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Carbon Stock Assessment and Prediction in the Periyar Tiger Reserve, India, Using Markov Chain and Invest Model

Veeramani S., Anoop V., Ramesh Babu M., Patil Suyog Subashrao and P.J. Suhyb
Periyar Tiger Conservation Foundation, Periyar Tiger Reserve (East Division), Thekkady, Idukki-685 509, India
E-mail: Veeramanitkp@gmail.com

Abstract: Enhancing and conserving carbon pools in vegetation is a major strategy for mitigating climate change. Carbon dynamics in terrestrial ecosystems are influenced by processes such as photosynthesis, respiration, decomposition, and combustion, as well as anthropogenic activities such as greenhouse gas emissions and climatic variations in rainfall and temperature, and it is stored as biomass in various forms carbon sequestration is evaluated in this study based on the change in total carbon in two different scenarios using the Markov chain and the InVEST model for the years 2001, 2022, and 2043 . The 1.625 Tg carbon has already been lost from 2001 to 2022 in the forest area of Periyar Tiger Reserve and another 0.415 Tg of carbon is expected to be lost in the predicted future, when we compare the forest cover in 2043 to the current scenario. The lower carbon release in 2022 compared to 2001 is due to natural disasters such as the 2018 major flood in the Idukki District. The research findings assist policymakers in simulating ecosystem carbon storage and its trade-offs for a variety of environmental and economic objectives.

Keywords: Carbon sequestration, Ecosystem services, Markov chain model

According to a report by the Forest Survey of India in 2017, India's carbon stock was estimated at 7083 million tonnes. The carbon stock has increased by 39 million tonnes since the previous assessment in 2015. AGB had the greatest carbon change when compared to SOC, litter, and deadwood carbon (Adame et al 2015, FSI Report 2017, Pechanec et al 2018). Similar study for quantifying forest carbon sequestration rate using InVEST model has been done in Three-North shelterbelt Program region, China (Chu et al., 2019). Thus, the premise of this paper revolves around carbon stocking and sequestration as one of the most significant drivers of climate change mitigation measures. The methods to assess it using geospatial techniques and machine learning algorithms for future prediction and valuation of carbon stocks is then formulated from which solutions are framed. Forest management through targeted afforestation/restoration/reforestation drives and simultaneously alleviating problems like forest land conversion and unsustainable/ illegal extraction of resources like fuelwood is also dealt with. The addition and removal of carbon dioxide (CO2) and other greenhouse gases by ecosystems regulates the Earth's climate (Smith et al. 2014). Terrestrial ecosystems, such as forests, grasslands, and peat swamps, store more carbon than the atmosphere, keeping the air clean from excessive CO2 concentrations (Eggleston et al. 2006). Moreover, it requires information about the quality of sequestered carbon or carbon lost over time and is necessary to draw spatial relationships between change in land use and its effect on carbon storage.

Forests store more carbon than the atmosphere and young forests sequester more carbon compared to older ones. However, older forests can hold a large volume of carbon for a longer time in the form of biomass and, thus, act as perfect reservoirs (Cao and Yuan 2019). Carbon sequestration has the potential to stabilize atmospheric carbon for the next few decades; however, it is not a complete solution to all carbon-related problems. Thus, there is a research gap in the application of advanced methods that allow the spatio-temporal integrated assessment of land-use change impacts on carbon storage services. Some studies applied field inventory data along with LULC maps for modeling carbon stock at land-use level with limited above-ground carbon pool (Wu et al 2019).

In this paper, the carbon stock for the PTR has been geospatially assessed. This study makes a fresh attempt at carbon sequestration studies by attempting to anticipate carbon sequestration in the tropical evergreen forests region of India. The objective of study are evaluation of forest cover and its forecast and carbon sequestration measurement of current and future years. The research output will help inform planning, development, implementation, and monitoring at the landscape level to research groups on sustainable forests and climate change such as the reduction of emission from deforestation and degradation (REDD+).

MATERIAL AND METHODS

Study area: Periyar Tiger Reserve (PTR) is an important biodiversity region in Idukki district of the state of Kerala in India. The PTR comes within the western ghats with altitude between 97 and 2017 m. The geographical extent of the area is 9° 17' 56.04" N latitude and 77° 25' 5.52 E longitude (Fig. 1). The major portion of the Reserve forms the catchment of River Periyar and the rest is that of River Pamba. Administratively, PTR falls in Idukki, Kottayam and Pathanamthitta Districts of Kerala. The 'Periyar Wildlife Sanctuary Proper' with an extent of 777 km2 comprising of Periyar Lake Reserve Forest (600.88 km^2), areas of Rattendon Valley (12.95 km^2) and Mount Plateau (163.17 km^2) was constituted in 1950. The Sanctuary was brought under Project Tiger in 1978 as the 10th Tiger Reserve in the country and named as Periyar Tiger Reserve. Presently, the total extent of PTR is 925 km^2 of which 881 km^2 is notified core or critical tiger habitat and the remaining 44 km^2 is notified buffer. PTR lies in the range of 76-2017 m above MSL. PTR with adjoining forests forms the largest remaining benchmark climax forest vegetation in the entire peninsular India. This is a representative of Bio-geographic Zone 5-B of the Western Ghats and plays a key role in maintaining regional connectivity in the otherwise fragmented forest tracts. It is contiguous with the forest areas of Theni Forest Division, Megamalai Wildlife Sanctuary, Srivilliputhur Grizzled Squirrel Sanctuary and Tirunelveli Forest Division (in Tamil Nadu) and Kottayam, Ranni, Konni, Achenkovil, Punalur and Thenmala Forest Divisions in Kerala. At landscape level, the Periyar Conservation Unit extends right up to the Arienkavu Pass and has tenuous linkages with the Agasthyamalai Conservation Unit comprising of Kalakkad-Mundanthurai Tiger Reserve in Tamil Nadu and Shendurney, Neyyar, Peppara Wildlife Sanctuaries and Thiruvananthapuram Forest Division in Kerala.

Data and methods: Forest cover for the year 2001 and 2022 was been prepared; these two were further used to develop the forest cover of the predicted year 2043 using MOLUSCE IN QGIS. Forest cover analyses of the years 2001, 2022, and 2043 have been used to develop the carbon sequestration maps using InVEST model and quantify the total carbon loss which would occur in near future.

GIS and InVEST in study: Forest cover change is attributed as the major consequence of forest degradation (IPCC 2006, Sahana et al 2018A). Remote sensing data and geospatial techniques are deliberately used to identify forest cover change and estimate forest carbon pool, especially for aboveground biomass. In this study, the InVEST model developed by Natural Capital project and LULC derived from Land sat data were used to estimate the carbon stock for the years 2001 and 2022. It also predicted the carbon stock for the year 2043 along with the mapping and estimation of carbon sequestration over the years. Modules for Land Use Change Simulations (MOLUSCE) is a plug in within QGIS aligned to the pressing problem of higher rate of land conversions. MOLUSCE interface is organized around a set of 3 major models: Change analysis, Transition potential and Change prediction. For smart development and forest management practices, the understanding of transitions into the future is very important. By using machine learning procedures, the change analyses past forest cover data to estimate, model and predict Forest cover change. The InVEST model uses maps of LULC and stocks of carbon

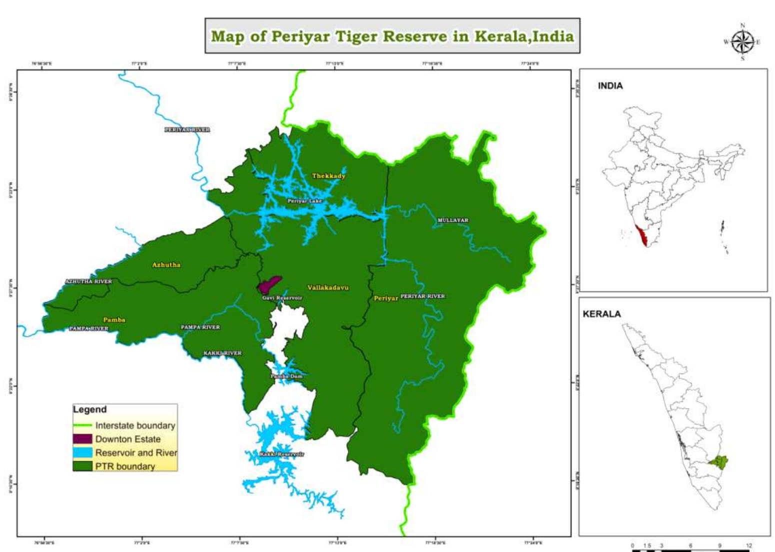

Fig. 1. Periyar Tiger Reserve in Kerala, India

pools (soil organic carbon, belowground biomass, aboveground biomass, dead organic matter) to estimate how much carbon is currently fixed in a landscape or how much has been sunk through time. The model gives outcomes using LULC maps: How much carbon is fixed in different carbon pools and net amount of carbon over the years in a landscape. InVEST is one such spatially clear-cut model that uses “ecological production functions” to forecast the supply of ecosystem services. Later, in order to find the economic value of these services, these estimates are integrated with economic valuation methods for a given landscape. The study reveals the potential of Periyar Tiger Reserve area and answers the question of how much carbon it is withstanding, how changes in LULC cover also changes the forest's potential for carbon sequestration and how much gain/loss of fixed carbon has occurred and how can manage those losses by afforestation and reforestation activities using certain specific species in the forest area. The InVEST Model used here is the most appropriate method of detecting carbon present in the study area using satellite data with the help of remote sensing and GIS. It is the best method to study any protected area without disturbing its natural habitat and wild animals living there and is also helpful in the study of inaccessible areas.

Preparation of land use land cover map: The land sat images for the years 2001 and 2022 were used to prepare the forest cover map of PTR region (Table 1). The study area was extracted from the satellite imagery. Ground truth data were applied for determining the forest cover identity of each pixel in the images. In this software analysis process, the result is an assemblage of pixels with common features without the user giving sample classes. For the preparation of Forest classification, spectral classes were grouped into 6 classes. Classes like water body, evergreen, semi evergreen, moist deciduous, thickets and grass land. Using ground truth data (for 2001 image) and Google Earth Pro (for 2022 image), accuracy assessment was also done for both the years. Random sample points were laid down with a minimum of 10 points for each forest cover class. User's accuracy, producer's accuracy and kappa statistics were generated for the forest cover map. The forest cover maps generated were used for change detection in ENVI software, and statistical changes were calculated to see the conversion of classes into one another, from the year 2001-2022 which also helped in finding the possible reasons behind it. A detailed Ground Truthing (GPS Points) field survey was carried out in 2022 to improve the accuracy of the Forest cover map. A total of 100 GPS readings were taken from the ground (Fig. 2).

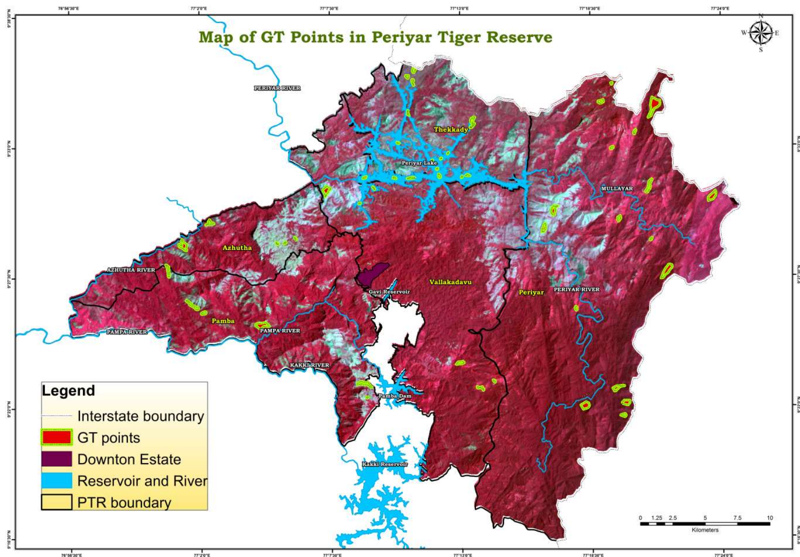

Fig. 2. GT points in PTR region

Table 1. Details of data used

Data	Data types	Source	Details	Period
Landsat-7 ETM+	Spatial	USGS Earth Explorer	30 m resolution	2001
Landsat-8	Spatial	USGS Earth Explorer	30 m resolution	2022
Vegetation type	Spatial	Kerala Forests and Wildlife Department	Polygon shape	2001, 2022

LULC prediction for the year 2043 using QGIS software: QGIS (MOLUSCE) was used to get the predicted Forest Cover map for the year 2043 using driver variables based on Cramer's value. InVEST model was used for estimation of carbon stock and carbon sequestration over the years and calculate the economic cost of carbon added or lost from the environment. The Forest cover map of the years 2001 and 2022 were used as inputs in the MOLUSCE model of QGIS as baseline map for the prediction of forest cover for the year 2043. All input maps were converted into the raster format and imported. It includes 3 steps to get the prediction map in QGIS software. Change analysis and land use transitions, transition potentials and change demand Modelling using Markov chain. Change analysis and land use transitions were done using the MOLUSCE of QGIS. The prerequisite of the model is: forest cover maps (2001, 2022 year). These layers used in order to run the change analysis.

Generation of carbon sequestration map using InVEST model: The forest cover map of current year i.e., 2022 and the predicted year i.e., 2043 were used as the input for preparation of carbon sequestration map in InVEST model. A carbon pool table was generated using FSI report and IPCC 2006 guidelines and from literature review, which shows the carbon pool in aboveground biomass, belowground biomass, soil organic carbon and deadwood carbon in different classes of Forest cover map (Table 2).

Accuracy assessment and model validation: Accuracy assessment is done using stratified random sampling and the minimum number of observations placed in each class is 30. Overall accuracy of forest cover classification shows the comparison of each pixel classified by us versus the actual conditions of the ground, as per the field survey. More the overall classification accuracy, more accurate is the classified image. Here, forest cover for the year 2022 is more accurate as compared to that for the year of 2001. Producer's accuracy measures the error of omission; this shows how well real-world land cover types can be classified. Kappa statistics evaluate the accuracy of the classification. Kappa coefficient can range from 1 to 1. The value close to 1 indicates that the classification is significantly better than random classification i.e., a value closer to 1, denotes more accurate results. Here the kappa coefficient for 2001 and 2022 Forest cover classified map is 0.83 and 0.94. This shows that the 2022 Forest cover classification is more accurate in comparison to the 2001 classification, for validation of the predicted LULC map of the year 2043. Limitations of the InVEST model include an assumption based on linear alteration in sequestration of carbon over time that the carbon cycle is oversimplified, and potential of considering inappropriate discounting rates. The detailed steps followed to develop the methodological framework for this study are given in Figure 3.

Field survey for the validation of LULC maps: Remote sensing and GIS provides an approximate idea about the study site but ground truthing validates the results. Here, in order to get more accurate results, forest field watchers were interviewed. A comparative data was generated by taking

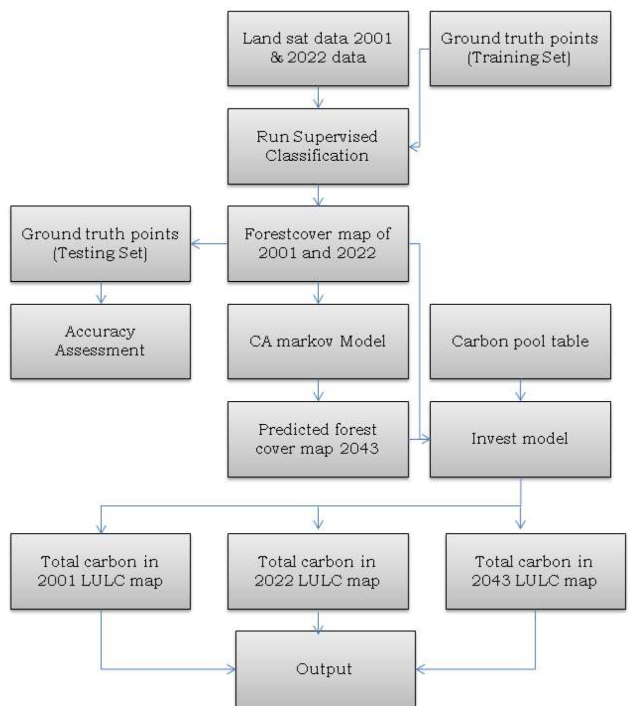

Fig. 3. Methodology

Table 2. Carbon pool table (Input of InVEST)

Lucode	LULC_name	C_above	C_below	C_soil	C_dead	C_litter
1	Waterbody	0	0	68.15	0	0
2	Moist Deciduous	72.58	14.92	79.19	1.17	4.84
3	Grassland	6.29	10.35	68.15	0	0
4	Ever Green	78.54	27.17	97.19	4.1	9.21
5	Semi Ever Green	62.91	12.94	85.19	4.1	5.94
6	Thickets	3.15	5.15	34.07	0	0

(Chacko et al 2018)

100 random GPS points and for each GPS point, past knowledge and future perception of villagers and forest range officers for that location was used.

RESULTS AND DISCUSSION

Six forest cover classes for the years 2001, 2022 and 2043 were identified in the Periyar Tiger Reserve namely; waterbody, evergreen, semi evergreen, moist deciduous, thickets and grass land (Fig. 4). During the time period 2001-2022, Semi Evergreen forest increased by 8.28 %. It could be attributed to lower climatic pressure on the forest area, as a result of better management practices followed by the forest department. Grassland decreased by 3.10 % by conversion into moist deciduous and evergreen forest area decreased by 16.2 % and converted into semi evergreen forest .There was increase in water body area by 0.16% as a result of low temperature and high annual rainfall. (Fig. 4 , Table 3) .

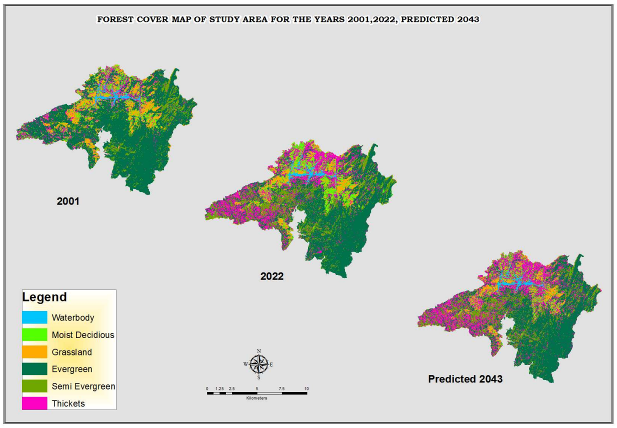

Fig. 4. Forest cover for 2001, 2022, 2043

For the year of 2001, total carbon in the PTR region is 15.95 Tg, and includes carbon present in all forest classes, i.e, water body, evergreen, semi evergreen, moist deciduous, thickets and grass lands. The forest area contains 3.81-18.6 Mg of carbon in each grid cell (Fig. 5, Table 6). The carbon stock in each grid cell for 2022 is the same as that shown in the map for the previous year (2001). Due to the exchanges that have occurred in the Forest cover classes, the total carbon in each class has differed and hence the total carbon

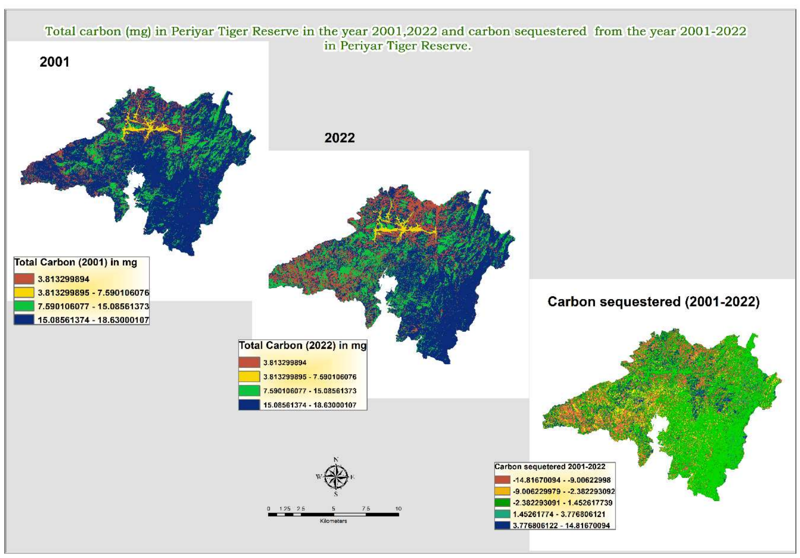

Fig. 5. Total carbon (mg) in Periyar Tiger Reserve in the year 2001, 2022 and carbon sequestrated (2001-2022)

Table 3. Forest cover statistics (2001, 2022 and 2043)

Forest type	2001		2022		2043		Change (2001-2022)		Change (2022-2043)	
	Sq.km	%	Sq.km	%	Sq.km	%	Sq.km	%	Sq.km	%
Waterbody	14.11	1.52	15.61	1.68	14.01	1.51	1.5	0.16	-1.6	-0.17
Moist Deciduous	88.22	9.53	91.49	9.89	66.6	7.2	3.27	0.34	-24.89	-2.65
Grassland	84.67	9.15	55.59	6.009	53.4	5.77	-29.08	-3.1	-2.19	-0.23
Ever Green	564.8	61.06	413.07	44.65	416.77	45.05	-151.82	-16.2	3.7	0.39
Semi Ever Green	81.84	8.84	159.41	17.23	147.17	15.91	77.57	8.28	-12.24	-1.3
Thickets	91.99	9.94	190.53	20.59	227.76	24.62	98.54	10.52	37.23	3.97

stored in the study area is 14.33 Tg of carbon (2022), which is a decrease by 1.62 Tg as compared to carbon levels for the year 2001 (Table 6).

Future carbon stock of 2022 in the previous study is like the current carbon stock in 2022-2043 study. Total carbon stored as shown in the predicted map of year 2043 (Fig. 6). Total carbon stored in the PTR forest area is 13.916 Tg, which further decreased by 0.415 Tg when compared with 2022 statistics.

Survey was conducted to find out possible reasons for carbon loss like climate change i.e., declining trends in rainfall and temperature or the anthropogenic pressure from local communities. The results show that along with climatic variations, anthropogenic pressure is the main reason for carbon loss into the atmosphere. The maps generated for the years 2001 a 2043 using the InVEST software match with the past and future perceptions of local people and forest officers. The Forest cover changes inside PTR is majorly because of climatic variations.

Ecosystem history and trajectory of the ecosystem at present are helpful to assess the potential carbon storage of any region (Lubowski et al 2006, Zhao et al 2019). InVEST model was used to predict provision of ecosystem services and carbon sequestration for three contrasting scenarios including the past (year 2001), present (year 2022) and future (year 2043) Forest cover. Forests have the potential to sequester carbon which may otherwise contribute to global warming. The economic view of carbon emission reductions as given by the Kyoto protocol helps forest owners to realise revenue. specifically for regulating climate, quantifying biomass/carbon in highland forests is crucial in numerous ways. Due to the fragile, inhospitable, and difficult-to-access terrains, predicting the spatial distributions of carbon stocks in the varied alpine ecosystems has always been difficult. Research on modelling carbon stock at landscape levels is unusually scarce in emerging nations like India. However, these countries mostly contain mountainous regions where climate regulation is highly delicate to the process of climate change and global warming and from both environmental and intense human-induced activities. Therefore, it is necessary to evaluate inadequate carbon pools for these mountainous regions in developing countries in their whole. By fusing remote sensing with the carbon storage and sequestration InVEST model, this research intended to spatially estimate the carbon stock in the Periyar Tiger Reserve. In developing nations with little access to data, calibrating such complicated models at broad scales is difficult. Using field inventory data, we classified Landsat imagery using an object-based approach. The amount of carbon used for each pool has a significant impact on the total carbon stock estimated by the InVEST model. However, the carbon inventories predicted by the model and their economic values are crucial for upcoming efforts to reduce the effects of climate change.

Table 4. Carbon values and total carbon sequestrated in 2001, 2022, 2043

Year	Carbon (mg)	Year	Sequestered carbon (mg)
2001	15957018.2	2001	NA
2022	14331629.72	2001-2022	-1625388.45
2043	13916396.26	2022-2043	-415233.46

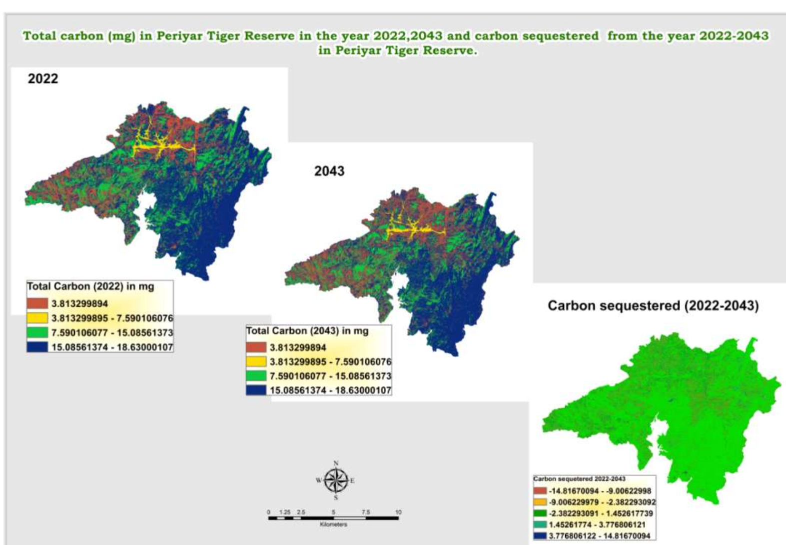

Fig. 6. Total Carbon (mg) in Periyar Tiger Reserve and carbon sequestrated (2022-2043)

CONCLUSION

The study shows that carbon content in the PTR region has decreased from the year 2001-2022 and stands to decrease further from 2022 to the predicted year 2043. The carbon sequestration results show that the change in carbon from the year 2001-2022 was 1.625 Tg. So, in order to avoid this carbon getting lost into the atmosphere in near future and experience its worst effects must plan for its sequestration. The maps generated from the InVEST model depict the total carbon stock present in the total study area, for the respective years (2001, 2022, 2043), with the description of carbon present in each grid of the different LULC classes. It also generates a carbon sequestration map for the time period 2001 to 2022 and 2022 to 2043 which helps to understand a general trend of whether carbon is sequestered or lost to the atmosphere over time. This helps us to take protective measures for the forested area via providing guidance to stakeholders, NGOs, governments, and businesses. Such maps are useful as they help them in supporting their decisions, for example, to grab opportunities like earning credits for REDD. Governments can use them for detecting the target landscape home to most of the carbon fixed and provide incentives to land- owners as a trade-off for forest conservation.

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