Environmental Footprints and Eco-design of Products and Processes

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Carbon Footprint Case Studies

Municipal Solid Waste Management, Sustainable Road Transport and Carbon Sequestration

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Carbon Footprint of Karnataka: Accounting of Sources and Sinks

T. V. Ramachandra and Setturu Bharath

Abstract Higher greenhouse gas (GHG) footprint with the burgeoning anthropogenic activities has altered the energy cycle contributing to the changes in the climate with the global warming. Imbalances are evident with the increasing levels of carbon dioxide (CO_2) concentrations in the atmosphere. The increased loads of Green House Gas (GHG) emission due to a higher release of carbon content are causing loss of ecosystem services further resulting in climate changes. The forests ecosystems account for ~82% of the continental biomass, a source for higher terrestrial carbon sequestration, playing a vital role in maintaining the carbon cycle and provision of various goods and services, which play a primary role in human's socioeconomic development. The various initiatives and concerns across the globe are rising to account for the carbon emissions and finding the potential measures for regulation. The carbon dynamics in the Karnataka state has been investigated considering the present status of ecosystems, quantification of sector-wise emissions, and projected likely change in sequestration by modeling land-use changes. Karnataka state now has 15% of the geographical area under forest compared with 21% in 1985. The total above and below ground biomass from forests of Karnataka was 782.1 (Tera Gram) in 1985 and reduced to 519.36 Tg by 2019 due to the largescale land-use changes leading to deforestation and land degradation. The loss of 168 Tg carbon sequestration potential confirms the extent of anthropogenic pressure on the state's forest. Carbon sequestered is about 16.1 Tg/year, whereas total emission is around 150.65 Tg. The various sources of carbon emissions were accounted for covering livestock, agriculture to industries for the year 2019 as 150.65Tg, which accounts 5% of India's total emission. Around 11% of the emission has been captured by the forests of Karnataka. The sequestered carbon accounts to INR 34 billion ($0.5

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billion) considering INR 2142 ($30) per tonne for carbon trading, which highlights the scope for higher carbon credits with reforestation of degraded landscapes.

Keywords Carbon sequestration · Emission · Biomass · Footprint · Carbon ratio

1 Introduction

Carbon constitutes the fundamental element in the earth system including the food chain of biota and exists in different forms and reservoirs, which are distributed and continually exchanged among the atmosphere, biosphere, lithosphere, and hydrosphere. Autotrophic organisms uptake carbon dioxide (CO_2) during photosynthesis transforming the energy from the sun into a chemical carbohydrate molecule, converting carbon in the atmosphere to fuel and structural materials for living organisms. Rampant deforestation and fossil fuel burning have been adding to the global carbon dynamics with the transformation of inactive carbon. The activities include burning of fossil fuel (transportation, power generation), industry, agriculture, polluting streams as well as water bodies and unplanned urbanization. Postindustrialization era witnessed an increase in GHG footprint, which constitutes 72% of CO_2. The escalation in human-induced greenhouse gas (GHG) emissions has been witnessed as 400 ppm (parts per million) from 280 ppm CO_2 emissions as compared with preindustrial era, which has contributed to the global warming [5] with changes in the climate, which affected people's livelihood with the erosion of key ecosystem services including ecosystem productivity, water holding capacity, etc.

Forest ecosystems are the large repositories of terrestrial carbon and play a crucial role in the carbon cycle (C-cycle) through sequestration of atmospheric carbon in the above ground biomass (AGB), below ground biomass (BGB), and soil organic carbon (SOC). Forest and soil ecosystems' role in maintaining the carbon balance is evident from the uptake of 30% (2 Pg (petagrams) of the annual anthropogenic CO_2 emissions. The forests storing large quantities of carbon per unit area packed down through photosynthesis, which gets released with the mismanagement of fragile ecosystems due to unplanned developmental activities with anthropogenic pressures [52]. The annual carbon sequestration by the world's forests has been estimated as 2.4 Gigaton C [34]. Soil stores about two to three times more carbon in organic form apart from forest woody biomass [56]. Carbon stored in soils as soil organic carbon (SOC) and the studies focusing on soil's potential in sequestering carbon is scanty and received relatively limited attention from the policy community, compared with carbon storage in the above ground wood biomass [3, 24, 56]. SOC constitutes the largest terrestrial carbon pool with an estimate of 700–3000 PgC (1 PgC = $1*10^{15}$gC) across the globe [6]. SOC content in the soils varies based on climate, moisture, physiography, soil type, elevation, terrestrial vegetation type, density, and extent. However, inappropriate land-use changes with mismanagement, soil becomes a source of greenhouse gas emissions (CO_2, CH_4). This necessitates prudent land management in agricultural practices, restoration of eroded and degraded forest soils to improve soil carbon pool [25]. The C pool in the topsoil is about 2011 PgC [33] accounting to 4.1 times of the biotic pool, and three times of the carbon in the atmosphere. Soil Organic Carbon (SOC) in the top 50 cm soil depth in India is estimated to be about 92.1 tons per ha in littoral swamp and 37.5 tons per hectare in tropical dry deciduous forests [6]. The total SOC in Indian forests accounts to 4.13 PgC (top 50 cm soil depth) and 6.81 PgC (top 1 m), which highlights the need for protection of soil with the appropriate conservation strategies to mitigate greenhouse gas emissions and associated climate changes.

Burning of fossil fuel [30], escalated industrial activities [29], higher deforestation [4], and land degradation [41] highlight the extent of anthropogenic-induced global warming. This unrestrained increase in global atmospheric carbon since the dawn of industrial revolution and implications changes in the climate on water and food security has driven the attention of policy-makers across the globe to focus on the earth's carbon stocks and flows. Large-scale land-use land cover changes (LULC) altering the integrity of forests, soil and aquatic ecosystems with the associated emissions have been contributing toward higher greenhouse gas (GHG) footprint. LULC changes have not only eroded the sequestration capability directly but also disturbed the amount of vegetation residues (organic matter) returned to the soil [36, 49]. LULC changes have been posing a greater threat by altering their potential of sequestration, escalating vegetation die-off, and increasing instances of wildfire [13] and have contributed to about one-third of all anthropogenic carbon [19]. LULC change-induced deforestation resulting in 90% of net carbon emission across the globe and acting as a source of 20% annual greenhouse gas emissions into the atmosphere [33]. This has prioritized the need for understanding of LULC changes with the associated decline of biomass and carbon storage for framing international policy strategies to reduce greenhouse gas emissions by reducing the abrupt LULC changes. LULC changes and their impacts vary across the regions, which necessitates the regional-specific management [42] in contrast to the global policy and regulation. Agriculture, energy production, industrial activities, waste mismanagement, and transportation are the major carbon-emitting sectors to be accounted for carbon budgeting as mismanagement in these sectors have contributed to a higher quantum of greenhouse gas emissions [1, 2, 58, 63].

The systematic quantification of carbon stock with an assessment of GHG emissions from various sectors would aid in framing the land-use policies and curb the irrational carbon emission from abrupt LULC changes. The global CO_2 emission is quantified as 36,153 million tons, with countries such as China (27%), USA (15%), European Union (10%), and India (7%) accounts 58% of the total emissions [26]. The top 15 countries contribute 26,125 million tons and the rest of the world as 10,028 million tons. The top 15 countries contribute 72% of CO_2 emissions and 28% by the rest (of 180 countries). China alone accounts to produce on its own 28% of CO_2 emissions (9.8 billion tons), 18.8% of global methane emissions (1.7 billion tons CO_2e), and 18.4% of N_2O emissions (545 million tons CO_2e). Large-scale LULC changes leading to deforestation account for 8% of the global carbon emissions (4.9 billion tons per year in the tropical forests). This has been responsible for dynamics in carbon stocks with the lowered capability of carbon sequestration, which has prompted to assess the extent and role of drivers of the carbon emissions to evolve strategies to mitigate changes in the climate. Advancements in Geoinformatics (GIS technologies) and availability of the multi resolution temporal remote sensing data with field data have aided in the land-use land cover mapping, quantification of above ground biomass (AGB), below ground biomass (BGB), and soil carbon. The remote sensing with continuous data support has been useful in the quantification of carbon footprint through measurement of carbon stock and emissions, which vary with the climate, land-use practices, and changes in the land cover and land uses [7, 40]. The insights of carbon dynamics through quantification of carbon footprint and the extent of carbon removal by carbon sinks would help in evolving strategies and frame appropriate policies to mitigate carbon footprint and implement location-specific conservation measures.

Afforestation with the location-specific endemic species of vegetation, arresting deforestation process through the improved regulatory mechanisms, transition to the energy-efficient devices, and environmentally sound technologies are some of the potential approaches for sequestering carbon and mitigate carbon emissions. Plants (trees, grasses, herbs) take up atmospheric carbon dioxide during photosynthesis and stored as carbon in biomass (trunks, branches, foliage, roots) and soils. Storing carbon in forests or through plantations in the form of standing biomass constitutes a potential carbon capture and storage (CCS) option [32]. The global potential of carbon sequestration through plants was estimated as 5–15 Gt C/year, which depends on the land-use practices, climate, etc. [23]. REDD and REDD + initiative (Reducing Emission from Deforestation and Degradation) developed by Parties to the United Nations Framework Convention on Climate Change (UNFCCC) is an efficient strategy to promote conservation while reducing greenhouse gas emissions due to deforestation and forest degradations (accounting to 11% of global carbon emissions). Mitigation of impacts of the changes in climate and stabilizing global average temperatures within two degrees Celsius entails reducing emissions from the forest sector, in addition to other sector mitigation actions. REDD + creates a financial value for the carbon stored in forests by providing financial incentives to the developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development through increasing forest cover, lessening nationwide deforestation rates, carbon emissions, and reducing degradation of various geographical regions [57]. The carbon credit payment scheme as per the Kyoto Protocol obligations is another initiative to curb the carbon and carbon sequestration through effective management. The scheme allocated credits according to the actual amount of carbon sequestered by the trees as modest land based ($77.91 per hectare per year) and tree based ($0.2 per m^3 per year) to minimize the abandonment or degradation of forests [18]. These international initiatives toward mitigation of carbon dioxide emissions through improved forestry activities necessitate the understanding of spatial and temporal carbon dynamics. Objectives of the current research are (i) understanding spatial patterns of land-use dynamics in Karnataka State, India; (ii) quantification of the carbon emissions; (iii) estimation of the carbon sequestration potential of forests plants and soil; (iv) assessment of the impact of LULC changes on carbon sequestration potential; (v) likely scenario of carbon dynamics with the current trends of changes and also likely changes due to the policy of large scale developmental projects; and (vi) suggestions towards reducing deforestation and land degradation.

2 Materials and Method

2.1 Study Area

Karnataka covers an area of 191,976 km^2 (19 million hectares) with a share of 6% in the national GDP is located in the southern part of India, sharing borders with Maharashtra and Goa; Andhra Pradesh and Telangana to the east; Tamil Nadu and Kerala to the south, while the Arabian Sea forms the western boundary (Fig. 1). The population of the state was 611,30,704 inhabitants (as per 2011 census) with a density of 319 per km^2. The state is known for its diverse culture, scenic beauty, languages, economic, and social profiles. Karnataka state is divided into four revenue divisions, 49 subdivisions, 30 districts, 175 taluks, and 745 hoblies/revenue circles for decentralized administration. The Western Ghats, one of the 36 global biodiversity hotspots (https://www.conservation.org) covers 60% of the state's forest cover in the western portion with diverse flora and fauna. The region has diverse forest cover types such

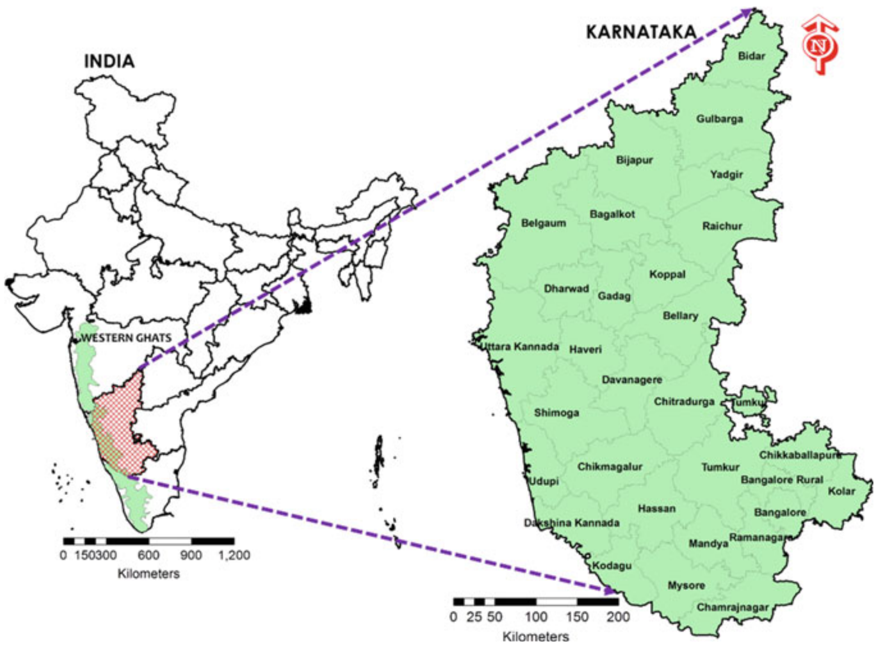

Fig. 1 Study Area—Karnataka State, India. *Source* Author

as evergreen, moist as well as dry deciduous, scrub, thorny, sholas, grasslands, and mangroves in the estuarine areas. The state harbors 4500 species of flowering plants, 508 species of birds, 150 varieties of mammals, 156 reptile species, amphibians of 156 species, 405 fish species, and 330 butterflies. Soils of the state are fertile by two major river systems (Krishna, Cauvery) and its tributaries. The state has a protected area network of five national parks (2431.3 km^2) and 21 wildlife sanctuaries (3887.83 km^2), covering nearly 16% of forest area. Agriculture and horticulture sectors are the backbone of the state's economy. The state is the prime destination for IT and BT technologies with knowledge, innovation, research, and development centers. It has a gross domestic product (GDP) of ₹15.10 lakh crore (US$220 billion) as fourth largest in India, growing at a healthy 7% per year with a per capita GDP of ₹207,000 (US$3,000).

3 Method

The protocol adopted to assess the carbon dynamics in Karnataka is presented in Fig. 2. The research involved (i) assessment of land-use dynamics through spatial data acquired using spaceborne sensors at regular intervals; (ii) field data collection to classify remote sensing data, (iii) quantification of AGB through field measurements of girth and height and sampling of the locations through transect based quadrat; (iv) quantification of carbon across various forest types and soil; (v) data mining pertaining to carbon emissions, sequestrations in forests and soils through published literature; (vi) visualization of likely changes in carbon dynamics (a) with the current rate of deforestation and degradation; (b) interventions with the afforestation; (c) implementation of the proposed development projects. This was implemented in three phases. Phase 1 focused on the land-use analyses, Phase 2 estimates the carbon sinks as well as its variation over time; quantified the emissions across each sector followed by carbon budgeting, and likely changes in carbon dynamics are predicted in Phase 3.

Land-use dynamics—Spatial patterns of land-use dynamics assessment using temporal remote sensing data: The remote sensing data of Landsat series for 1985, 2005, 2019 (downloaded from the public domain https://landsat.org) were analyzed through efficient supervised classifier based on GMLC (Gaussian Maximum Likelihood Classifier) algorithm using free and opensource GRASS GIS (Geographical Analysis Support System—https://wgbis.ces.iisc.ernet.in/grass/). The field investigation has been carried out for collecting training data, which was used to classify the remote sensing data of 2019 coinciding with the field data collection period. The earlier time remote sensing data were classified using collateral data compiled from various sources such as Karnataka Forest Department reports (https://aranya.gov.in), vegetation map of South India of 1:250,000, the French Institute of India (https://www.ifpindia.org). The process of remote sensing data classification involved (i) preparation of false-color composite (FCC) using five bands (R, G, and NIR) of LANDSAT satellite data, which assisted in the selection of training sites through the

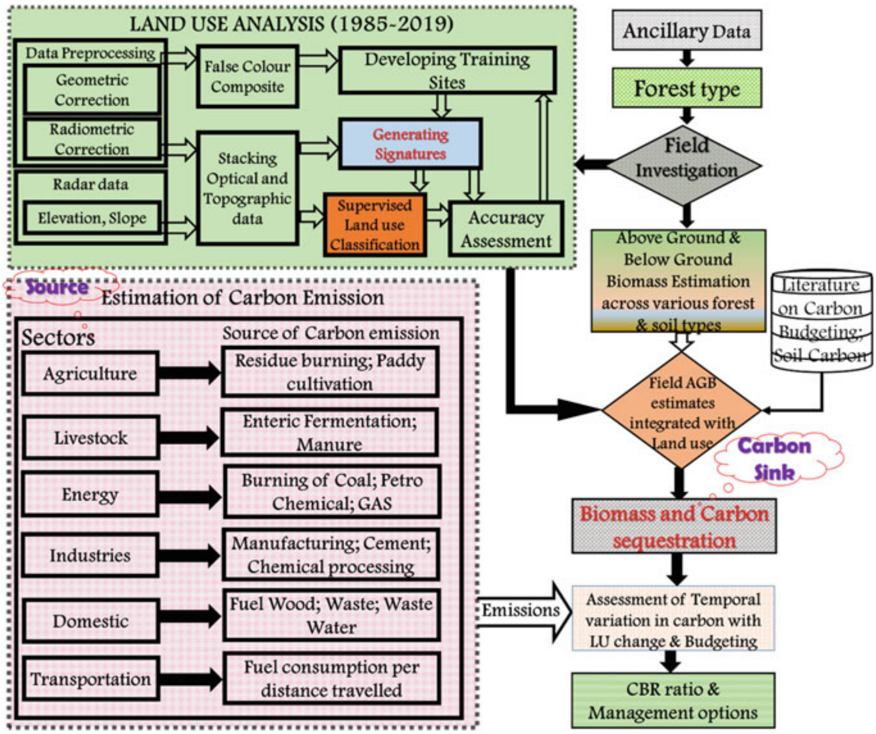

Fig. 2 Method adopted for carbon budgeting for Karnataka. *Source* Author

identification of heterogeneous patches corresponding to diverse landscape elements, (ii) attribute data collected in the field corresponding to these training polygons using precalibrated GPS (Global positioning system) and virtual data (Google Earth—https://earth.google.com, Bhuvan https://bhuvan.nrsc.gov.in), (iii) classification of RS data for eight different land-use categories through GMLC algorithm using training data, and (iv) accuracy assessment of classified remote sensing information was done through error matrix (contingency matrix) and $K^{\wedge}$ statistics (Kappa). The training data compiled from field (60%) have been used for classification, while the balance is used for accuracy assessment and validation [28].

3.1 Estimation of Spatiotemporal Carbon Sequestration Potential

The carbon sequestration potential of forest ecosystems, plantations, and agriculture areas was assessed based on (i) field estimations carried out in the forests across Karnataka state using transect cum quadrat based sampling techniques and (ii) published literature based on the rigorous distinctive biomass experiments. The study region (Karnataka State) was divided into 2597 grids of $5' \times 5'$ (or 9 km × 9 km) grids corresponding to $5' \times 5'$ grids of 1:50,000 topographic maps of the Survey of India. Select grids corresponding to agroclimatic zones were chosen for biomass and carbon estimation through field investigations. The basal area, height, vegetation type (evergreen, deciduous, semievergreen, moist deciduous, scrub forests), diversity, biomass, carbon, etc., were estimated aiding field data. The comprehensive field evaluations were done across various forest cover types with about 424 transects in Uttara Kannada, Dharwad, Shimoga, Udupi, Chikmagalur, Dakshina Kannada, and Kodagu districts. The number of quadrats per transects varied between 3 and 5 depending on the occurrence of species in the sampling locality. The biomass was estimated using GBH or DBH (girth/diameter at breast height) for the trees >30 cm. The transect data and standard literature data were used for biomass quantification. The biomass, annual increment in biomass of various forest types, sequestered carbon, productivity have been computed using field data integrating with the information compiled from literature, which are listed in Tables 1 and 2. The probable relationship of biomass with the vegetation cover has been evaluated through multivariate regression analysis across coastal, Sahyadri, plain regions of Karnataka. The carbon for above ground vegetation is computed as 50% of AGB value. The carbon is deposited in the soil as soil organic matter in both organic (SOC) and inorganic forms. SOC is calculated based on the field estimations in top 30 cm soil for different forests (Table 3) and mean soil carbon reported in the literature [31, 55, 40].

3.2 *Quantification of Carbon Emission from Various Sectors*

Data pertaining to emission for sectors such as agriculture, livestock, industry, energy, transportation, etc., were compiled from published literature.

3.2.1 Agriculture

Agricultural residue burning is practiced in some taluks across Karnataka. Emissions due to crop residue burning were computed as per the guidelines of IPCC and literature [11, 61] based on the area of crop grown to the standard crop residue ratio. The total emission is estimated by summing of CO_2; methane (CH_4) and Carbon monoxide (CO) (its equivalent CO_2) values [17, 33]. The emission from agriculture residue (AR_e) burning is estimated as,

$$AR_e = \sum_{i=1}^{3} \sum \left[\text{Cropresidueratio} \times \text{emissioncoefficient}\right] \quad (1)$$

Table 1 Forest type-wise quantification of biomass and sequestered carbon

Index	Forest type	Equation	Quantification
Biomass (T/Ha)	Evergreen	(Forestcover) × 485.67	Above ground biomass content
	Deciduous	(Forestcover) × 258.12	
	Scrub	(Forestcover) × 74.25	
	Plantations	(Extent) × 45.25	
Carbon stored (T/Ha)	All	(Estimatedbiomass) × 0.5	Sequestered carbon
Annual Increment in Biomass (T/Ha)	Evergreen	(Forestcover) × 10.48	Incremental growth in biomass [8, 10, 35, 40, 46, 48]
	Deciduous	(Forestcover) × 13.82	
	Scrub	(Forestcover) × 5.4	
	Plantations	(Extent) × 1.4	
Annual increment in Carbon (T/Ha)	All	(AnnualIncrementinBiomass) × 0.5	Incremental growth in carbon storage
Net annual Biomass productivity (T/Ha)	Evergreen	(Forestcover) × 3.6	Used to compute the annual availability of woody biomass in the region
	Deciduous	(Forestcover) × 3.9	
	Scrub	(Forestcover) × 0.5	
Carbon sequestration of soil (T/Ha)	Evergreen	(Forestcover) × 132.8	Carbon stored in soil [7, 38, 55]
	Deciduous	(Forestcover) × 58	
	Scrub	(Forestcover) × 44	
	Agriculture	(Extent) × 2.43	
	Plantations	(Extent) × 55	
Annual Increment of soil carbon (T/Ha)	All	(Cover) × 2.5	Annual increment of carbon stored in the soil

Table 2 Above ground biomass for different forest types and plantations

Sno	Forest cover type	Standing Biomass (T/ha)	Source
1	Dense Evergreen to Semi evergreen	486–834	Field-based transect cum quadrat method; [20, 37, 38, 40, 43, 46–48, 53]
2	Low evergreen	226	
3	Dense Deciduous	258	
4	Degraded Deciduous	130	
5	Savanna Woodlands	75–90	
6	Thorn degraded	40	
7	Littoral and swamp	215	
8	Plantations	45–126	

Table 3 Soil carbon storage in different forest types and agriculture filed

Sno	Forest cover type free and opensource	Mean SOC in top 30 cm (t/ha)	Source
1	Tropical Wet Evergreen Forest	132.8	[20, 22, 40, 54, 55, 62]
2	Tropical Semi Evergreen Forest	171.75	
3	Tropical Moist Deciduous Forest	57.14	
4	Littoral and Swampy Forest	34.9	
5	Tropical Dry Deciduous Forest	58	
6	Tropical Thorn Forest	44	
7	Tropical Dry Evergreen Forest	33	
8	Agriculture Fields	4	
9	Plantations	55”	

3.2.2 Livestock

Livestock plays an important role in the agroecosystem, apart from the critical energy input to the croplands, also provides economic support to the farmers in terms of milk, manure, soil nutrient enrichment, etc. Livestock also produces CH_4 emissions from enteric fermentation and CH_4 and N_2O (nitrous oxide) emissions are from manure management systems. The agriculture sector accounts for approximately 20 and 35% of global GHG emissions [11]. The grid-wise livestock density has been estimated and associated emission was quantified under enteric fermentation as well as manure management [9, 21, 60]. Livestock population (Census 2012) data were obtained from the State Veterinary Department, Government of Karnataka, and respective emission factors are listed in Table 4. CH_4 emissions (kg CH_4/animal/year) due to the enteric fermentation are computed as,

Table 4 Emission factors associated with livestock

Livestock variety		Emission factor(Kg/Head/Yr)	
		Enteric fermentation	Manure management
Cattle	Indigenous	34.05	3
	Crossbred	29.42	3.46
Buffalo		54.28	3.36
Sheep		3.67	0.16
Goat		4.99	0.17
Others		8.64	4

$$CH_4\text{EntericFermentation} = \sum_{I}(EF_I \times N_I)/10^6 \quad (2)$$

where, EF_I is an emission factor for the individual livestock category, N_I is the number of animals of livestock for category I. The emission from manure depends on volatile solids or ruminants, their productivity, and manure handling system [51]. Methane emission due to manure management is estimated as,

$$CH_4\text{Manuremanagement} = \sum_{I}(EF_I \times N_I)/10^6 \quad (3)$$

where EF_I is an emission factor for each livestock category; N_I is the number of livestock for category I in the region. Further, CO_2 equivalent values have been estimated across the grids for the fermentation and manure emissions.

Paddy cultivation is another major activity across the globe, contributing for 20% methane emission [64]. Paddy is grown in all taluks of Karnataka state and emission from paddy *(Oryza sativa)* is estimated across the grids as,

$$CH_4\text{Paddy} = [EF \times T \times A] \quad (4)$$

where EF is the daily emission factor (kg CH_4/Ha/Day), T is the cultivation period, A is the harvested area (in two seasons-*Kharif; Rabi*).

3.2.3 Domestic

The fuelwood consumption is causing deforestation and an increase in C02 emission. The Per Capita Fuel Consumption (PCFC) was analyzed to account fuelwood consumption pattern across the agroclimatic zones of state and determined the carbon emissions (EFC) as,

$$EFWC = [NH \times PCFC \times EF] \quad (4)$$

where EFWC is carbon emission from fuelwood consumption in rural households, PCFC is per capita fuel consumption (which was computed as ration of fuelwood consumed in kgs/day and number of adults in a household), EF is emission factor.

The waste generated per household level is also contributing to the CH_4 emissions due to the disorganized management of waste across the state. The waste generated across individual households of Karnataka at the grid level has been estimated considering 0.35 g per person per day [45]. The average of four people per household was considered for a total of 2,281,419 households. The emission from waste per year is calculated as,

$$EWC = [0.35 \times NH \times 365] \quad (5)$$

where EWC is carbon emission from waste generated, NH is the number of households.

Nitrous oxide (N_2O) emissions can occur as both direct and indirect emissions, apart from CH_4 through domestic wastewater, which has significant carbon loading [16]. The emission from wastewater generated from the individual households is estimated by considering average water consumption per person per day as 135 L [39, 45, 59].

3.2.4 Industries

Karnataka state is endowed with rich mineral resources as well as a large pool of human resources. The state has public sector units and also gives impetus simultaneously to private sector growth, which prompted to establish many industries. The state has major manufacturing industries due to progressive industrial policies. The good Institutional networks such as Search Results Karnataka Industrial Area Development Board-KIADB (en.kiadb.in), Karnataka State Small Industries Development Corporation Ltd-KSSIDC (kssidc.co.in), Karnataka State Small Industries Development Corporation Ltd-KSSIMC, Technical Consultancy Services Organisation of Karnataka-TECSOK (tecsok.com), Federation of Karnataka Chambers of Commerce and Industry-FKCCI (fkcci.org), and Industries and Commerce Department (kum.karnatka.gov.in) were set up to provide various assistance for industrial development in the state. The major manufacturing industries such as cement, steel, iron ore processing, petrochemical, sugar, paper, and paper board, etc., were considered [12] and associated emissions [51] were estimated based on the standard protocol (Annexure-I).

3.2.5 Energy

The energy sector is considered to account emissions from thermal (burning of coal) and diesel power generation. The state has an installed power generation capacity of 28,789.99 MW of which, central utilities contribute 4123 MW, private utilities contribute 13,259.71 MW and 11,407.28 MW under state utilities. The thermal power contributes 9,560.82 MW, 698.00 MW by nuclear, and 8,431.34 MW by renewable energy sources for the total installed power generation capacity. The various thermal and diesel power generating units were mapped across the state and emissions associated were estimated (Annexure-II).

3.2.6 Transportation

Karnataka stands fifth as per registered motorized vehicles and contributing 7% of registered vehicles of India. Bengaluru has a large quantum of vehicles after Delhi with higher vehicle registrations. The quantum of registered vehicles in the state has been gradually increasing at an average growth rate of 10% per annum and the decadal growth rate of vehicles at 138%. The two-wheelers account for 70% of the registered vehicles across the six divisions (Table 5). The emission from each type of vehicle was evaluated by computing annual average distance traveled (AADT) [15, 39, 44]. The total emission from the transportation sector has been quantified as,

$$Et = \left[\sum \left(V_i \times AADT_i \times EF_{i,jkm}\right)\right] \tag{6}$$

where, E_t is the total emission from the transportation sector, V_i = Number of vehicles per type i, $AADT_i$ is the annual average distance traveled per different vehicle types and $EF_{i,j,km}$ is the vehicle type (i) emission of factors (j), per driven kilometer (Table 6).

3.3 Carbon Ratio (CR)

CR was computed as a ratio of total carbon uptake (from AGB, SOC) to the total emissions across all sectors, which will provide the carbon status across the grids in Karnataka. CR values of "0" and close to 0 represent the regions of higher emission and value greater than 1 represent carbon sequestration is higher in that grids.

$$CR = \left[\frac{\sum (CarbonSequestration)}{\sum (CarbonEmission)}\right] \tag{7}$$

4 Results and Discussion

4.1 Quantifying Spatiotemporal Land-Use Changes

Temporal land-use analyses reveal the decline of forest cover in Karnataka from 1985 to 2019 (Fig. 3). Currently, 15% of the State's geographical area is under forests compared with 21% in 1985. Large-scale developmental activities such as the construction of a series of reservoirs and dams, creation of special economic zones, townships, land conversion for built-up areas have led to the loss of large tracts of forests. The abrupt land-use conversion has resulted in a loss of productive agriculture lands near the cities such as Bengaluru, Mysore, Hubli-Dharwad, Shimoga, etc. The districts such as Kodagu, Uttara Kannada, Bengaluru, Shimoga, Belgaum, Dakshina Kannada, and Chikmagalur have been experiencing a large-scale land cover due to the unplanned developmental activities. Post-1990s, the state witnessed large-scale land-use transitions due to industrialization, urbanization, an increase of horticulture crops, conversion from agriculture to market-based crops (higher economic), etc.

Table 5 Vehicle details of Karnataka

Division (JCT)	Area (km^2)	Two-wheeler	Car	Tractor	Truck	Bus	Taxi	Auto	Other vehicles
Shimoga	38,459.99	1,174,399	74,474	141,372	56,292	22,083	18,538	47,184	24,055
Belgaum	54,488.08	1,343,729	157,265	98,754	57,899	17,952	21,353	51,520	31,274
Kalburgi	44,140.98	1,714,243	262,872	151,226	101,795	24,939	43,036	83,077	54,259
Mysore	27,828.62	2,136,040	166,668	265,345	102,511	44,927	30,955	71,196	40,006
Bangalore Rural	22,333.5	4,186,111	1,188,284	17,439	197,462	88,731	105,421	203,787	71,955
Bangalore Urban	4492.67	1,109,947	96,344	108,718	45,003	14,318	22,230	45,890	18,589
AADT (km)		10,000	15,000	5000	30,000	60,000	30,000	40,000	12,600

Table 6 CO_2, CH_4, and N_2O EF for different type of vehicles

Type of Vehicle	CO_2 EF (g/km)	CH_4 EF (g/km)	N_2O EF (g/km)
Two-wheeler	27.79	0.18	0.002
Car	164.22	0.17	0.005
Taxis	164.22	0.01	0.01
Bus	567.03	0.09	0.03
Auto	64.16	0.18	0.002
Truck	799.95	0.09	0.03
Tractor	515.2	0.09	0.03
Other Vehicles	273.46	0.09	0.03

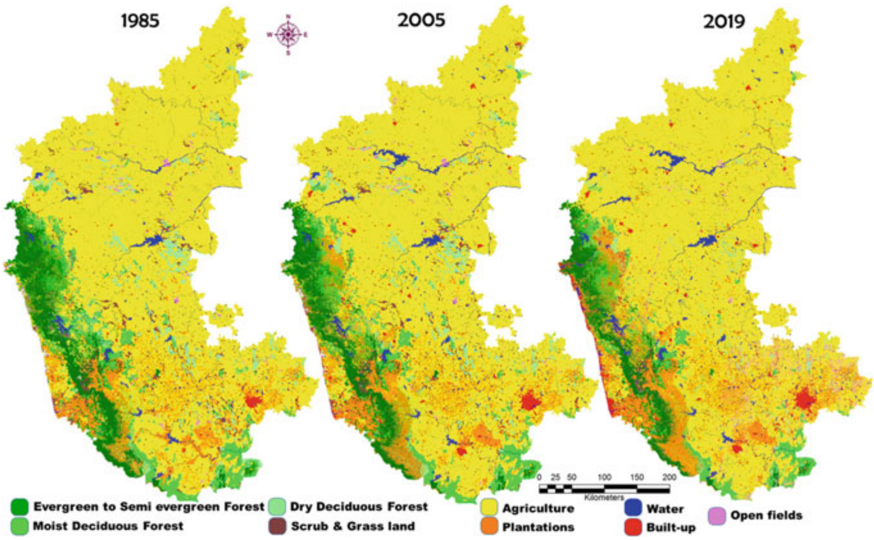

Fig. 3 Spatiotemporal land-use changes in Karnataka. *Source* Author

The forest cover now is confined to major conservation reserves such as protected areas, national parks, wildlife sanctuaries. The built-up cover has increased from 0.47 to 3% from 1985 to 2019 causing an impact on agriculture, forest, and lakes (Fig. 4). This necessitates the sustainable land-use policies to arrest deforestation and abrupt land conversions.

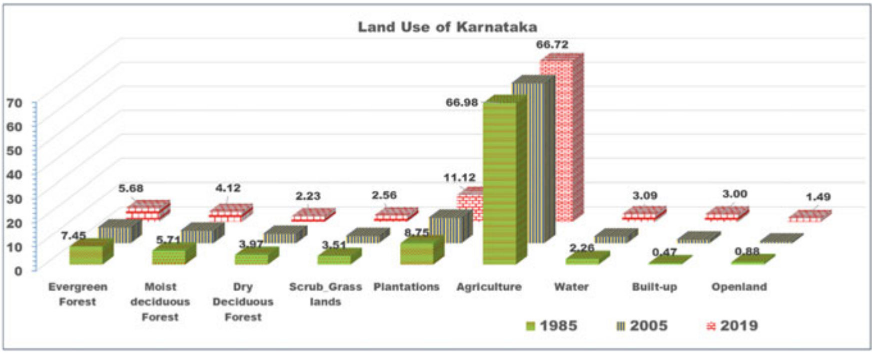

Fig. 4 Land-use dynamics in Karnataka during (1985–2019). *Source* Author

4.2 Carbon Sequestration Potential of Forest Ecosystems in Karnataka

The field data supplemented with data from published literatures were used to compute per hectare biomass across various types of forests in Karnataka. The analyses of the above ground biomass show that the grids in the Western Ghats part of Karnataka have higher AGB > 1000 Gg (Giga gram). The grids of evergreen forested areas represent the greater values of biomass compared with the other forest types. The total AGB of forests is about 1013.7 Tg (Teragram) with stored carbon of 506.8 Tg (in 1985), which is now reduced to 678 Tg and 339 Tg, respectively (2019). The temporal decline of AGB values in the districts of Kodagu, Shimoga, Uttara Kannada, and Dakshina Kannada is due to anthropogenic pressure (Fig. 5). The Mysore Chamrajnagara and Bellary districts also reflect a decline in AGB values during 2005–2019. The districts of Uttara Kannada, Kodagu, Udupi, Chikkamagaluru with relatively higher forest cover have higher carbon sequestration compared to the other parts of the state. The temporal decline in carbon sequestration is due to the deforestation and land degradations due to the sustained anthropogenic pressures (Fig. 6). The annual increment in carbon from forests depicts the grids of Western Ghats has higher increment (>20 Gg) compared with other parts of the state due to less disturbances (Fig. 7). The temporal changes in incremental biomass and carbon highlight the decline of forest cover. The districts such as Shimoga, Mysore, Bellary have lower incremental biomass and carbon values due to deforestation with the rapid land-use changes (Fig. 8). Temporal BGB highlights the decline from 275 Tg (1989) to 180 Tg (2019). The grids consisting of evergreen forests (of Western Ghats) show higher values of >600 Gg SOC, while other regions are with relatively lower values (Fig. 9). The loss of forest cover has degraded the SOC potential and the region is exposed to the sunlight resulting in emissions. The incremental BGB is estimated to understand the increment during 1989–2019, which further confirm of variations (Fig. 10). The districts such as Uttara Kannada, Kodagu, Dakshina Kannada forests

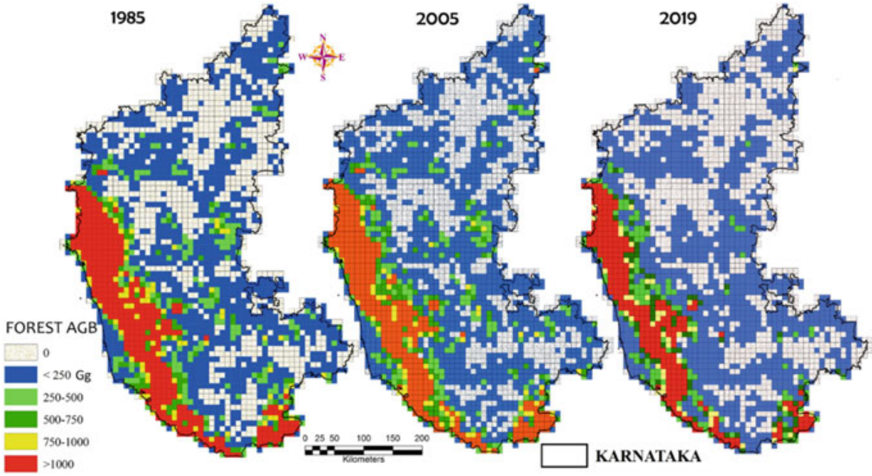

Fig. 5 Temporal AGB in forest areas of Karnataka. *Source* Author

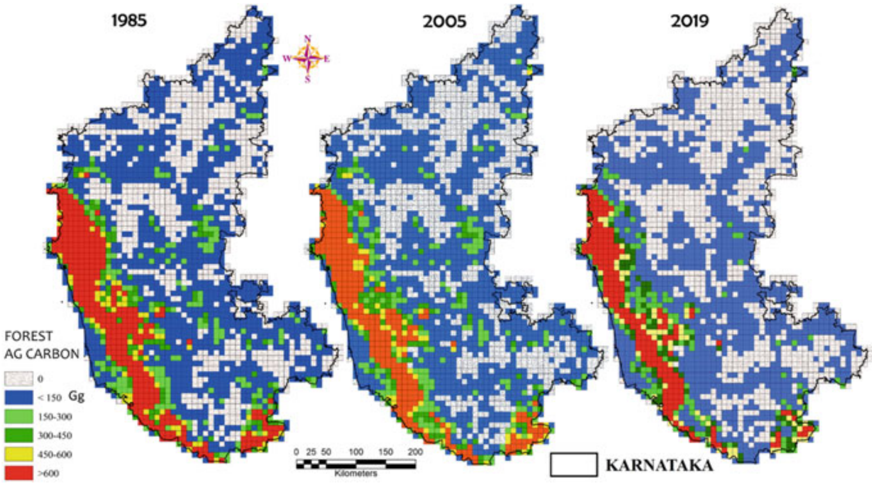

Fig. 6 Temporal variation in carbon sequestration for forest areas of Karnataka. *Source* Author

have grids expressing moderate incremental BGB of greater than 6 Gg compared with other districts across the state.

In order to protect the land under greening initiatives and to sustain market demand for the timber, Karnataka forest department has implemented monoculture plantations in the state. The AGB, BGB, and their carbon values were accounted to understand the role of plantations in carbon sequestration apart from arresting land degradations. The total carbon has been estimated based on the AGB and BGB values as a sum of forest and forest plantations biomass. Figures 11 and 12 show the AGB

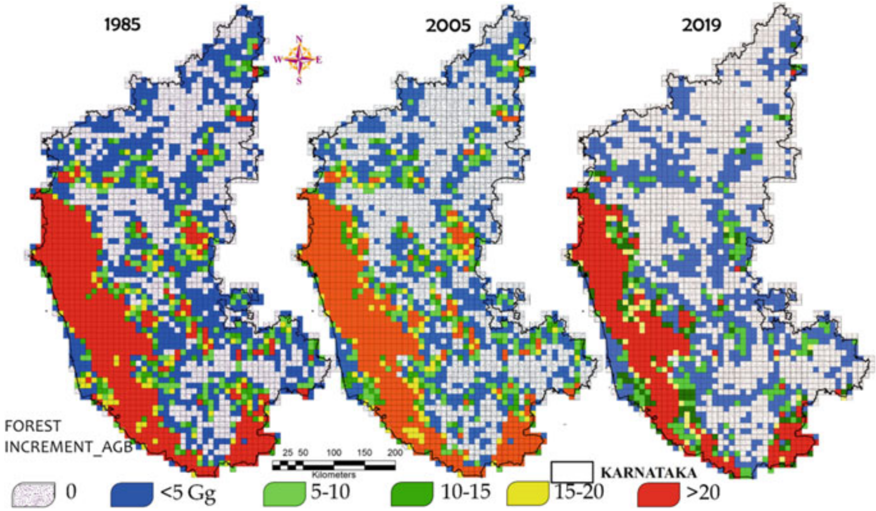

Fig. 7 Annual increment in AGB in forest from 1989 to 2019. *Source* Author

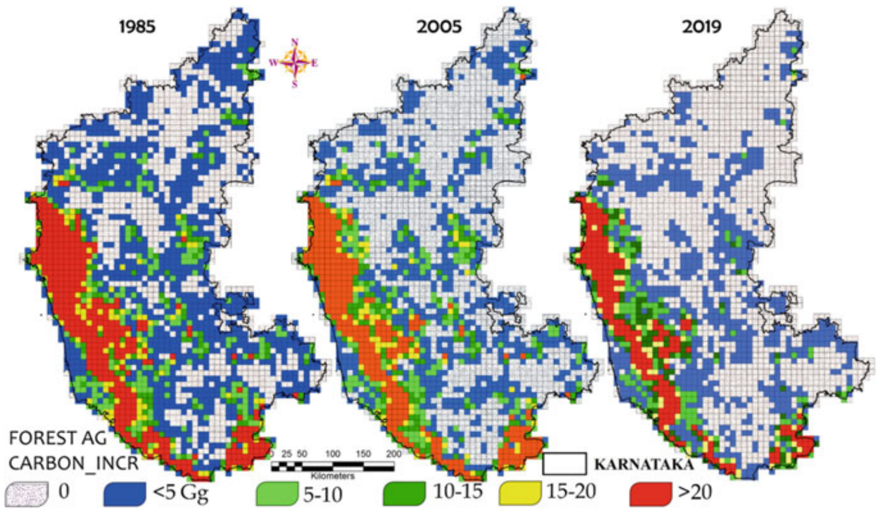

Fig. 8 Annual increment in forest carbon from 1989 to 2019. *Source* Author

for forest and plantations accounted to 1056.90 Tg with carbon sequestration of 528.45 Tg (in 1985), which is now reduced to 732.83 Tg and 366.41Tg, respectively. Figure 13 shows BGB from forest plantation and agriculture areas across the state accounted to 275.43 (1985), which is now reduced to 180.54 Tg. The plantations though not shown any significant contribution of ecosystem services compared with

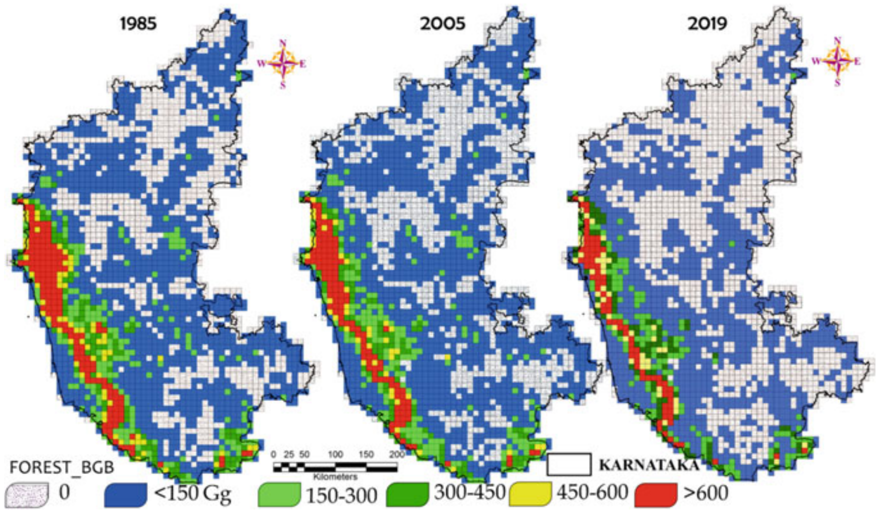

Fig. 9 BGB across the forests of Karnataka from 1989 to 2019. *Source* Author

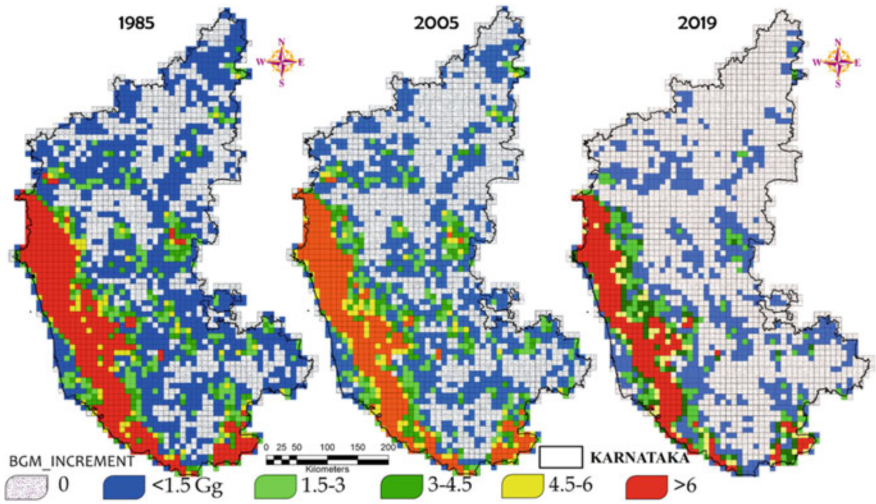

Fig. 10 Incremental BGB values in Forests of Karnataka. *Source* Author

the forest, but supported in sequestration. The Uttara Kannada grids have significant AGB and BGB values.

Total AGB and BGB from forests are about 782.1 Tg (1985), which is reduced to 519.36 Tg (2019) due to LU conversions (Fig. 14). The total carbon sequestration from forest plantation and agriculture areas together is about 1289.1 Tg (1985) and 858.48 Tg (2019) due to changes in LU with the burgeoning anthropogenic pressures.

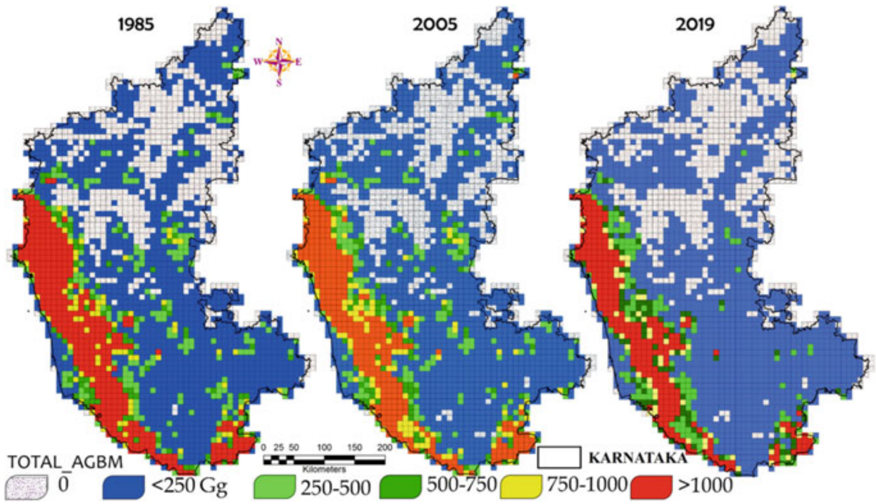

Fig. 11 Total AGB of Karnataka from 1985 to 2019. *Source* Author

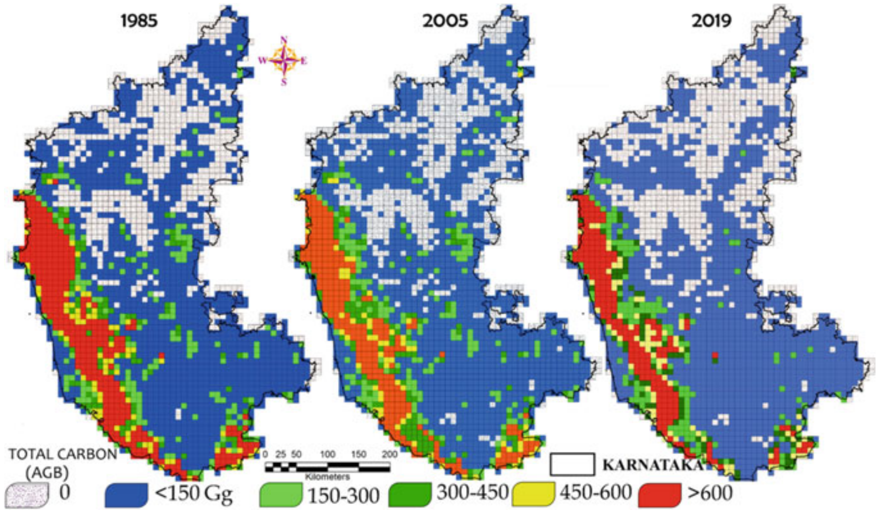

Fig. 12 Total carbon from AGB of Karnataka from 1985 to 2019. *Source* Author

Figure 15 depicts the loss of carbon sequestration of 433.43 Tg during 1985–2019 in the forest, plantation, and agriculture sectors. The loss of 264 Tg carbon sequestration potential during 1985–2019 emphasizes the need for prudent management activities to curb the forest loss and improvement of carbon sequestration (Fig. 16). The grids covered in districts of Bellary, Mysore, Chamarajanagar, Uttara Kannada, Kodagu have witnessed higher transitions in carbon sequestration potential.

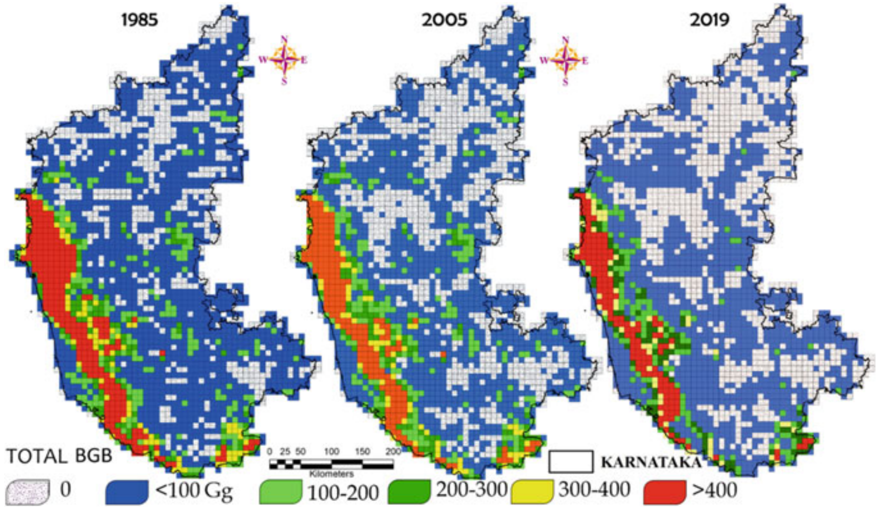

Fig. 13 Total carbon from BGB of Karnataka from 1985 to 2019. *Source* Author

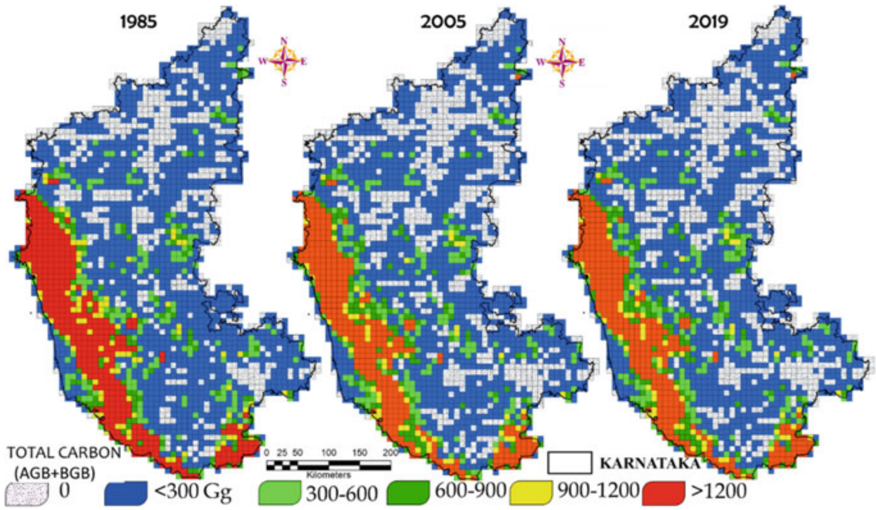

Fig. 14 Total carbon from AGB and BGB of Karnataka from 1985 to 2019. *Source* Author

4.3 Quantification of Carbon Emissions in Karnataka

The carbon emissions from various sectors including livestock, agriculture, and industries for the year 2019 were accounted to be 150.65 Tg. The energy and transportation are a major source of emissions in Karnataka, highlight the necessity of mitigative interventions. Figure 17 highlights major contributions from industrial

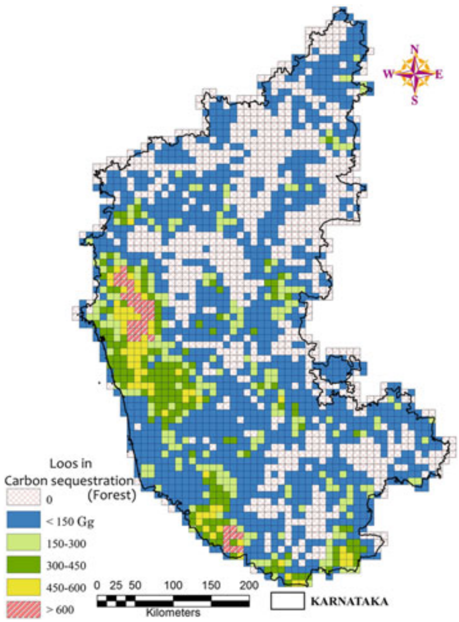

Fig. 15 Loss in carbon sequestration of forests from 1985 to 2019. *Source* Author

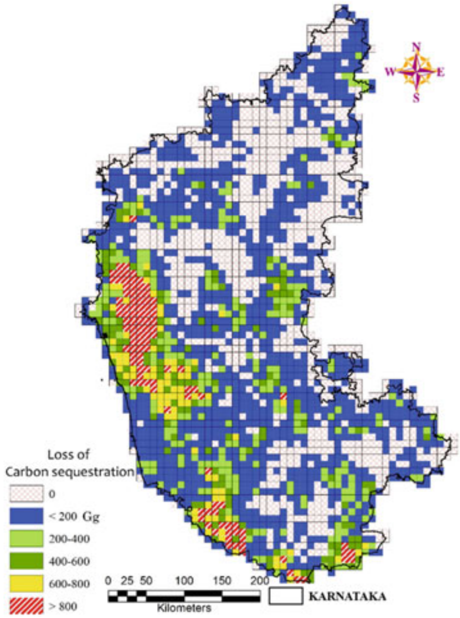

Fig. 16 Loss in carbon sequestration from forests, plantations, agriculture sectors (1985–2019). *Source* Author

Fig. 17 CO_2 emission from various sources in Karnataka. *Source* Author

activities (29%), energy generation (28%), transportation (25%), and paddy cultivation (13%). Large-scale industries having the capacity of greater than 20,000 tons and covering various sectors of cement, petrochemical, steel, paper mills, etc., were considered and the total emission is about 42,995.93 Gg. The energy sector contributes to emissions of 42,731 Gg from thermal—and diesel-based power generation. The residue available from the agriculture sector has been quantified, which shows the northern districts of the state have higher residues greater than 6000 tons per year, and the emissions respective residue burning account to greater than 1 Gg. Emissions due to the crop residue burning are about 2222.25 Gg (Fig. 18).

Considering the contribution of crop burning to atmospheric pollution as well as likely increase in GHG, there is a need to prohibit this practice of crop residue burning unless the burning is for the purpose of disease control or the elimination of plant pests, the disposal of straw stack remains or broken bales, for education or research. Retention of crop residues in the respective agricultural field after harvesting is an effective antierosion measure. The crop residue has alternative uses such as fodder, ethanol production, energy, paper and pulp industry, manure, etc. Barriers to commercial utilization of crop residues include dispersed generation, transportation cost, etc. However, with the incentive and support from the government would help in the conversion of agricultural residues to viable products while mitigating carbon emissions from burning. Figure 19 gives the distribution of livestock in Belgaum, Yadgir, Hassan, Mysore, Haveri, and Tumkur districts. The emission from livestock assessed for enteric fermentation and manure is about 2963 Gg. The farmers are growing paddy in all the districts and the larger area under paddy is in North Karnataka districts (Fig. 20). CH_4 emissions associated with paddy cultivation are about 19,215

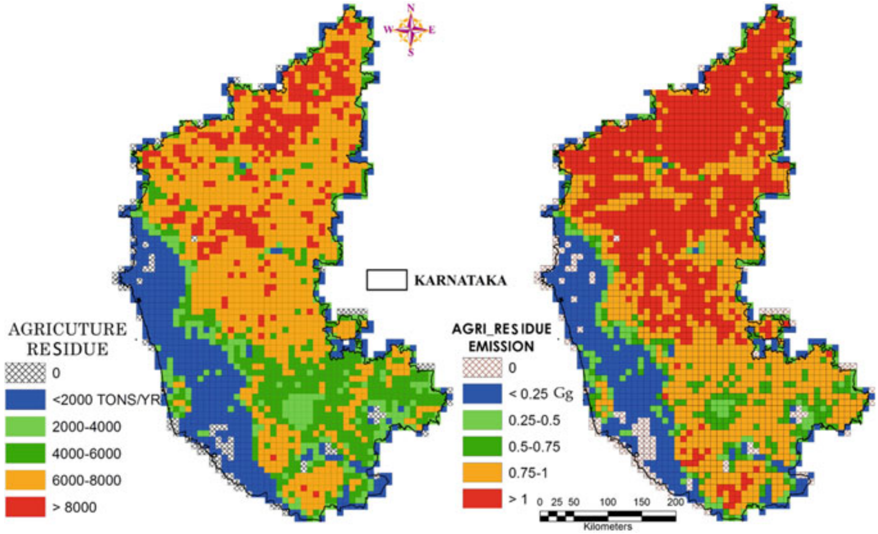

Fig. 18 Residue quantity and emission from agriculture sector. *Source* Author

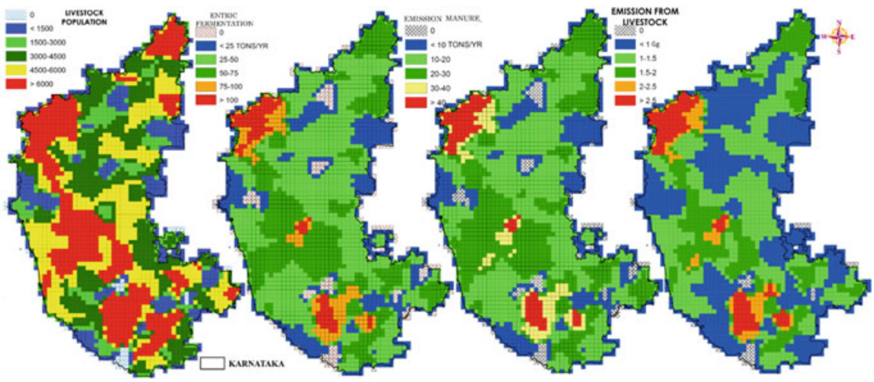

Fig. 19 Livestock population and its emission. *Source* Author

Gg (CO_2 equivalent) and Bagalkot, Raichur, Bellary, Gadag, Gulbarga districts have higher contributions toward emission from the livestock sector.

The emission due to the fuelwood burning in the domestic sector of a rural household is about 1138 Gg and Fig. 21 illustrates that Belgaum, Udupi, Dakshina Kannada, Kodagu, and Dharwad districts are with the higher fuelwood consumption (Fig. 21). The waste generated in households of Karnataka state is about 2,91,451 tons per year, which contributes emissions of 3886.72 Gg. Figure 22 demonstrates that major cities (Bangalore, Mangalore, Mysore, Dharwad) and towns (Shimoga,

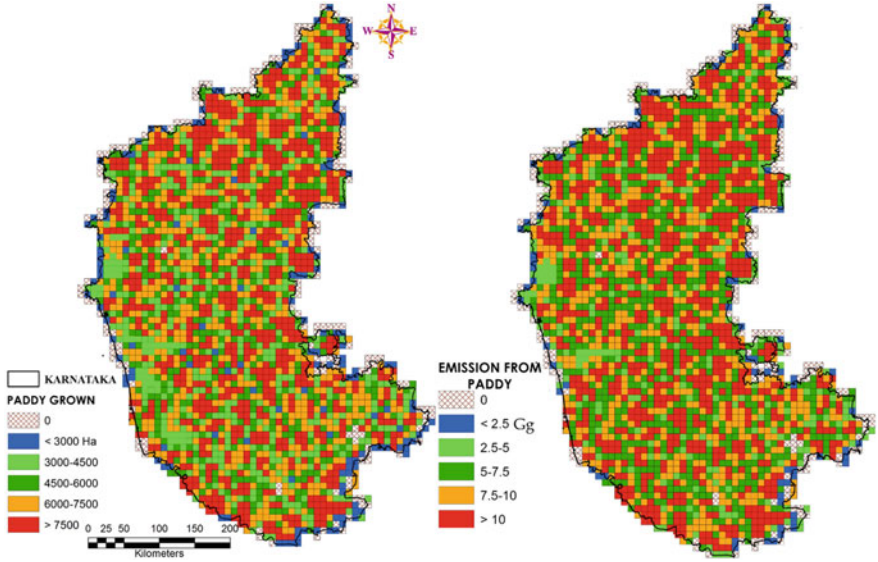

Fig. 20 Paddy grown in Karnataka and its associated emission. *Source* Author

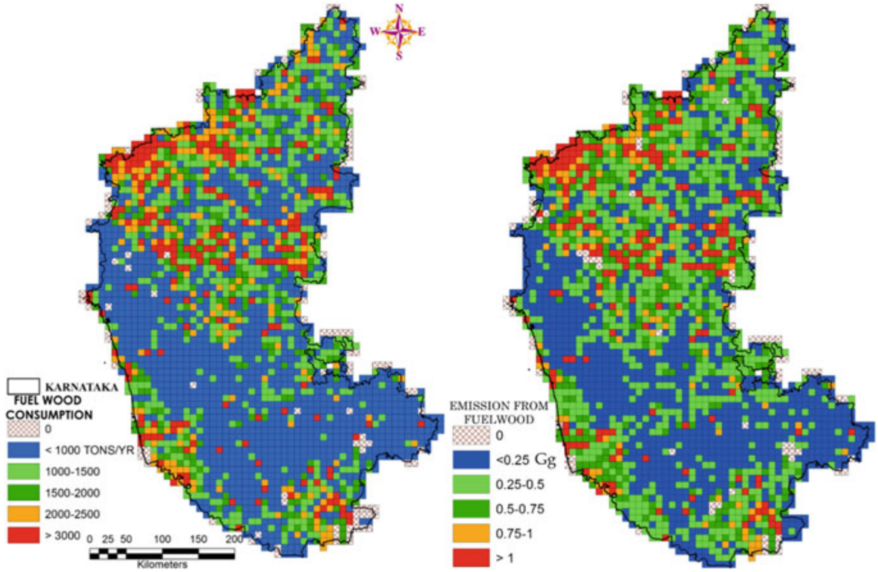

Fig. 21 Fuelwood consumption and its associated emission. *Source* Author

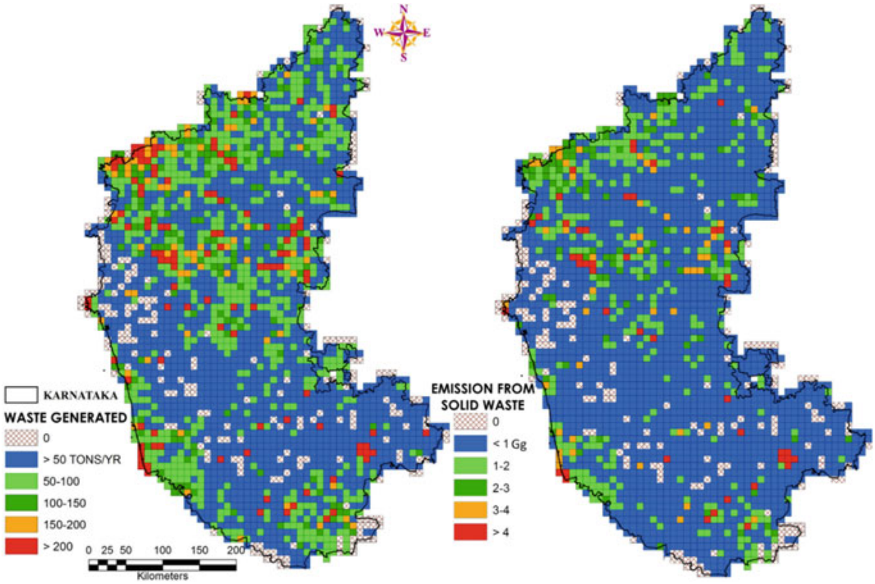

Fig. 22 Waste generated from households and its emission. *Source* Author

Bellary, Tumkur) of the state contribute significantly to the emission. due to indiscriminate disposal. Wastewater generated in urban areas is either partially treated or untreated and is discharged to the water bodies. Figure 23 presents the emission from wastewater indicating higher emissions from the major cities. Emissions from the transportation sector include CO_2, CO, NO_x, CH_4, SO_2, PM, HC, which accounts to 38,440.56 Gg. Figure 24 illustrates the spatial distribution of emission from the transport sector in Karnataka with the major contributions from Bangalore, Kolar, Chikballapur, Tumkur and Mysore districts due to higher number of vehicles.

4.4 Carbon Ratio (CR) or Carbon Status in Karnataka

The carbon status of a region or carbon ratio (CR) refers to the ratio of sequestered carbon in the ecosystems to emissions aggregated from all sectors or activities. CR values greater than 1 indicate carbon sequestration higher than emissions. Grid-wise carbon sequestration and emission were computed for 2019. Figure 25a and b give the grid-wise carbon sequestration and emissions during 2019. The annual sequestered carbon is about 16.1 Tg, while emission is 150.65 Tg, which highlights about 11% of the emission is sequestered by forest ecosystems in Karnataka. The districts or grids in the Western Ghats region have good sequestration potential with the least emissions compared with other regions. High carboemitting districts include Bangalore, Mysore, Dharwad, Bellary, and Raichur. CR ratio computed grid wise is

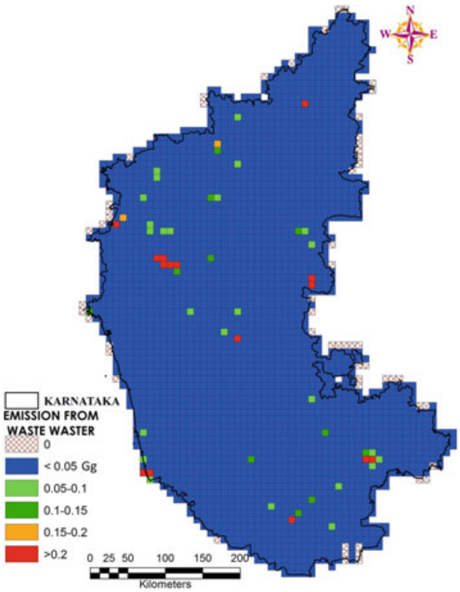

Fig. 23 Emission from domestic waste water. *Source* Author

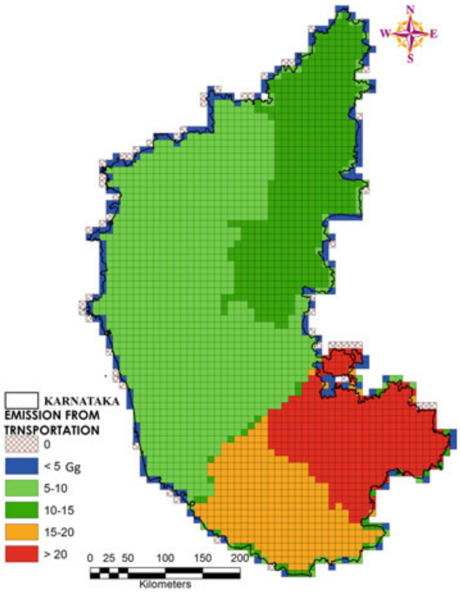

Fig. 24 Emission from transport sector. *Source* Author

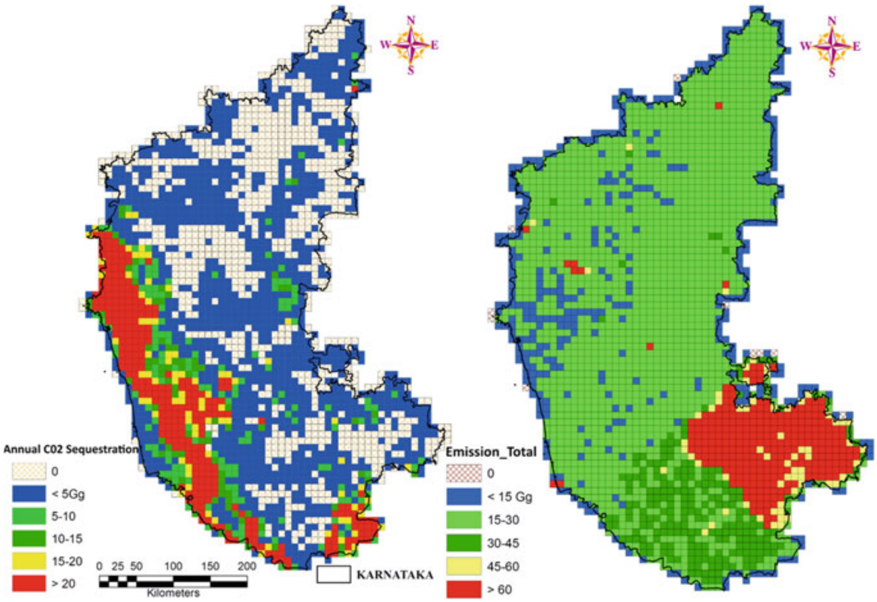

Fig. 25 Annual carbon sequestration and emission of Karnataka. *Source* Author

depicted in Fig. 26 highlights of CR > 1 for grids covered in the districts of Uttara Kannada, Kodagu, part of Dakshina Kannada, and Udupi. The other grids are with lower CR (≤0) indicating carbon-negative situation.

The study emphasizes the need to evolve appropriate policies to decarbonize through prudent afforestation policies to mitigate emissions. Afforestation with native species will not only aid in the carbon sequestration but also enhances hydrological and food security services, evident from the existence of perennial streams in the catchments dominated by native species compared with the seasonal or intermittent streams in either degraded catchments or catchments dominated by monoculture plantations. Also, due to pollination services with the presence of diverse pollinators, the crop productivity in agriculture is higher compared with the degraded landscapes highlighting the linkages of water availability, food security, and carbon security with the land cover dynamics.

4.5 Strategies for Carbon Mitigation

The strategies for carbon mitigation covering local and global perspectives would aid in framing prudent policies toward the sustainability of natural resources. Realizing the increase in greenhouse gas emissions due to the accelerated deforestation process has necessitated the measures toward adaptation and mitigation strategies for global

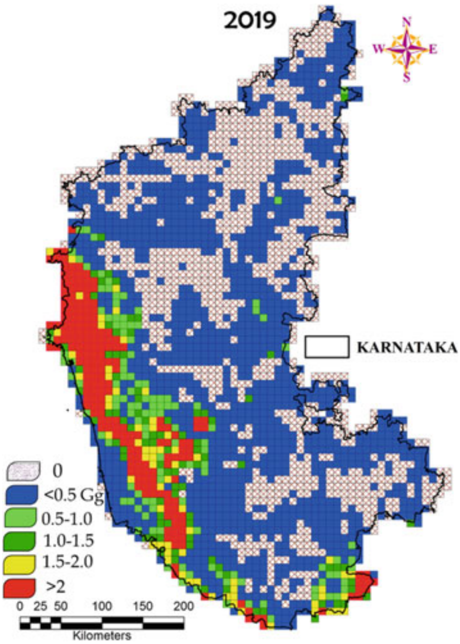

Fig. 26 Carbon ratio for the year 2019. *Source* Author

warming and climate change. Conference of the Parties (refer to the countries) signed up to the 1992 United Nations Framework Convention on Climate Change. Kyoto Protocol was the first global initiative proposed at 3rd Conference of Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 to curb deforestation and promote forest conservation (Humphreys, 2008). During the 21st COP at Paris 170 countries committed to reduce greenhouse gas emissions and limit the global temperature increase to below 2 degrees Celsius (3.6 F) above preindustrial levels by the year 2100. In this regard, India pledged that 40% of power capacity would be based on nonfossil fuel sources and of creating an additional "carbon sink" of 2.5–3 billion tonnes of carbon dioxide equivalent through additional forest and tree cover by 2030.

Reduced Emissions of Deforestation (RED) has emerged as an initiative for conservation in 2005 at 11th COP meeting to support developing countries. REDD + materialized at the 18th COP proposed to offer incentives for the conservation and enhancement of the forest carbon stock and the sustainable management of forests in 2012. REDD + has been playing a significant role in forest conservation while addressing challenges and supporting direct/indirect costs involved in forest management [14]. REDD + , while providing economic benefits to the local communities, has improved natural resource management in developing countries and is a form of Payments for Ecosystem Services (PES). The conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries have been achieved with the marketing of carbon credits under the voluntary carbon standard systems through a technical procedure [27]. Carbon trading is an effective measure toward payment for ecological services, such as forest conservation, which has been established based on a rigorous valuation of these ecosystem services to encourage afforestation in a larger scale and support community livelihoods, which are at the greatest risk due to LULC change and its associated impacts. The annual sequestered carbon in forest ecosystems of Karnataka is about 16.1 Tg, which as per carbon trading accounts to be INR 34 billion ($0.5 billion) at carbon trading of INR 2142 ($30) per tonne, which highlights the scope for higher carbon credits with reforestation of degraded landscapes. In this regard, the Government of India came up with CAMPA (Compensatory Afforestation Fund Management and Planning Authority) to compensate for the loss of forest area and to maintain sustainability. The act emphasized of ecological compensation based on net present value (NPV) for the loss of forest ecosystem, while implementing developmental projects.

Although policies to implement adaptation and mitigation measures may be established at a global, national, or regional level, the consequences of climate change and the necessary adaptation have to be undertaken locally. The management options to minimize the impact of climate change include: promotion of reduced use of fossil fuels and development of clean energy; efficient use of water resources; developing low-cost sustainable technologies; improving health care and pest control; developing and using drought-resistant crops; constructing disaster-resistant buildings and infrastructure. Renewable energy sources include solar power, wind, waste to energy, are to be promoted through incentivized mechanism across all levels. The creation of people's nurseries under benefit sharing in accordance with the various forest regulations and provisions and Forest Dweller's Act, 2006, is recommended to get location-specific species saplings would enhance the rural employment opportunities. The fencing of blocks of forest lands with basal areas of less than 15 sq. m each, for minimum periods of 8–10 years, will prevent the entry of domestic cattle and humans into these protected blocks and pave the way for natural regeneration of especially native species of plants. Carbon reduction is achieved by promoting alternative materials of least carbon footprint, efficient recycling technologies, and remanufacturing as well as recovering the virgin materials. Increased emphasis on research, education, training, and awareness needs to be provided to the employees to make aware all advanced/alternative energy technologies for reducing emission through nongovernmental organizations (NGOs) and public–private participation.

5 Conclusion

Forest ecosystems have been playing a key role in the global carbon cycle and Earth's climate by capturing, storing, and cycling carbon. Plants and soils in forest ecosystems drive the global carbon cycle by sequestering (storing) carbon dioxide through photosynthesis. The sustained anthropogenic pressure has been contributing to GHGs in the atmosphere, contributing to the alterations in the climatic conditions regime due to global warming. The land-use dynamics analyses using temporal remote sensing data reveal a loss of 6% forest cover during 1985–2019 in the state of

Karnataka with an increase in built-up and agriculture areas. The total AGB of forests is about 1013.7 Tg (Teragram) with stored carbon of 506.8 Tg (in 1985) which is now reduced to 678 Tg and 339 Tg, respectively (2019). The temporal decline of AGB values in the districts of Kodagu, Shimoga, Uttara Kannada, and Dakshina Kannada is due to anthropogenic pressure. The districts of Uttara Kannada, Kodagu, Udupi, Chikmagalur have higher carbon sequestration potential due to high forest cover as compared with the other parts of the state. Forest ecosystem sequesters 11% of emissions. The industrial activities (29%), energy generation (28%), transportation (25%), and paddy cultivation (13%) are the major contributors to the total emission of the state. The grids of Western Ghats have good sequestration potential with the least emission as compared across the other regions. The state is contributing 5% GHG emissions of India's total and signifies the necessity of policy interventions. The study has further suggested improving the carbon sequestration potential by various management initiatives such as promoting reduced use of fossil fuels; increasing forest cover by large scale afforestation with native species, providing employment to the rural women for creating nurseries, effectively managing water resources; promoting alternative or developing inexpensive materials and sustainable technologies for reducing carbon footprint; promoting drought-resistant native crops; developing disaster-resilient buildings and other infrastructure.

Acknowledgements We are grateful to the European Union for funding the NCAVES Project and the UNSD and UN Environment for leading the NCAVES Project globally and supporting its management and implementation in Karnataka, India.

Annexure-I

The major industries of Karnataka (Figure A) and their installed capacity have been shown in Table A and their respective emissions.

Industries considered and their emissions

Sno	Latitude	Longitude	Industry	Installed capacity Tons	CO_2 Emission Gg
1	13.830	75.702	Visvesvaraya Iron and Steel Plant (VISL)	98,280	62.41
2	13.841	75.701	Visvesvaraya Iron and Steel Plant (VISL)	216,000	137.17
3	12.359	76.630	Mysore steel	150,000	95.26
4	15.177	76.666	JSW Steel, Hospet	12,000,000	7620.43
5	15.337	76.253	Kalyani Steels Ltd (KSL)	290,000	184.16
6	15.308	76.212	Xindia steels	800,000	508.03

(continued)

(continued)

Sno	Latitude	Longitude	Industry	Installed capacity Tons	CO_2 Emission Gg
7	12.927	74.823	KIOCL Panambur	140,000	88.91
8	13.055	77.484	Jindal Nagar, Tumkur Road Unit-1	92,000	133.54
9	13.218	77.255	Jindal Aluminium Limited-RMD, Yedehalli	40,000	58.06
10	15.906	74.540	Hindalco Yamanapur, Belgaum	350,000	508.03
11	16.113	74.520	SQuAD Forging India Private Ltd	22,000	31.93
12	12.866	77.459	Devkiran Paper Mills Private Ltd	25,000	11.34
13	15.252	74.629	West Coast Paper mill	320,000	145.15
14	13.826	75.713	Mysore Paper mill	105,000	47.63
15	12.158	76.684	South India Paper Mills	200,000	90.72
16	15.219	76.784	ACC Kudithini Cement Works	1,100,000	628.69
17	17.059	76.982	ACC New Wadi Cement Works	3,500,000	2000.36
18	13.498	77.510	ACC Thondebhavi Cement Works	1,660,000	948.74
19	17.054	76.978	Wadi Cement Works	2,590,000	1480.27
20	16.314	77.357	Ashtech India Pvt Ltd	500,000	285.77
21	16.177	75.681	Bagalkot Cement & Inds.Ltd	300,000	171.46
22	17.159	77.293	Cement Corporation of India Ltd-Kurkunta	200,000	114.31
23	17.370	77.447	Chettinad Cement -Kallur	2,500,000	1428.83
24	16.205	75.210	Dalmia Cement (Bharat) Ltd - Belgaum	2,500,000	1428.83
25	13.495	77.044	Hebbal Cements	200,000	114.31
26	13.270	76.723	Heidelberg Cement India Ltd- Ammasandra	570,000	325.77
27	12.970	76.119	Hemawati Cement Industries	200,000	114.31
28	16.205	75.300	J.K. Cement Ltd—Muddapur	1,824,385	1042.69
29	15.180	76.700	J.S.W. Cement Ltd—Vijaynagar	600,000	342.92

(continued)

(continued)

Sno	Latitude	Longitude	Industry	Installed capacity Tons	CO_2 Emission Gg
30	17.302	77.435	Kalburgi Cement Pvt Ltd	2,750,000	1571.71
31	17.161	77.294	Kesoram Cement—Vasavadatta	5,160,000	2949.11
32	17.105	77.135	Orient Cement-Chittapur	3,000,000	1714.60
33	16.227	75.198	Ratna Cements (P) Ltd, Yadwad	160,000	91.45
34	17.042	77.222	SHREE CEMENT LIMITED—KODLA	3,000,000	1714.60
35	16.194	75.492	Shri Keshav Cements and Infra Ltd.—Kaladgi	330,000	188.61
36	16.205	75.299	Shri Keshav Cements and Infra Ltd.—Naganapur	330,000	188.61
37	15.351	76.264	UltraTech- Ginigera Cement Works (G)	1,300,000	742.99
38	17.139	77.178	UltraTech- Rajashree Cement Works	3,200,000	1828.90
39	12.984	74.845	Mangalore Refinery and Petrochemicals Limited	16,300,000	11,829.81
40	12.347	76.569	Venlon Enterprises Limited	35,200	25.55
Total Emission (Gg)					42,995.93

Annexure-II

The energy produced by various power stations (Figure B) and their capacity are shown in Table B with emissions.

Thermal and Diesel power stations and their installed capacity

Sno	Latitude	Longitude	Power Stations	Installed capacity MW	CO2	CO	Emission total Gg
(a) Thermal Power Stations							

(continued)

(continued)

Sno	Latitude	Longitude	Power Stations	Installed capacity MW	CO2	CO	Emission total Gg
1	16.350	77.343	Raichur Thermal Power Station 1–7 Unit	1470	6619.87	46.73	6666.60
2	16.379	77.339	Raichur Thermal Power Station Unit-8	250	1125.83	7.95	1133.77
3	15.190	76.723	Bellary Thermal Power Station Unit-I	500	2251.66	15.89	2267.55
4	15.210	76.724	Bellary Thermal Power Station-Unit-II	500	2251.66	15.89	2267.55
5	15.207	76.713	Bellari Thermal Power Station Unit-III	700	3152.32	22.25	3174.57
6	16.379	77.339	Godhna Thermal Power Station Chhattishgarh Thermal Plant(Pit Head)	1600	7205.30	50.86	7256.16
7	13.227	74.789	Udupi Power Plant	1200	5403.97	38.15	5442.12
8	16.295	77.357	Edlapur Thermal Power Station	800	3602.65	25.43	3628.08
9	16.295	77.357	Yermaras Thermal Power Station	1600	7205.30	50.86	7256.16
(b) Diesel based power generating stations							
10	13.116	77.583	Yelahanka Diesel Generating Station	108	486.36	0.00	486.36

(continued)

(continued)

Sno	Latitude	Longitude	Power Stations	Installed capacity MW	CO2	CO	Emission total Gg
11	12.776	77.422	Bidadi Gas Based Combined Cycle Power Plant	700	3152.32	0.00	3152.32
Total emission (Gg)							42,731.23

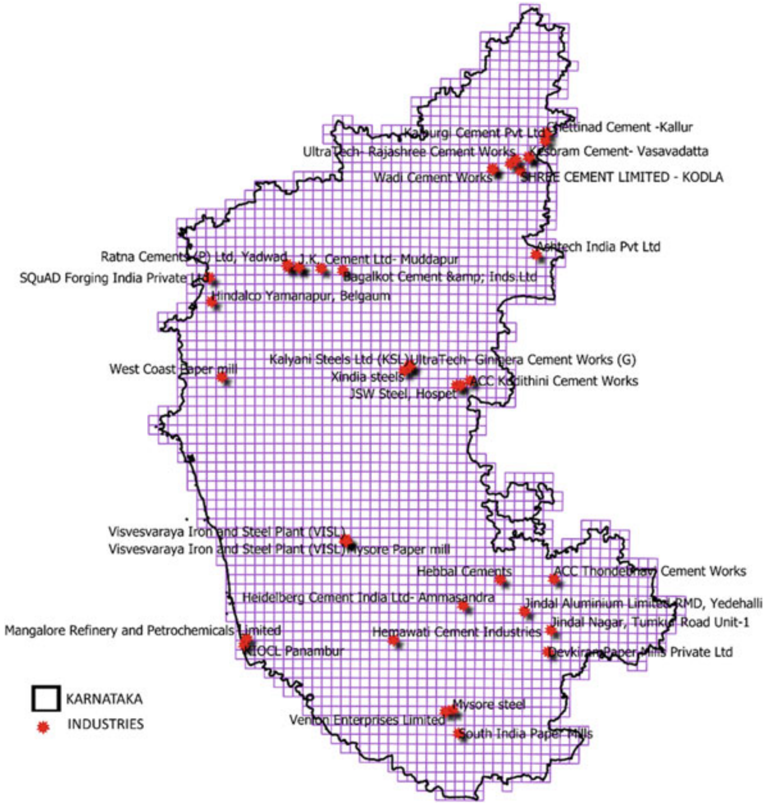

Fig. A Major industries of Karnataka. *Source* Author

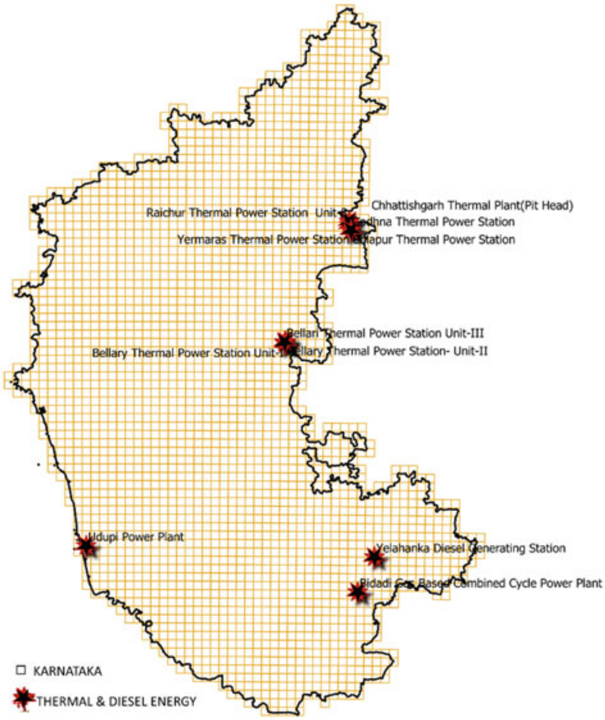

Fig. B Thermal and Diesel power stations of Karnataka. *Source* Author

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