fuel consumption, FC is the fuel consumed in kg/day, and Ai is number of adult equivalents, depending on the number of individuals and the age group ($i = 1$ for adult male, 0.8 for adult female, 0.6 for children (age group 6–18), 0.4 for children), for whom food was cooked. The emission is computed based on the field data of fuelwood consumption [49–51, 60] as per Eq. 10:

$$\text{Carbon dioxide emission} = (\text{No.of households} \times \text{PCFC} \times \text{emission factor}) \quad (10)$$

4.4 Transportation Sector

The basic infrastructures required for the region's economic growth are roads, railways, and water and air connectivity.

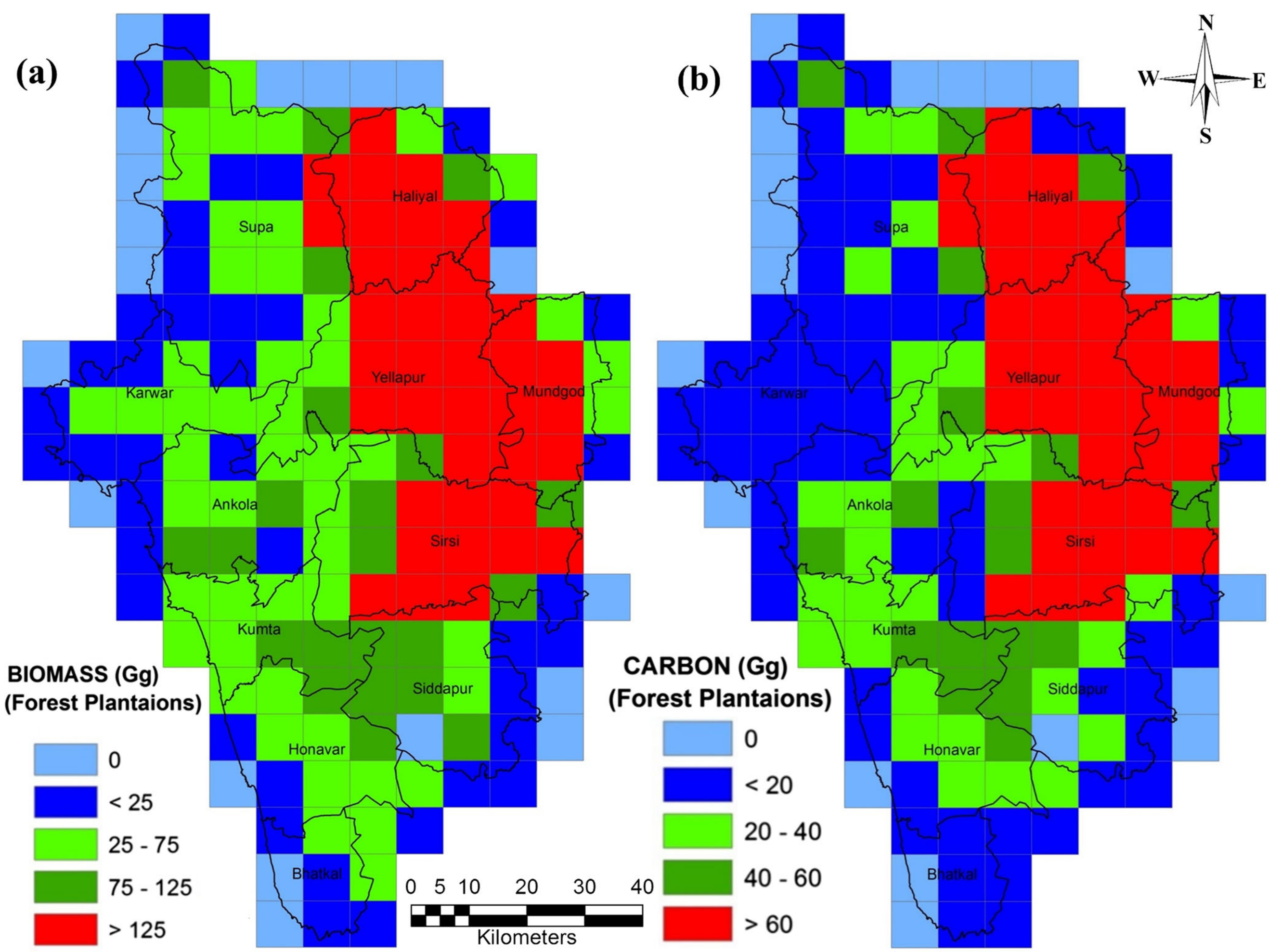


Fig. 11 Biomass and sequestration from forest plantations

The demand for infrastructure augmentation increases with the region's pursuit of development goals. The major pollutant emitted from transport are carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), nitrogen oxides (NO_x), nitrous oxide (N_2O), sulfur dioxide (SO_2), non-methane volatile organic compounds (NMVOC), particulate matter (PM), and hydrocarbon (HC). India stands at third biggest in crude oil consumption after China and USA. The transport sector in India consumes about 22% (56.1 mtoe (million tons of oil equivalent)) of total energy (255 Mt) [61]. Vehicular emissions account for about 60% of the GHGs from various activities in India [53]. Taluk wise transport details were collected (Table 14, Appendix), where Karwar has the highest number of goods vehicles and auto rickshaws. Sirsi has the highest number of vehicles (32,184) followed by Karwar with 26,820 vehicles. Region-specific emission factors based on the type of vehicle are compiled from various literature including regulatory agencies [12, 22, 38, 48, 58] (Table 14, Appendix). Vehicular emissions are calculated as per Eq. 11:

$$E_i = \sum\left(Veh_j \times D_j\right) \times E_{ij}km \tag{11}$$

where E_i is the emission of the compound; Veh_j is the number of vehicles per type (j); D_j is the distance traveled in a year per different vehicle type (j); and E_{ij} km is the emission of compound (i) from vehicle type (j) per driven kilometer.

5 Results

The source-wise carbon stock and sector-wise emissions have been computed for district-level carbon budgeting. Land uses were analyzed using remote sensing data, and emission factors from various sources were compiled. Land uses in Uttara Kannada region during 1973 to 2018 are depicted in Fig. 5, which indicates that the region now has the evergreen cover of 29.23% and moist deciduous forests account 16.07%. Plantations constitute 18.03% and horticulture covers 5.17%. The overall accuracy of classification is 82.52, 84.29, 90.0, and 90.96%, with kappa values of 0.81, 0.83, 0.88, and 0.89, respectively, for 1973, 1999, 2016, and 2018. Temporal analyses of LU reveal the trend of deforestation, evident from the reduction of evergreen–semievergreen forest cover from

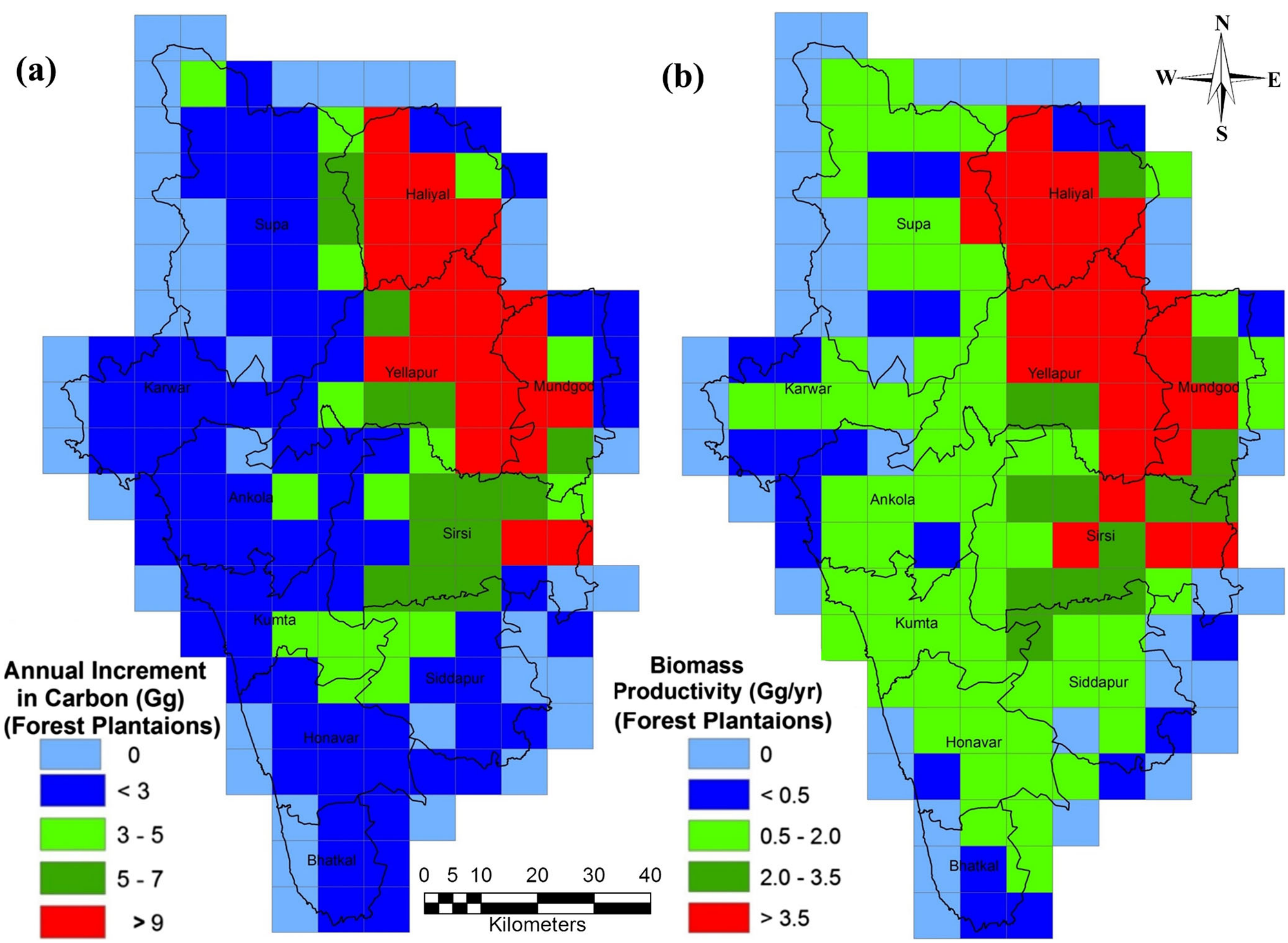


Fig. 12 Annual increment in carbon and biomass productivity from plantations

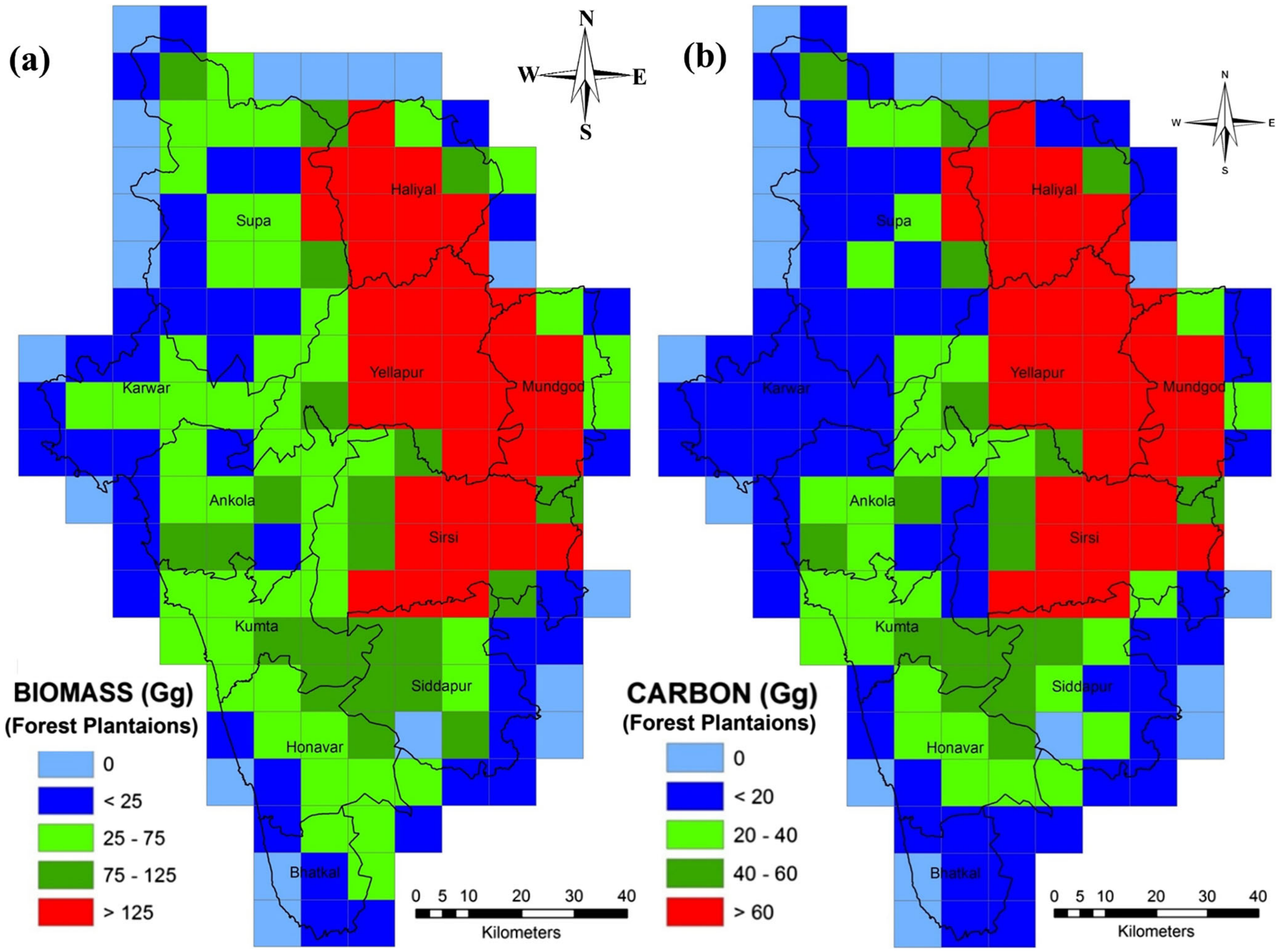


Fig. 13 Carbon sequestration in soil and annual increment in carbon from plantations

67.73% (1973) to 29.5% (2018) due to unplanned developmental activities and intensification of plantations. The transition of evergreen-semievergreen forests to moist deciduous forests is observed with increase in plantations (such as

Table 5 Emissions from enteric fermentation and manure (high case scenario)

Taluks	Number of animals (B)	Emissions from enteric fermentation (t/year) (Eef = B*EFT)	Emissions from manure (t/year) Ema = B* EFT	Total emissions (Eef + Ema)	
				(t/year)	Gg/year
Ankola	44,154	724.48	173.53	898.00	0.90
Bhatkal	37,267	611.48	146.46	757.94	0.76
Haliyal	72,908	1196.27	286.53	1482.80	1.48
Honnavar	64,189	1053.21	252.26	1305.48	1.31
Karwar	25,451	417.60	100.02	517.62	0.52
Kumta	53,585	879.22	210.59	1089.81	1.09
Mundgod	51,829	850.41	203.69	1054.10	1.05
Siddapur	71,227	1168.69	279.92	1448.61	1.45
Sirsi	88,413	1450.68	347.46	1798.14	1.80
Supa	33,772	554.13	132.72	686.85	0.69
Yellapura	52,134	855.41	204.89	1060.30	1.06
Uttara Kannada	594,929	9761.60	2338.07	12,099.67	12.10

Table 6 Emissions from enteric fermentation and manure (low case scenario)

Taluks	Number of animals (B)	Emissions from enteric fermentation (t/year) (Eef = B*EFT)	Emissions from manure (t/year) Ema = B* EFT	Total emissions (Eef + Ema)	
				(t/year)	Gg/year
Ankola	44,154	269.34	40.62	309.96	0.31
Bhatkal	37,267	227.33	34.29	261.61	0.26
Haliyal	72,908	444.74	67.08	511.81	0.51
Honnavar	64,189	391.55	59.05	450.61	0.45
Karwar	25,451	155.25	23.41	178.67	0.18
Kumta	53,585	326.87	49.30	376.17	0.38
Mundgod	51,829	316.16	47.68	363.84	0.36
Siddapur	71,227	434.48	65.53	500.01	0.50
Sirsi	88,413	539.32	81.34	620.66	0.62
Supa	33,772	206.01	31.07	237.08	0.24
Yellapura	52,134	318.02	47.96	365.98	0.37
Uttara Kannada	594,929	3629.07	547.33	4176.40	4.18

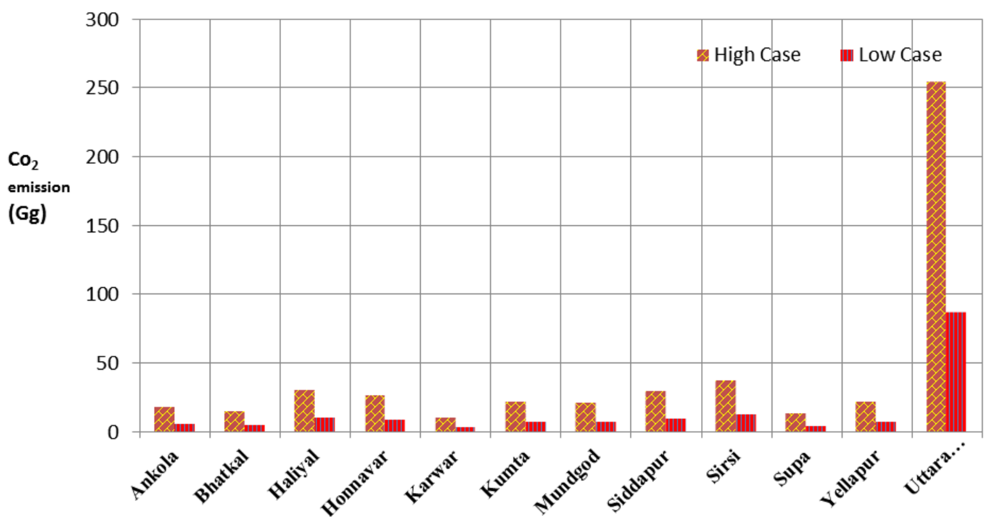


Fig. 14 CO_2 emission from livestock in Uttara Kannada

Table 7 Taluk wise methane and CO_2 emissions from paddy fields

Taluks	Area under paddy cultivation (ha)	Production in tons	Methane emission		Gg CO_2 equivalent/year (GWP = 21)
			(t/year)	Gg	
Ankola	5900	17,106	389.4	0.39	8.18
Bhatkal	4270	12,380	281.82	0.28	5.92
Haliyal	13,705	39,736	904.53	0.90	19.00
Honnavar	4559	13,218	300.894	0.30	6.32
Karwar	3374	9783	222.684	0.22	4.68
Kumta	5391	15,706	355.806	0.36	7.47
Mundgod	10,631	33,117	701.646	0.70	14.73
Siddapur	6594	20,029	435.204	0.44	9.14
Sirsi	9401	27,898	620.466	0.62	13.03
Supa	5208	15,100	343.728	0.34	7.22
Yellapura	4252	15,549	280.632	0.28	5.89
Uttara Kannada	73,285	219,622	4836.81	4.84	101.57

Acacia auriculiformis, *Casuarina equisetifolia*, *Eucalyptus* spp., *Tectona grandis*, etc.) constitute 16%. Human habitations have increased during the last four decades, evident from the increase of built-up area from 0.38% (1973) to 5.23% (2018). During 1973 to 2018, the district has witnessed about 398,963 ha loss of evergreen forests. Rapid LU changes are observed due to increased agriculture to meet the growing demand of population and large-scale developmental activities in the heart of evergreen forest cover. The deforestation has increased due to various anthropogenic activities, impacting the local ecology and increasing carbon emissions.

5.1 Carbon Sequestration by Forests

Biomass and carbon sequestration were estimated for each grid based in forest category (Fig. 6a, b) with the help of biomass data. Sahyadri region shows higher standing biomass (> 300 t/ha) due to the spatial extent of forests and in particular interior forests. In contrast to this, grids in the coastal and plains taluks have moderate and lower values of biomass per hectare. The total standing biomass of the district is 118,627.58 Gg. Grids in the Sahyadri region have higher storage of carbon than the other two regions (Fig. 7a, b). Sahyadri region (Supa, Sirsi, Yellapura) have a higher biomass of > 1200 Gg. Coastal region (Karwar, Ankola, Kumta, Honnavar) is with moderate biomass. The plains and part of coastal regions are with the lower biomass (< 200 Gg) due to higher forest degradation. The plains taluks mainly consist of agriculture lands, built-up environments, and sparse deciduous forest cover. Carbon sequestered by forests accounts to 59,313.8 Gg, and forests in Supa, Yellapura, and Sirsi regions have stored higher carbon (600–800 and > 800 Gg) compared to the plains and part of coastal regions. Sahyadri region with protected areas and "sacred kan" forests have sequestered higher carbon, emphasizing the need for protecting sacred forests to mitigate impending changes in the climate due to global warming (Fig. 8).

Bioenergy availability from forests is assessed as 80–85% population in this region [51] depends on fuelwood as a major source for cooking, heating, etc. Fuelwood demand is quantified for each grid considering the population and the annual PCFC (0.77 t/person/year). The population density for each grid as per 2011 population census (Appendix, Fig. 18) used for computing supply (availability) to demand ratio is computed to assess the bioenergy status in each grid, considering the annual biomass productivity and fuelwood demand in each grid. The supply (availability) to demand ratio is computed to assess the bioenergy status in each grid, considering the annual biomass productivity (Fig. 9a) and fuelwood demand in each grid. The bioenergy status of the district refers to the ratio of bioenergy availability to the demand. The ratio less than 1 indicates fuelwood scarcity situation, while the ratio greater than 1 indicates adequate availability of fuelwood.

Table 9 Taluk wise carbon emission and sequestration from various sectors

Taluks	Emission (CO_2 equivalent per year)					Carbon uptake (per year)			CBR
	Transport (Gg)	Livestock (Gg)	Agriculture (Gg)	Fuelwood (Gg)	Total (Gg)	Natural forest (vegetation + soil) (Gg)	Forest plantation (vegetation + soil) (Gg)	Total uptake (Gg)	
Ankola	37.22	6.51	8.18	5.64	57.55	358.03	38.91	396.94	6.90
Bhatkal	33.76	5.49	5.92	6.74	51.92	82.65	6.08	88.72	1.71
Honnavar	42.71	9.46	6.32	8.79	67.28	174.81	31.18	205.99	3.06
Karwar	79.70	3.75	4.68	9.45	97.57	257.51	15.92	273.42	2.80
Kumta	42.00	7.90	7.47	7.57	64.93	152.10	34.68	186.78	2.88
Siddapur	13.39	10.50	9.14	6.01	39.04	126.15	46.46	172.61	4.42
Sirsi	99.02	13.03	13.03	10.53	135.6	255.53	139.20	394.73	2.91
Supa	9.80	4.98	7.22	2.97	24.96	610.67	71.58	682.25	27.3
Yellapura	17.28	7.69	5.89	4.46	35.32	238.50	270.61	509.11	14.4
Haliyal	46.74	10.75	19.00	9.73	86.21	117.04	179.77	296.81	3.44
Mundgod	16.27	7.64	14.73	5.30	43.95	43.71	128.91	172.62	3.93
Uttara Kannada	437.87	87.70	101.57	77.2	704.4	2416.69	963.28	3379.9	4.80

Table 8 Agro-climatic region's carbon dioxide emissions from fuelwood consumption

Coastal region				
Taluk	No. of households (NH)	NH*PCFC (PCFC = 2.01 kg/person/day)	Carbon emission	
			(t/year)	Gg of carbon/year
Ankola	21,079	42,368.79	5644.58	5.64
Bhatkal	25,188	50,627.88	6744.90	6.74
Honnavar	32,808	65,944.08	8785.40	*8.79*
Karwar	35,273	70,898.73	9445.48	*9.45*
Kumta	28,251	56,784.51	7565.12	*7.57*
Sahyadri interior				
Taluk	No. of households (NH)	NH*PCFC (PCFC = 2.19 kg/person/day)	Carbon emission	
			(t/year)	Gg of carbon/year
Siddapura	20,598	45,109.62	6009.73	*6.01*
Sirsi	36,103	79,065.57	10,533.51	10.53
Supa	10,186	22,307.34	2971.90	2.97
Yellapura	15,292	33,489.48	4461.64	4.46
Plains				
Taluk	No. of households (NH)	NH*PCFC (PCFC = 2.32 kg/person/day)	Carbon emission	
			(t/year)	Gg of carbon/year
Haliyal	31,481	73,035.92	9730.21	*9.73*
Mundgod	17,163	39,818.16	5304.77	5.30
	Uttara Kannada			77.2

The supply to demand ratio (Fig. 9b) shows Supa taluk is having higher ratio revealing surplus biomass availability due to higher forest cover and lower demand. The central parts of grids (Karwar, Ankola, Sirsi) also show higher availability due to the higher forest in those regions, whereas towards the west in Karwar, Ankola, and east part of Sirsi region shows lower ratio due to higher demand (presence of a larger population). Bhatkal, Haliyal, Mundgod, and eastern part of Yellapura and Siddapur have the scarcity of resources evident from the supply to demand ratio less than 1. Fuelwood scarcity is evident in thickly populated plains and coastal taluks, necessitating the policy interventions to augment bioresources apart from viable energy alternatives.

Soil carbon constitutes the biggest terrestrial carbon pool. The net storage of forest soil carbon in Uttara Kannada district is 59,693.44 Gg, and Fig. 10a gives grid-wise carbon sequestered in forest soil. The annual increment of 958.81 Gg is depicted grid-wise in Fig. 10b. The taluk wise carbon sequestration by forest soils depicts that Supa (18,585.35 Gg), Ankola (7460.48 Gg), Sirsi (7469 Gg), and Yellapura (6331.05 Gg) have higher soil carbon due to good tree vegetation cover in the region. Bhatkal (1637 Gg) and Mundgod

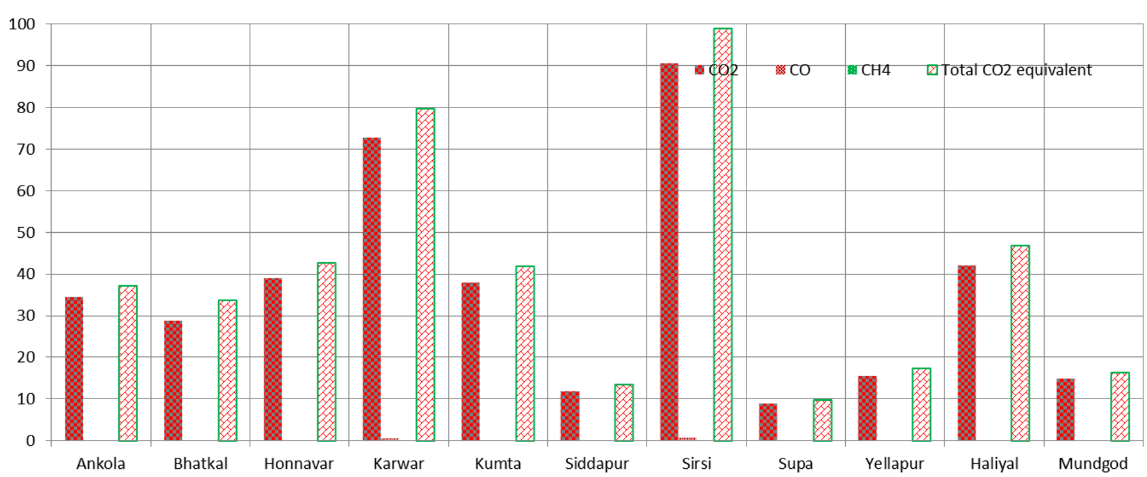


Fig. 15 CO_2 emission from transportation in Uttara Kannada

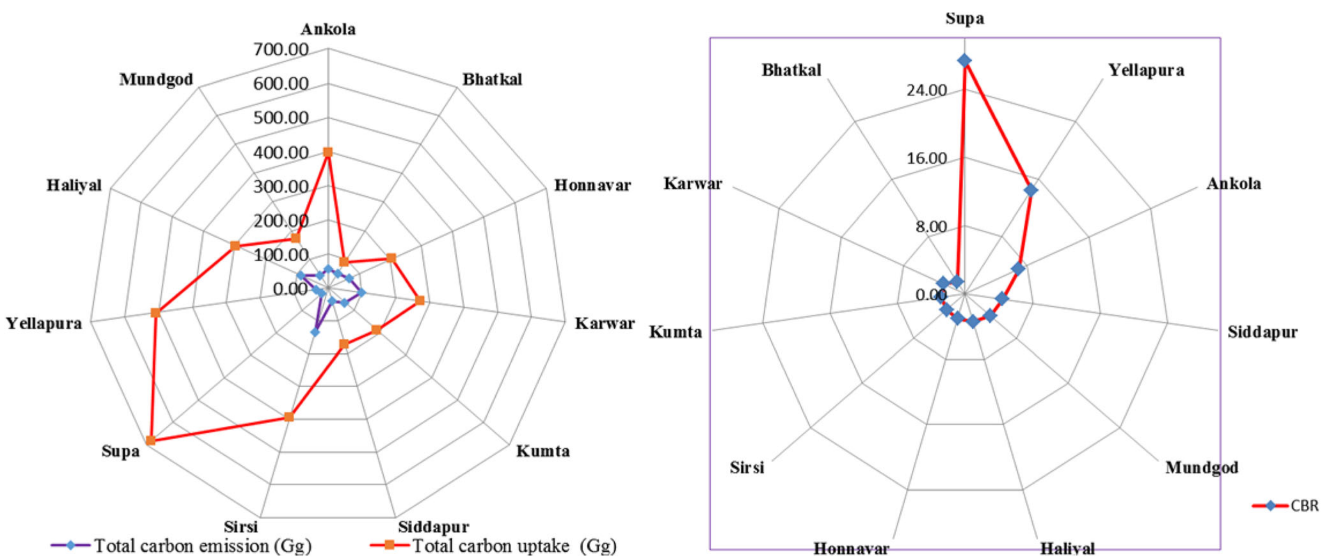


Fig. 16 Taluk wise estimates of carbon sink, sources, and carbon status

(595.49 Gg) taluks have very low soil carbon due to deforestation.

5.2 Biomass Estimation in Forest Plantations

Field-based estimates were carried out to compare the carbon sequestration potential in native forest and managed plantations in hilly regions of Uttara Kannada district. The spatial extent of forest plantations (land use analysis) is computed for each grid (Fig. 11a). The field-based estimates of transect data provided the status of biomass (77.54 t/ha). This is compared with the earlier estimates and used to estimate biomass as well as carbon stored in each grid of the district. The total accumulated biomass of Uttara Kannada district from forest plantation accounts to 14,228.08 Gg (Fig. 11b). The spatial extent of forest plantations of Acacia, Eucalyptus, Teak, and other hard and softwood plantations ranges from 25,957 (Mundgod) to 27,426 (Sirsi), 37,007 (Haliyal), and 49,703 ha (Yellapura). Haliyal, Yellapura, Mundgod, and Sirsi taluks are with higher biomass (> 125 Gg) while Siddapur and Kumta have moderate biomass (75–125 Gg). The carbon sequestered in plantations is about 7441 Gg. Higher carbon storage is in plantations of Haliyal, Yellapura, Mundgod, and Sirsi (> 60 Gg) while native vegetation has carbon of 100 to 250 Gg. Annual increment in forest plantation biomass in the district is about 1055.55 Gg/year (Fig. 12a) and carbon is 527.77 Gg/year (Fig. 12b). Haliyal (biomass > 12; carbon > 9 Gg), Yellapura (> 12; > 9 Gg), part of Mundgod (> 12; > 9 Gg) have a higher annual increment in biomass as well as carbon. Figure 13a reflects the carbon stored in soils of plantations. The annual increment in carbon by the soil of forest plantations given in Fig. 13b shows that Haliyal, Yellapura, and Mundgod have greater than 6 Gg due to the higher area under plantations. As compared with natural forests, plantations did not show any significant values of CO_2 sequestration. In absence of forests, plantations can be considered an alternative solution to fix carbon.

5.3 Carbon Emissions

Livestock management in Uttara Kannada offers opportunities for reducing GHG emissions through biogas production from readily available source of manure to replace fossil fuel or forest wood usage. Methane emissions from manure management tend to be smaller than enteric emissions. Two scenarios (low and high) were considered to analyze potentiality of the region. Tables 5 and 6 list methane emissions from enteric fermentation and manure (under high as well as lower case scenarios), respectively. Methane from animal wastes is an alternative viable rural energy, providing sufficient feedstock. Energy and biogas potential of livestock residues of all major groups of animals were estimated based on the livestock population (2011). It was seen that Sirsi, Honnavar, and Siddapur had the highest biogas potential. Analyses reveal that the domestic energy requirement can be met by biogas option in 428 villages in Uttara Kannada district for more than 60% population. This highlights optimal use of resources (animal residues) for energy (biogas generation) as well as manure.

CO_2 emission analysis from fermentation and manure in low case scenario, reveals that taluks such as Sirsi, Siddapur Haliyal has the highest CO_2 emissions in both processes. The least values are in Karwar and Supa taluks (Fig. 14).

Paddy is grown in two seasons, viz., Kharif (June/July) and rabi or summer (January/February). In all the rice-growing ecosystems, Kharif sowing is common while during the summer season, the crop is cultivated mainly in the irrigated areas and the tank-fed areas. In each taluk, nearly 60–80% of the total area is covered during Kharif (wet) season while the remaining area is occupied in late Kharif and summer (dry) season. The taluk wise area under paddy cultivation is shown in Table 7. The total methane emission from Uttara Kannada paddy cultivation is estimated to be 4.84 Gg/year, and its CO_2 equivalent is 101.57 Gg. Higher paddy cultivation can be seen in Haliyal, Mundgod, and Sirsi taluks. The methane emission (Gg) is more in Haliyal (0.90), Mundgod (0.70), and Sirsi (0.62) due to the presence of both rainfed and tank-based irrigations. The least can be seen in Karwar taluk (0.22) with an area of 3377 ha under paddy.

Emission from fuelwood is computed, which shows that the coastal taluks (Karwar, Honnavar, Kumta), Sahyadri

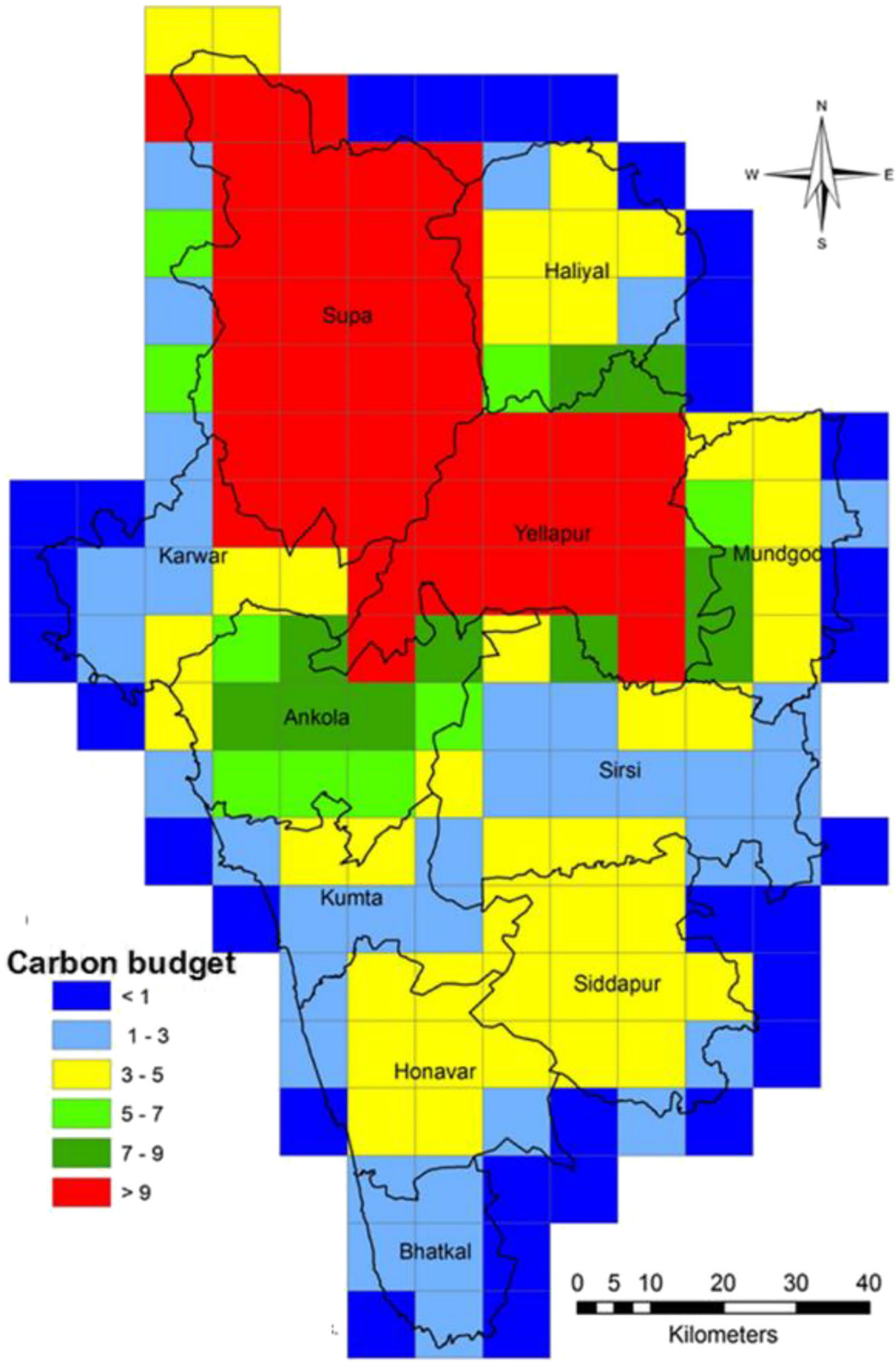


Fig. 17 Carbon status in Uttara Kannada district

taluks (Sirsi and Siddapura), and plains (Haliyal) have higher emissions of carbon. The overall emission from fuelwood consumption of district accounts to be 77.2 Gg. Supa taluk (2.97 Gg) and Yellapura (4.46 Gg) are having least emission values among all taluks (Table 8).

Transportation is another major sector of CO_2 emission. The taluk wise vehicle details are analyzed and emission from CO_2, CO, and CH_4 is estimated and converted to CO_2 equivalent. The distance traveled by each vehicle type and emission factors considered are shown in Table 9. The total emission from transportation sector of Uttara Kannada accounts to be 424.9 Gg. The total CO_2, CH_4, and CO from Uttara Kannada transport is 396.93 Gg, 1.72 Gg, and 3.19 Gg, respectively (Table 9). The taluk wise estimate shows that Karwar (Gg) and Sirsi (Gg) have higher CO_2 as well as CO emissions (Fig. 15). The CH_4 emissions are more in Yellapura (29.31 Gg), Sirsi (24.31 Gg), and Kumta (23.59 Gg).

5.4 Carbon Budgeting in Uttara Kannada

Carbon budgeting would provide information of GHG emissions (especially CO_2 in the atmosphere, and on the carbon cycle in general), which helps in implementing strategies to mitigate carbon emissions and manage dynamics of the carbon–climate–human system. The ratio of carbon sinks to sources would provide the carbon status in the region. Table 9 and Fig. 16 show various sources and sinks of carbon in the region at taluk level. The total carbon sequestered from natural vegetation and soil at the district level is 2416.69 Gg. The forest plantation accumulates 963.28 Gg at the district level. The higher accumulation can be seen in Yellapura, Haliyal, Sirsi, and Mundgod covering the major part of the region under plantations. Bhatkal and Karwar taluks show least values. Carbon status computation (Fig. 17) shows that Supa (27.33), Yellapura (14.41), and Ankola (6.90) are having higher values, revealing that the taluks are aiding in higher carbon sequestration as the area under forest cover.

6 Conclusion

Forest ecosystems play a pivotal role in managing carbon in the global carbon cycle, vital habitats of many animal and plant species, retaining water, groundwater recharge, preventing soil erosion and reduction of mud or landslides (as roots help in binding the soil). Based on the detailed investigation and synthesis of biomass resource availability and demand data, the study categorizes the Uttara Kannada district into two zones, i.e., biomass surplus zone (consisting of taluks mainly from the Sahyadri interior) and biomass deficit zone (consisting of thickly populated plains and coastal taluks such as Bhatkal, Honnavar, Kumta, Mundgod, and Haliyal). Total accumulated biomass of natural forest of the district is 118,627.54 Gg. The present study reveals that the total carbon emitted from major sectors (livestock, paddy cultivation, transportation, and fuel consumption) was 704.35 Gg/year and carbon sequestered is 3379.97 Gg/year. The taluk wise assessment shows Supa (682.25 Gg/year), Yellapura (509.11 Gg/year), and Ankola (396.94 Gg/year) of carbon stored. Least values can be seen in Mundgod and Bhatkal taluks. Supa taluk has a positive carbon status (of 27.33) due to the presence of higher spatial extent of protected forests with moderate disturbances. The least values are in Mundgod, Bhatkal, and Haliyal due to higher anthropogenic activities and disturbed forests. Renewable energy technologies are prompted for energy requirement in this ecologically sensitive region as they generate near-zero emissions of GHGs. Generation-based incentives would help in the large-scale penetration of renewable energy technologies. This would also bring down the local pressure on the forests. Arresting deforestation in ecologically sensitive regions such as the Western Ghats by regulating large-scale LU changes and promoting afforestation through the planting of native species are cost-effective ways of reducing greenhouse gas emissions and mitigation of impending changes in the climate. Creation of *people's nurseries* across all regions is encouraged to get ready saplings instead of centralized nurseries of the forest department, which also generate more of rural employment potential. Biomass enrichment is an urgent necessity, and poor grade tree plantations of Haliyal, Mundgod, and Kirvathi division of Yellapura regions need to be restored with natural forest species through the planting of saplings and seeds to enhance eroded soils. The effective forest management with forest regeneration activities with native species would help in further enhancing carbon status of a region.

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Appendix

Table 10 The livestock available at category wise of Uttara Kannada region for the year 2011

Taluk	Livestock category								
	Cattle	Buffalo	Pig	Sheep	Goat	Rabbits	Dogs	Others	Taluk total
Ankola	28,570	5967	0	0	40	2	9575	0	44,154
Bhatkal	24,619	6094	84	0	110	44	6316	0	37,267
Haliyal	41,485	20,820	32	354	3738	58	6421	0	72,908
Honnavar	47,828	8849	83	18	6	9	7396	0	64,189
Karwar	11,218	5460	294	55	4	85	8335	0	25,451
Kumta	35,891	5820	6	0	18	3	11,847	0	53,585
Mundgod	32,122	8686	62	1433	3039	8	6460	19	51,829
Siddapur	43,881	18,897	0	128	235	0	8080	6	71,227
Sirsi	52,230	18,845	24	673	3101	44	13,488	8	88,413
Supa	19,052	8224	0	0	843	6	5647	0	33,772
Yellapur	30,053	11,007	315	41	860	18	9838	2	52,134
Uttara Kannada	366,949	118,669	900	2702	11,994	277	93,403	35	594,929

Table 11 Emission factors for enteric fermentation

Source categories	Details	Emission factors (kg CH_4/animal/year)
Cattle	Cattle-crossbred (male), 4–12 months	9.02
	Cattle-crossbred (male), 1–3 years	19.67
	Cattle-crossbred (male), 3 years breeding	36.14
	Cattle-crossbred male, working	36.31
	Cattle-crossbred (male), breeding and working	34.05
	Cattle-crossbred (male), others	26.07
	Cattle-crossbred (female), 4–12 months	9.71
	Cattle-crossbred (female), 1–3 years	21.31
	Cattle-crossbred (female), milking	38.83
	Cattle-crossbred (female), dry	38.51
	Cattle-crossbred (female), heifer	21.49
	Cattle-crossbred (female), others	23.6
	Cattle-indigenous (male), 0–12 months	7.6
	Cattle-indigenous (male), 1–3 years	16.36
	Cattle-indigenous (male, < 3 years breeding	34.86
	Cattle-indigenous (male), working	32.94
	Cattle-indigenous (male), breeding and working	29.42
	Cattle-indigenous (male), others	24.37
	Cattle-indigenous (female), 4–12 months	7.39
	Cattle-indigenous female, 1–3 years	15.39
	Cattle-indigenous (female), milking	35.97
	Cattle-indigenous (female), dry	29.38
	Cattle-indigenous (female), heifer	22.42
	Cattle-indigenous (female), others	24.1
Buffalo	Buffalo (male), 0–12 months	5.09
	Buffalo (male), 1–3 years	14.78
	Buffalo (male), < 3 years breeding	58.69
	Buffalo (male), working	66.15
	Buffalo (male), breeding and working	54.28
	Buffalo (male), others	60.61
	Buffalo (female), 0–1 month	6.06
	Buffalo (female), 1–3 years	17.35
	Buffalo (female), milking	76.65
	Buffalo (female), dry	56.28
	Buffalo (female), heifer	36.81
	Buffalo (female), others	38.99
Goat	Goat (male), < 1 year	2.83
	Goat (male), > 1 year	4.23
	Goat (female) < 1 year	2.92
	Goat (female, < 1 year milking)	4.99
	Goat (female), < 1 year dry	4.93
Sheep	Sheep	3.67
Others	Others	8.64
Livestock enteric fermentation [65]		

Table 12 Emission factors for manure

Source categories	Details	Emission factors (kg CH_4/animal/year)
Cattle	Dairy cattle (crossbred), adult	3.3 ± 0.16
	Dairy cattle (indigenous), adult	2.7 ± 0.13
	Non-dairy cattle (crossbred), 0–1 year	0.8 ± 0.04
	Non-dairy cattle (crossbred), 1–2.5 years	1.7 ± 0.08
	Non-dairy cattle (crossbred), adult	2.3 ± 0.11
	Non-dairy cattle (indigenous), 0–1 year	0.8 ± 0.04
	Non-dairy cattle (indigenous), 1–3 years	2 ± 0.1
	Non-dairy cattle (crossbred), adult	2.8 ± 0.14
Buffalo	Dairy buffalo	3.3 ± 0.06
	Non-dairy buffalo, 0–1 year	1.2 ± 0.02
	Non-dairy buffalo, 1–3 years	2.3 ± 0.04
	Non-dairy buffalo, adult	2.7 ± 0.05
Livestock manure management [26, 25]		

Table 13 Taluk wise transport and communication of Uttara Kannada district

Taluks	Motorcycles	Car	Cabs	Auto rickshaws	Omnibuses	Tractors and trailers	Ambulance	Goods vehicle	Others
Ankola	8141	775	55	341	124	31	10	592	406
Bhatkal	16,776	1056	117	1078	76	41	6	353	467
Haliyal	14,705	968	28	289	184	751	11	566	309
Honnavar	11,479	687	145	449	177	22	8	645	376
Karwar	21,763	1601	139	1018	325	85	12	1129	748
Kumta	12,835	989	159	557	36	22	11	741	534
Mundgod	4171	275	11	87	35	574	4	227	105
Siddapur	4970	226	12	81	38	90	2	204	94
Sirsi	26,001	1792	118	678	316	423	16	1545	1295
Supa	2423	400	25	9	39	96	8	89	63
Yellapura	5339	304	15	110	35	154	4	293	105
Total	128,603	9073	824	4697	1385	2289	92	6384	4502

Table 14 Emission factors for vehicular emission

Type of vehicle	Emission factors (g/km)			Reference
	CO_2	CH_4	CO	
Two wheelers for 2001–2005			2.2	CPCB [12]
Motorcycles	26.6			Mittal and Sharma [37]
Motorcycles		0.18		EEA [16]
Auto rickshaw	60.3			Mittal and Sharma [37]
Auto rickshaw		0.18		EEA [16]
Passenger car gasoline(PCG)			2	CPCB [12]
Cars	223.6			Mittal and Sharma [37]
Cars		0.17		EEA [16]
Taxi	208.3			Mittal and Sharma [37]
Taxi		0.01		EEA [16]
Taxi			1	CPCB [12]
Busses	515.2			Mittal and Sharma [37]
Busses		0.09		EEA [16]
Busses			3.6	CPCB [12]
Goods vehicles	515.2			Mittal and Sharma [37]
Goods vehicles		0.09		EEA [16]
Trucks			3.6	CPCB [12]
Light commercial vehicles (LCV)			5.1	CPCB [12]

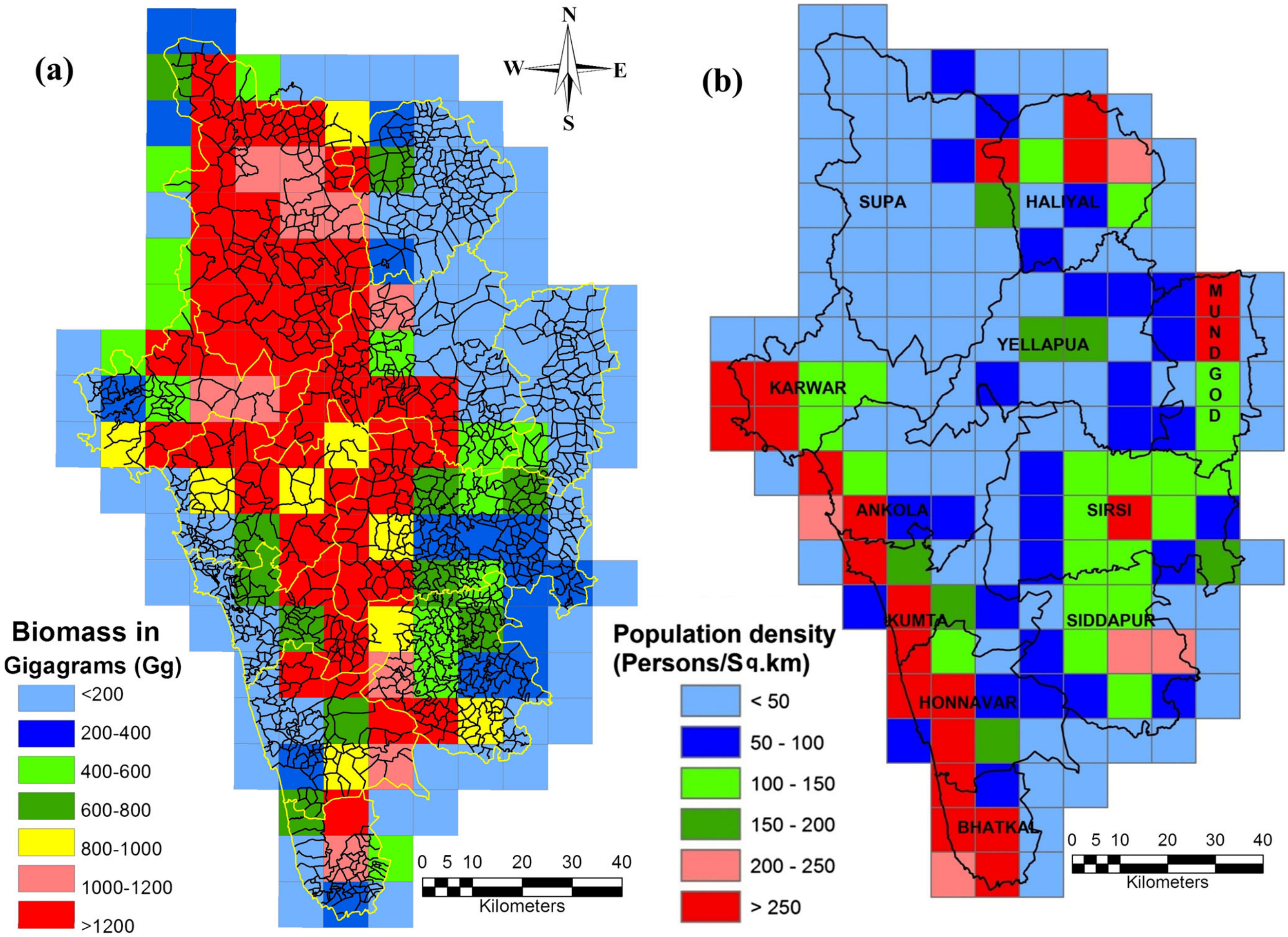

Fig. 18 Annual biomass availability in the villages (Gg) and the population density of Uttara Kannada

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