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Space-based assessment of changes in terrestrial carbon sequestration with special reference to the proposed Silver Line railway project (K-rail) corridor in Kerala, India

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ABSTRACT

Carbon dioxide from the atmosphere is absorbed naturally through photosynthesis and stored as carbon in biomass and the process is commonly referred to as Terrestrial Carbon Sequestration. Silver Line/ K-Rail project is an upcoming major infrastructure project in Kerala, which could cause a sizeable reduction in 'Trees outside forest' which in turn affect the terrestrial carbon sequestration. This study aims to find the spatio-temporal changes in terrestrial carbon sequestration estimation in the proposed Silver Line railway project (K-Rail) corridor area, in India. Geospatial Technology is the most efficient technology for spatio-temporal analysis. The summer and winter seasons of Sentinel-2 images of the year 2021 are taken as the data source for this study. The extent of vegetation cover has a significant influence on the carbon variations; and thus Normalized Difference Vegetation Index (NDVI) of the study area was determined and its metadata obtained was utilized for the further calculation of carbon stock, above-ground biomass, and carbon dioxide using QGIS software. Distance zone classification was performed with the help of zonal statistics in a 10 m, 30 m, and 500 m buffer distance. The result indicated seasonal changes in the terrestrial carbon sequestration and a noticeable difference in carbon, above-ground biomass, and greenery in the K-Rail corridor after the completion of the project.

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1. Introduction

1.1. General

The phenomenon of securing carbon dioxide to prevent it from entering the Earth's atmosphere, in order to stabilize carbon in solid and dissolved forms so that it does not cause the atmosphere to warm, is termed carbon sequestration. Terrestrial Carbon Sequestration is the phenomenon through which the atmospheric carbon dioxide (CO_2) is absorbed by the plants and tree canopy, through the process of photosynthesis and stored as carbon in the biomass. It is important to remember that terrestrial sequestration does not store CO_2 as a gas but stores the carbon portion of the CO_2 (Rajkumar and Venkata, 2017). The forests and vegetative cover thus have a greater

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potential for carbon sequestration in which the carbon dioxide from the atmosphere is in turn stored as the biomass in those trees and vegetation.

Carbon accounting is an important analytical task that provides baseline information to assist in establishing emissions targets, developing market-based carbon trading programs, and facilitating sustainable carbon management at the regional to international scales (Zhao et al., 2011). Urban trees which fall under the category of "Trees outside Forests" (TOF) play an important role in the carbon cycle, being a potential carbon sink (Singh and Chand, 2012). Even though urban forests have the potential for carbon sequestration, the data on TOF is largely inadequate for any potential assessment of their influence on carbon dioxide sequestration (FAO, 2010).

Due to the variability and heterogeneity of TOF systems, their sparse distribution, and limited spatial footprint, assessing TOF is more challenging than assessing forests. Promisingly, satellite remote sensing and GIS techniques offer the facility to monitor and analyse vegetation cover over large areas on a routine basis (Roy et al., 2010; Ravindranath and Ostwald, 2008; Dahowski et al., 2001). Geo-Spatial technologies which include Remote Sensing (RS) and GIS, opens a wide window of opportunity to enable rapid assessment of terrestrial biomass over large areas and thereby allow estimation of the amount of carbon sequestrated in the biomass in a timely and cost-effective manner. The GIS tool will integrate the vegetation inventory data to quantify and to map the carbon sink and stock values (Bindu et al., 2021). Kinds of literature on global, national as well as regional levels are available on the application of remote sensing and GIS in carbon sequestration assessment. Danardono et al. (2021) studied the spatio-temporal variation of terrestrial carbon sequestration in tropical urban areas of Surakarta district, Indonesia. The carbon sequestration was modeled using NPP (net primary production), NDVI, FPAR (fractional absorption of photosynthetically active radiation), SOL (solar radiation) and (light energy utilization). In the study conducted by Kuldeep and Upasana (2011), satellite remote sensing data has been used as a primary data source for forest classification, LULC mapping, biomass estimation, land use-forest-carbon change detection and ecology mapping for forest carbon management, and satellite remote sensing techniques, RS-LULC based method, vegetation index (NDVI) based method and ArcGIS based model was used for the carbon stock estimation of Sagar District, Madhya Pradesh. Carbon stock in a natural forest area of Kolli hills, part of the Eastern Ghats of Tamil Nadu, India has been estimated using geospatial technology by Ramachandran et al. (2007). Chinchu et al. (2017) investigated the spatio-temporal changes that occurred in terrestrial carbon sequestration due to the metro rail project at Kochi city in India from the years 2013 to 2015 have been investigated. NDVI was used to detect the tree cover change and for the quantification of carbon stock. Bindu et al. (2021) assessed the temporal change in terrestrial carbon sequestration capacity with land use land cover (LULC) changes along the metro corridor in Kochi and focused on a decrease in carbon sequestration capacity due to the clearing of vegetation, in a study area proceeded with NDVI estimation, biomass estimation using the volumetric equation, carbon stock using NDVI and change in carbon sequestration using overlay method. Most of these studies utilized vegetation indices such as normalized difference vegetation index (NDVI) for the quantitative measurements of biomass or vegetation cover. NDVI values derived from satellite measurements could be useful in assessing the carbon sequestration and storage potential of urban forests (Myeong et al., 2006). Infrastructure projects are a major cause of the sizeable reduction of urban trees, which in turn affect terrestrial carbon sequestration (Chinchu et al., 2017).

Silver Line or K-Rail project is a semi-high speed railway project that would run trains at 200 km/h between the northern and southern ends of Kerala state, spanning 529.45 km with 11 intermediate stations. The Thiruvananthapuram–Kasaragod semi-high speed rail project is a visionary project which will create a new era of safety, speed and service for the people of Kerala (Centre for Environment and Development, 2020). Experts have said that the project would require acquiring 1,383 hectares of land, including wetlands, forest areas and backwater regions, residential areas with a high density of population, rice fields and existing building spaces thereby causing huge environmental damage. Thus the impacts of such development on the carbon cycle are very prominent (Shaji, 2021).

The present study investigates the spatio-temporal changes in the terrestrial carbon sequestration due to the proposed Silver Line project of Kerala in India during the summer and winter seasons using Geospatial Technology which is the most efficient technology for spatio-temporal analysis. The normalized difference vegetation index (NDVI) derived from satellite data was used to estimate the difference in carbon stock due to the reduction in tree cover as per IPCC guidelines.

1.2. Objectives of the Study

The general objective of this study is to assess the spatio-temporal changes in Terrestrial Carbon sequestration due to Silver Line or K-Rail project in Kerala, India. Being more precise on the objective of this study, the specific objectives of the study are:

- Assessment of spatio-temporal changes in Terrestrial Carbon Sequestration for the two seasons, summer and winter seasons of the year 2021, of the study area due to the proposed Silver Line project in Kerala state, which is spanning 529.45km connecting the Northern end of Kasaragod and southern end Thiruvananthapuram, using Geospatial Technology and GIS as a tool.
- To estimate the seasonal changes in carbon stock, Above-Ground Biomass (AGB), and carbon dioxide of the study area during summer and winter.

1.3. Scope of the study

In the present scenario of the state of Kerala, the infrastructure project ‘Silver Line / K-Rail’ is the most sensational subject that is being discussed. Infrastructure projects are a major cause of reduction in the urban canopy which in turn increase the emission of greenhouse gas into the atmosphere of urban areas and causes warming of the surrounding atmosphere. Thus from an environmental engineering point of view, a study on spatio-temporal changes in carbon sequestration is very much relevant as it is the process that helps reduce the emission of greenhouse gas. This study could estimate the carbon emission, which would otherwise have been sequestrated, due to the loss of vegetation for the Silver Line project. Thus the study area chosen reveals the need for this work.

2. Study Area

The study area taken for this study is along the route of the proposed Silver Line heading from Kasaragod to Thiruvananthapuram with a width of 1 km buffer zone, 500 meters each on either side from the centerline of the alignment, and a length of 529.45 km which is the proposed length of Silver Line project. The proposed Silver Line route lies between 8°30 44.88 N to 12°29 28.37 N latitudes and 74°59 15.57 E to 76°53 52.43 E longitudes. The index map of the study area is illustrated in Fig. 1.

3. Materials and Methods

3.1. Data used

The images of Sentinel-2 satellite data with a 10 m resolution from the United States Geological Survey (USGS) earth explorer were used for this study. All the geometrical and radiometric corrections were performed in the dataset. A total of ten tiles in the summer season and nine tiles in the winter season of the year 2021 have been collected from USGS Earth Explorer. The study area was extracted from the Georeferenced political map of Kerala. The proposed rail route of the Silver Line is collected from the Detailed Project Report (DPR) of the K-Rail corridor (Table 1).

Table 1. Data source details.

Data Type	**Source (Satellite/Product)**	**Spatial Resolution (m)**
NDVI	Sentinel-2	10
Administrative Boundary	Survey of India	NA

3.2. Methodology

The schematic representation of the methodology of the entire study is shown in Fig. 2. The Silver Line route or alignment is vectorised along its length of 529.45 km connecting Kasaragod and Thiruvananthapuram using lines and the 11 intermediate stations are vectorised using points. Thus, these two layers are created as separate shapefiles in QGIS software and overlayed along with the georeferenced map of Kerala to prepare the map in ArcGIS software.

The present study area is extracted by providing a 1 km buffer area. A buffer of 500 meters each on both sides from the centerline of the proposed Silver Line alignment was extracted using the buffer tool in ArcGIS software, which comprises the study area of this work.

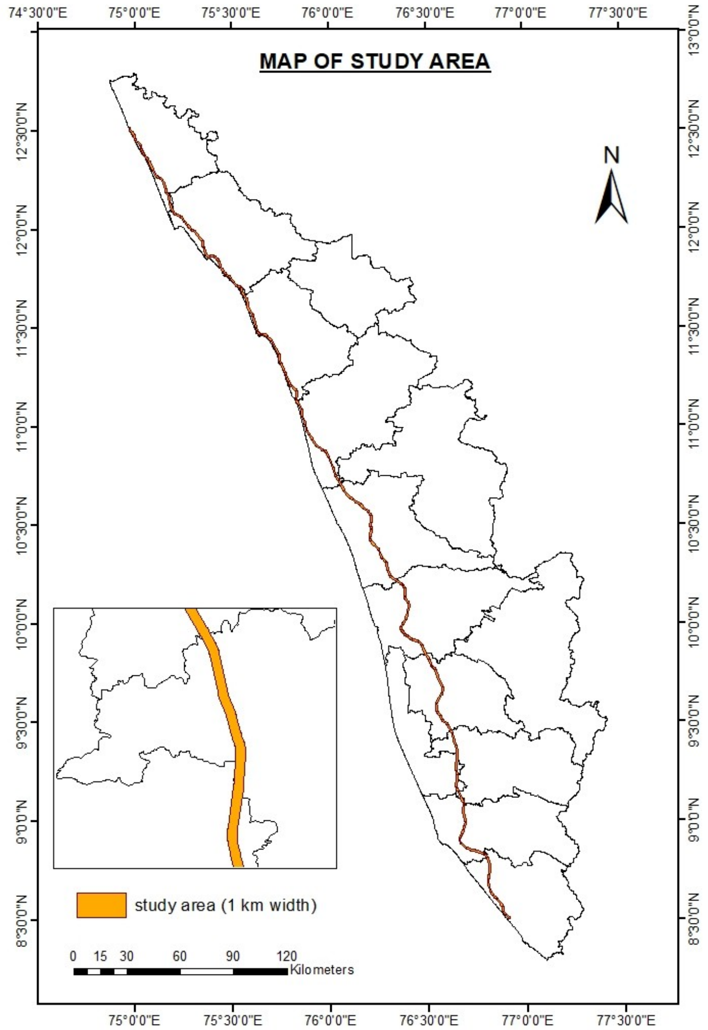

Fig. 1. Index map of the study area.

3.2.1. Digital Image Processing

The digital image was processed for the estimation of the Normalized Differential Vegetative Index (NDVI) estimation, carbon stock estimation, biomass estimation, carbon dioxide estimation and vegetative area estimation. The carbon stock was estimated from NDVI and thereby the carbon dioxide sequestrated in the study area, biomass, and carbon dioxide (CO_2) were estimated.

Normalized Differential Vegetative Index estimation. NDVI estimation is performed by using the near-infrared band and red band of the satellite images of the study area (Table 2). The calculation was done using a raster calculator, making use of equation (1) (Rouse et al., 1974) in QGIS software as a ratio of measured intensities in red and near-infrared (NIR) spectral bands.

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}} \tag{1}$$

Carbon stock/storage estimation. The carbon stock is estimated using an urban carbon storage equation and thereby the carbon dioxide sequestrated in the study area, for both the summer and winter seasons are determined. The urban carbon storage equation (2) (Myeong et al., 2006) was used to determine the carbon stock or carbon storage in the study area.

$$\mathrm{Carbon(C)} = 107.2 * \mathrm{e}^{(\mathrm{NDVI}} * 0.0194) \tag{2}$$

where,

- C: carbon storage or stock in(kg C/pixel)

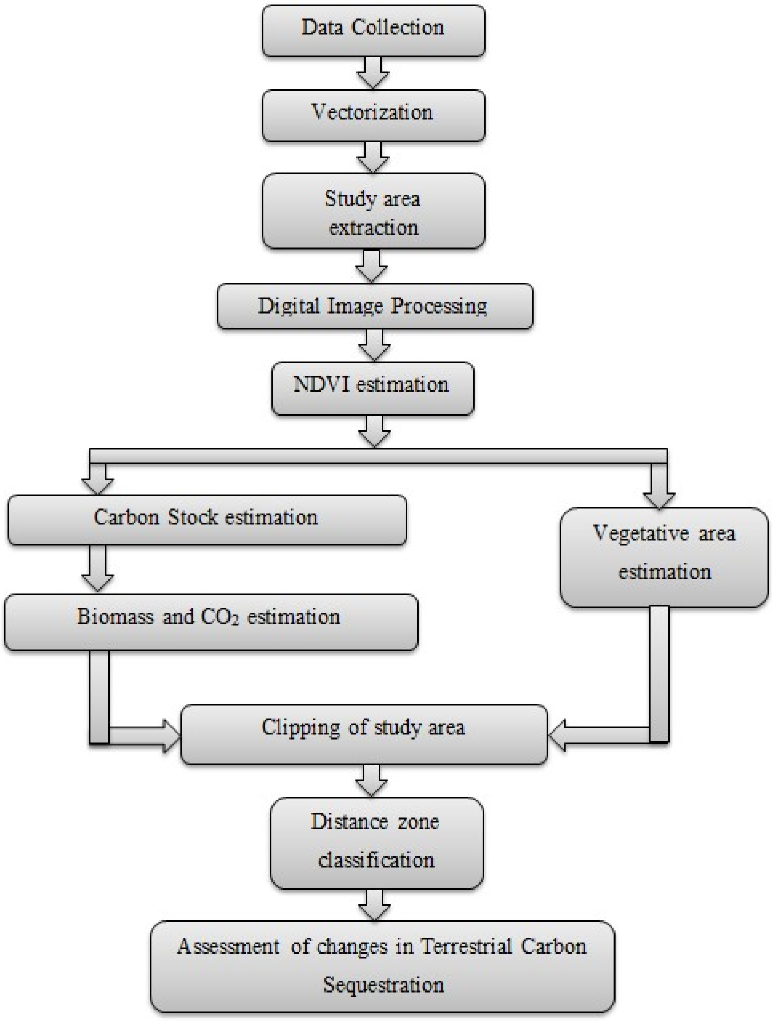

Fig. 2. Flow chart of Methodology.

Table 2. NDVI value range vs land use/cover type

NDVI Value	Vegetation Condition / Land Cover Type
+0.6 to +1.0	Dense, healthy vegetation (e.g., tropical forests, crop fields at peak growth)
+0.2 to +0.6	Moderate vegetation (e.g., shrubs, grasslands, agricultural land)
0.0 to +0.2	Sparse vegetation, degraded areas, grassland, fallow land
0 to -0.1	Bare soil, built-up land
-0.1 to -1.0	Water bodies (rivers, lakes, sea)

- NDVI – Normalized Differential Vegetative Index ranges between -1 and +1
- 107.2: Empirical constant
- 0.0194: Sensitivity coefficient for NDVI
- e: Base of natural logarithm (~2.718)

Above Ground Biomass estimation. The biomass for both the summer and winter seasons in the study area are determined using equations (3), (4) (Shuhong et al., 2010).

$$\text{Carbonstock} = \text{Biomass} * 0.5 \tag{3}$$

i.e,

$$\text{Biomass} = \text{Carbonstock} * 2 \tag{4}$$

where, carbon storage or stock and above-ground biomass is in kg C/pixel.

Carbon dioxide estimation. Carbon dioxide sequestrated in the study area, for both the summer and winter seasons was determined using equation (5) (Danardono et al., 2021).

$$\text{Carbonstock} = \frac{\text{Carbondioxide} * 12 \text{ g of C}}{44\text{g of } CO_2} \ldots (5)$$

i.e,

$$\text{Carbondioxide} = \text{Carbonstock} * 3.67 \ldots\ldots (6)$$

Table 3. Reclassification range of the summer season.

-0.3620 to 0	No vegetation cover
0 to +1	Vegetation cover

Table 4. Reclassification range of the winter season.

-0.3133 to 0	No vegetation cover
0 to +1	Vegetation cover

where, carbon storage or stock is in kg C/pixel and Carbon dioxide is in kg CO_2e/pixel.

The processed tiles of each season are merged separately into eight different single images using the mosaic tool in ArcGIS software and the study area of 500 m buffer is clipped from the merged images using the raster clip tool from ArcGIS software.

3.2.2. Vegetative area estimation

The clipped image of NDVI of 500 m, 30 m and 10 m buffer for both the summer and winter seasons has been used for the vegetative area estimation using the tool reclassified in the geoprocessing software. The reclassification range of both summer and winter seasons is shown in Table 3 and Table 4 respectively.

3.2.3. Distance Zone classification

Both zonal, as well as district and distance-wise zone classification, were performed. In zonal-wise classification, multiple buffers of 10 m, 30 m, and 500 m buffers from the centerline of the proposed line are created as shown in Fig. 3, using the multiple buffer method. The assumption of the largest effect area from the existing roadways was the rationale for selecting a distance of up to 500 m from the existing roads.

The district-wise classification was done concerning the area covered by the study area in each district of Kerala state by overlaying the georeferenced district map of Kerala. Zonal statistics as the table is the tool used for distance zone classification. Thus, zonal statistics were performed on the clipped images, with the created multiple buffers of 10 m, 30 m, and 500 m as well as the georeferenced district map of Kerala, and the results are tabulated accordingly.

3.2.4. Assessment of change in terrestrial carbon sequestration

The carbon stock derived from the above step is used to determine the changes in carbon sequestration in two different seasons, summer and winter using the stock difference approach as in equation (7) (Eggleston et al., 2006). The difference in carbon stock with respect to time is assessed and various spatial variation maps are generated using ArcGIS software.

$$\begin{aligned} \text{Change} &\in \text{TerrestrialCarbonSequestration} \\ &= \frac{C_{S2} - C_{S1}}{S2 - S1} \end{aligned} \tag{7}$$

where,

C_{S2} – Carbon pre-monsoon (summer season)

C_{S1} – Carbon stock post-monsoon (winter season)

S2-S1 – Time period (Number of seasons under consideration)

4. Results and Discussions

4.1. Vectorization

The proposed Silver Line route from Kasaragod to Thiruvananthapuram and the 11 intermediate stations, including Kasaragod, Kannur, Kozhikode, Tirur, Thrissur, Kochi Airport, Ernakulam, Kottayam, Chengannur, Kollam and Thiruvananthapuram, has been vectorised and the map composed is as shown in Fig. 4.

4.2. Extraction of Study Area

The extracted study area has a 529.45 km length and a width of 1 km along the Silver Line alignment, i.e., 500 meters each on both sides of the centreline of the Silver Line alignment. The extracted study area is shown in Fig. 5.

4.3. Image Processing and Analysis

4.3.1. NDVI Estimation

The result of NDVI is obtained as an image holding values in terms of cells. Each cell contains the DN values of the particular feature involved which will be the basis of understanding the feature. The values of NDVI range from 1.0 to −1.0 in which positive values represent high vegetation and negative values represent little or no vegetation. Light colour infers more reflectance thus having higher values of NDVI ranging from 0 to 1.0 and darker colour infers less reflectance thus having lesser values of NDVI ranging from -1.0 to 0.

The study area has been clipped from the processed and merged output of NDVI for both the summer and winter seasons. As per the study, in the summer season, the range of NDVI lies between +1.0 and

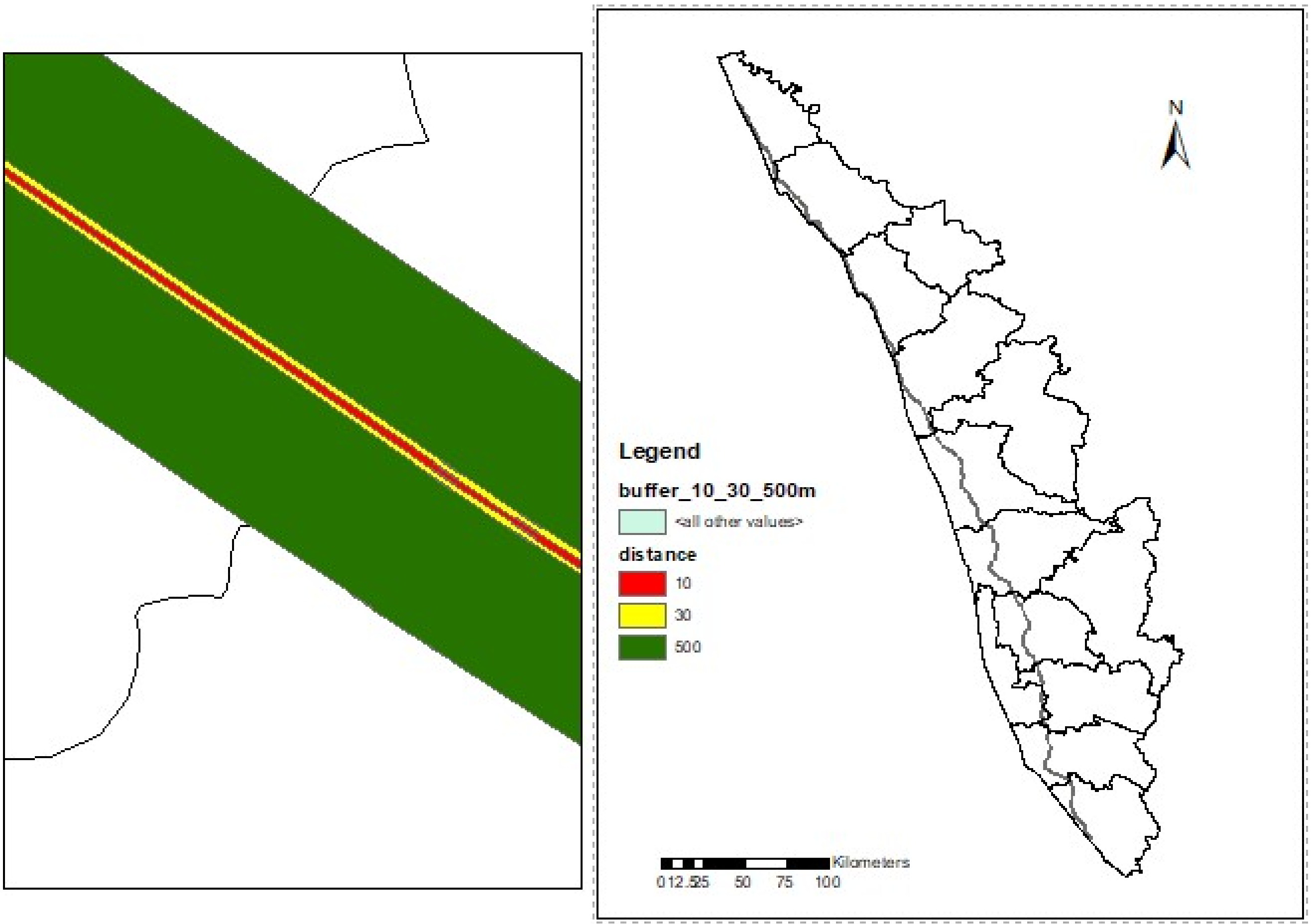

Fig. 3. Multiple buffers of 10 m, 30 m and 500 m.

-0.3620 (Fig. 6) and in the winter season, it ranges between +1.0 and -0.3133 (Fig. 7).

Reclassification is done for the NDVI distribution of both the summer and winter seasons of the year 2021. NDVI range of 0 to +1 denotes the vegetation cover and from that, the vegetative area in 500 m buffer is estimated as 5255.43 ha in summer and 5282.14 ha in winter. The vegetative area for the buffer of 30 m is estimated as 317 ha in summer and 318.10 ha in winter and similarly, for the 10 m buffer, the vegetative area is estimated as 105.70 ha in summer and 106 ha in winter. There is a significant reduction in vegetation cover in the study area, after the completion of the Silver Line project, which is about 98% of the total study area considered.

The NDVI value for the 10 m buffer zone from the proposed Silver Line comprising an area of 10.678 km^2 is estimated as 0.4598 in summer and 0.4503 in winter. Also, for a 30 m buffer zone with an area of 21.356 km^2, the NDVI value estimated is 0.4468 in summer and 0.4472 in winter. Similarly, the estimated NDVI value for a 500 m buffer zone with an area of 500.952 km^2 is 0.4451 in the summer season and 0.4434 in the winter season. The district-wise variation in the NDVI value is given in Table 5 and Table 6, for the summer season and winter seasons respectively.

4.3.2. Carbon Stock Estimation

The study area has been clipped from the processed and merged output of carbon stock for both the summer and winter seasons. As per the study, in the summer season, the range of carbon stock lies between 547.54 ktC and 526.70 ktC (Fig. 8) and in the winter season, it ranges between 547.54 ktC and 533.76 ktC (Fig. 9).

The carbon storage for the 10m buffer zone from the proposed Silver Line comprising an area of 10.678 km^2 is estimated as 11.5477 ktC in summer and 11.5498 ktC in winter. Also, for a 30m buffer zone with an area of 21.356 km^2, carbon storage estimated is at 23.0934 ktC in summer and 23.0935 ktC in winter. Similarly, the estimated carbon storage for a 500m buffer zone with an area of 500.952 km^2 is

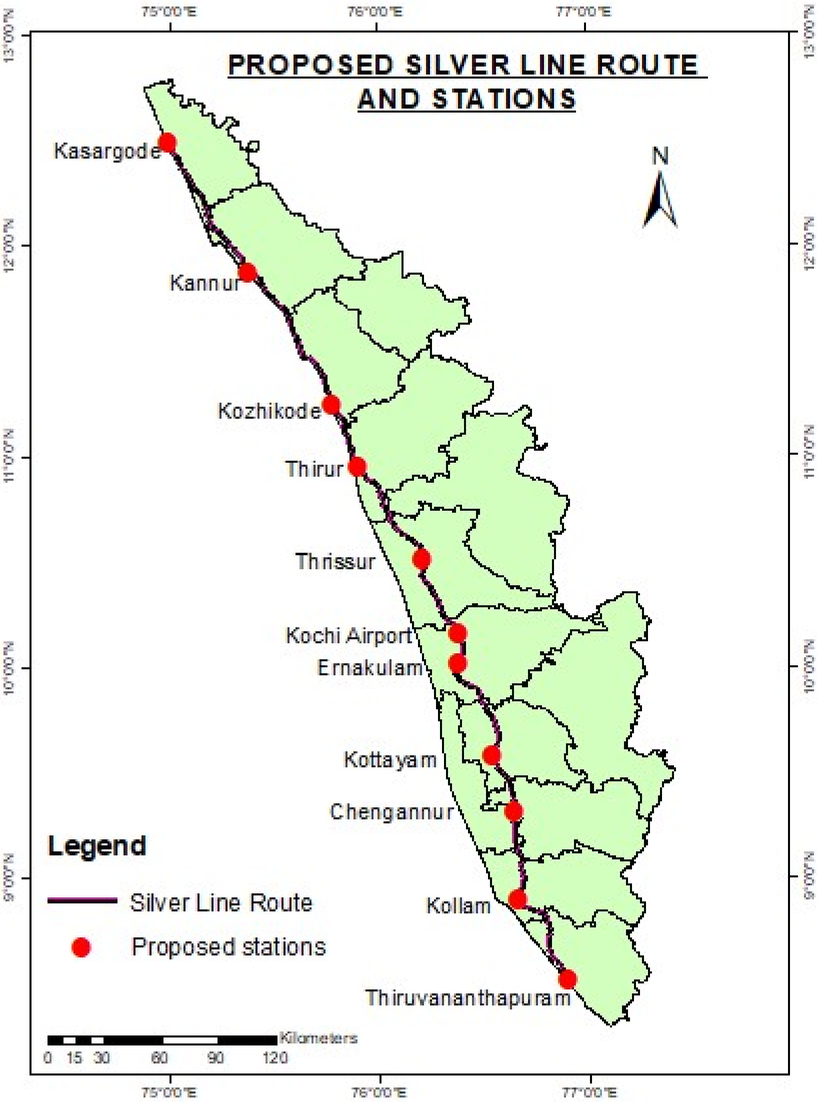

Fig. 4. Proposed Silver Line Route map along with stations.

Table 5. District zonation of NDVI in summer.

Sl.No.	District	Area (km^2)	Average (ktC)
1	Kasaragod	52.672	0.3918
2	Kannur	61.286	0.3713
3	Kozhikode	74.130	0.4209
4	Malappuram	54.154	0.3208
5	Thrissur	67.214	0.3831
6	Ernakulam	51.885	0.4718
7	Alappuzha	18.886	0.5903
8	Kottayam	49.114	0.5835
9	Pathanamthitta	21.636	0.6105
10	Kollam	41.997	0.5556
11	Thiruvananthapuram	39.269	0.4973

541.6621 kt C in the summer season and 541.6831 ktC in the winter season. The district-wise variation in the carbon storage is as given in Table 7 and Table 8, for the summer season and winter seasons respectively.

4.3.3. Above-Ground Biomass Estimation

The study area has been clipped from the processed and merged output of above-ground biomass for both the summer and winter seasons. As per the study, in the summer season, the range of above-

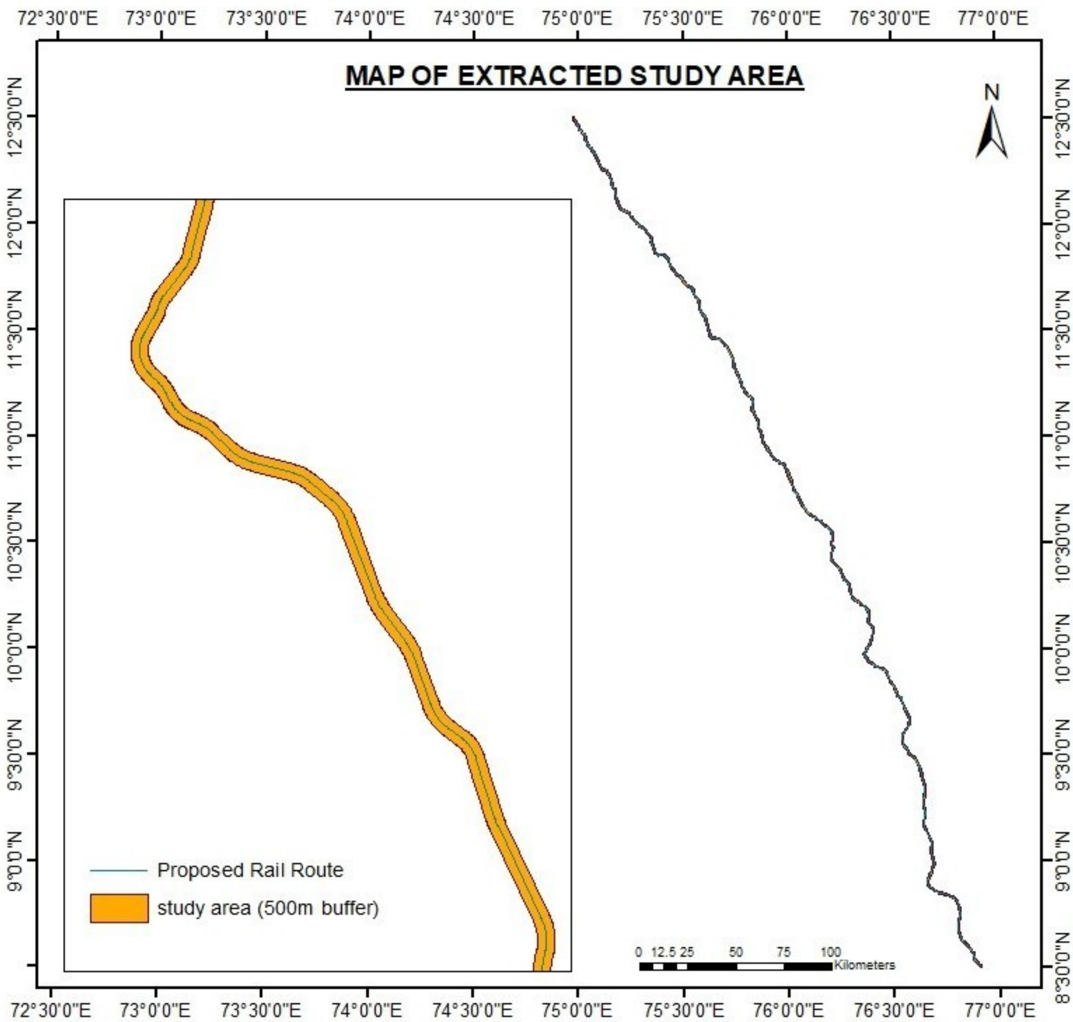

Fig. 5. Extracted study area.

Table 6. District zonation of NDVI in winter.

Sl.No.	District	Area (km^2)	Average (ktC)
1	Kasaragod	52.672	0.4318
2	Kannur	61.286	0.3939
3	Kozhikode	74.130	0.4380
4	Malappuram	54.154	0.4295
5	Thrissur	67.214	0.4060
6	Ernakulam	51.885	0.4148
7	Alappuzha	18.886	0.5192
8	Kottayam	49.114	0.5327
9	Pathanamthitta	21.636	0.5583
10	Kollam	41.997	0.4678
11	Thiruvananthapuram	39.269	0.4568

ground biomass lies between 1095.08 ktC and 1053.41 ktC (Fig. 10) and in the winter season, it ranges between 1095.08 ktC and 1067.53 ktC (Fig. 11).

The above-ground biomass for a 10m buffer zone from the proposed Silver Line comprising an area of 10.678 km^2 is estimated as 23.0997 ktC in summer and 23.0954 ktC in winter. Also, for a 30m buffer zone with an area of 21.356 km^2, the above-ground biomass estimated is 46.1870 ktC in summer and 46.1866 ktC in winter. Similarly, the estimated above-ground biomass for a 500m buffer zone with an area of 500.952 km^2 is 1083.3661 ktC in the summer season and 1083.3242 ktC in the winter season. The district-wise variation in the above-ground biomass is

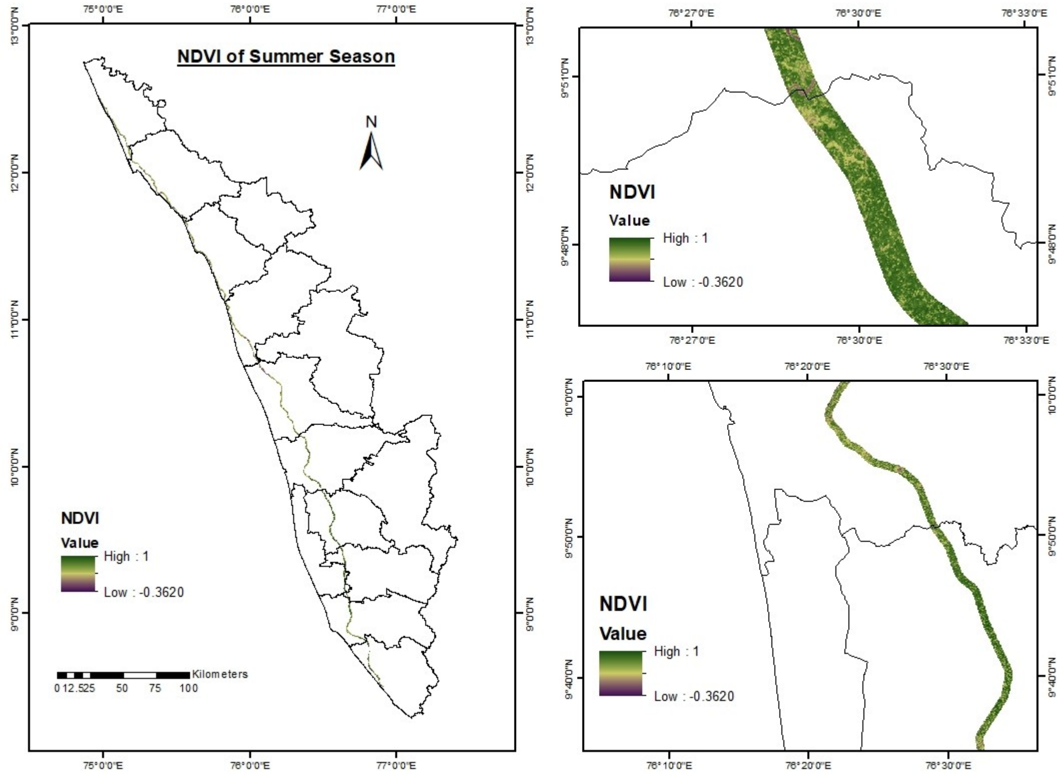

Fig. 6. NDVI of the summer season.

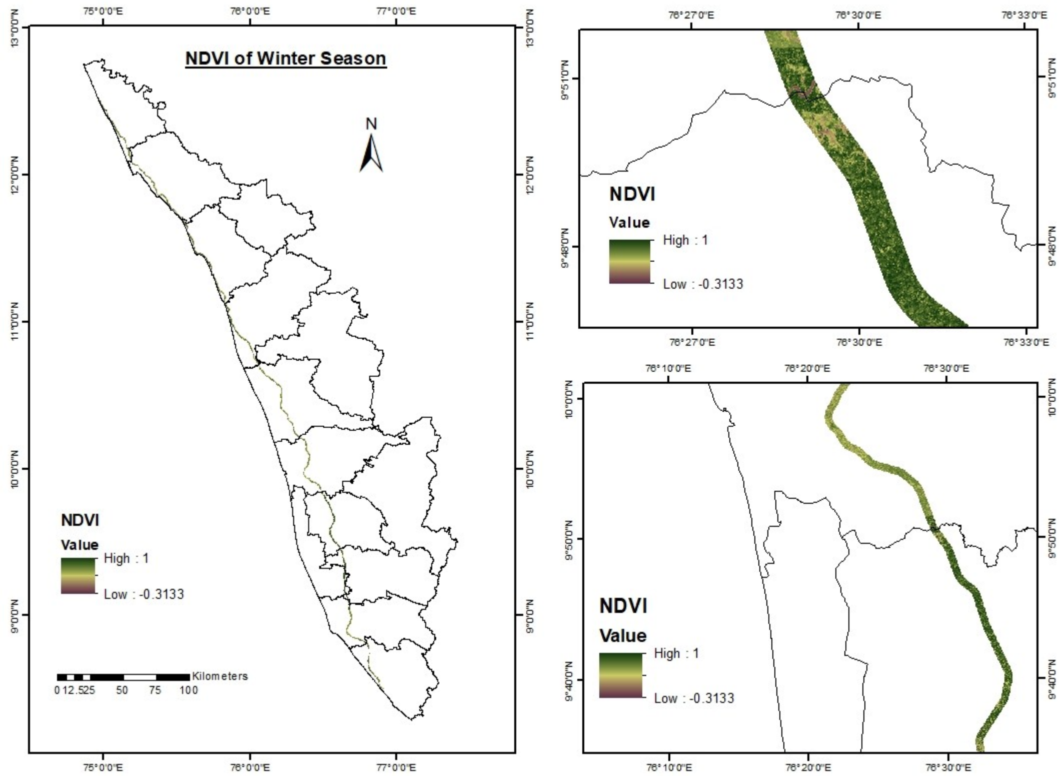

Fig. 7. NDVI of the winter season.

given in Table 9 and Table 10, for the summer season and winter seasons respectively.

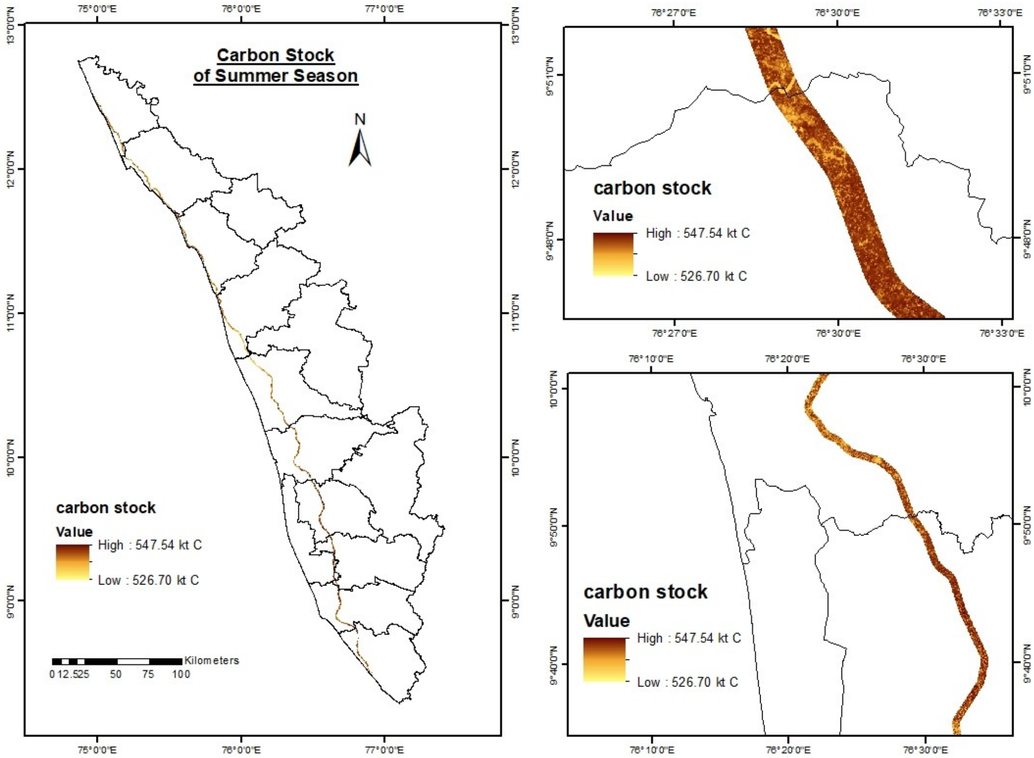

Fig. 8. Carbon stock of the summer season.

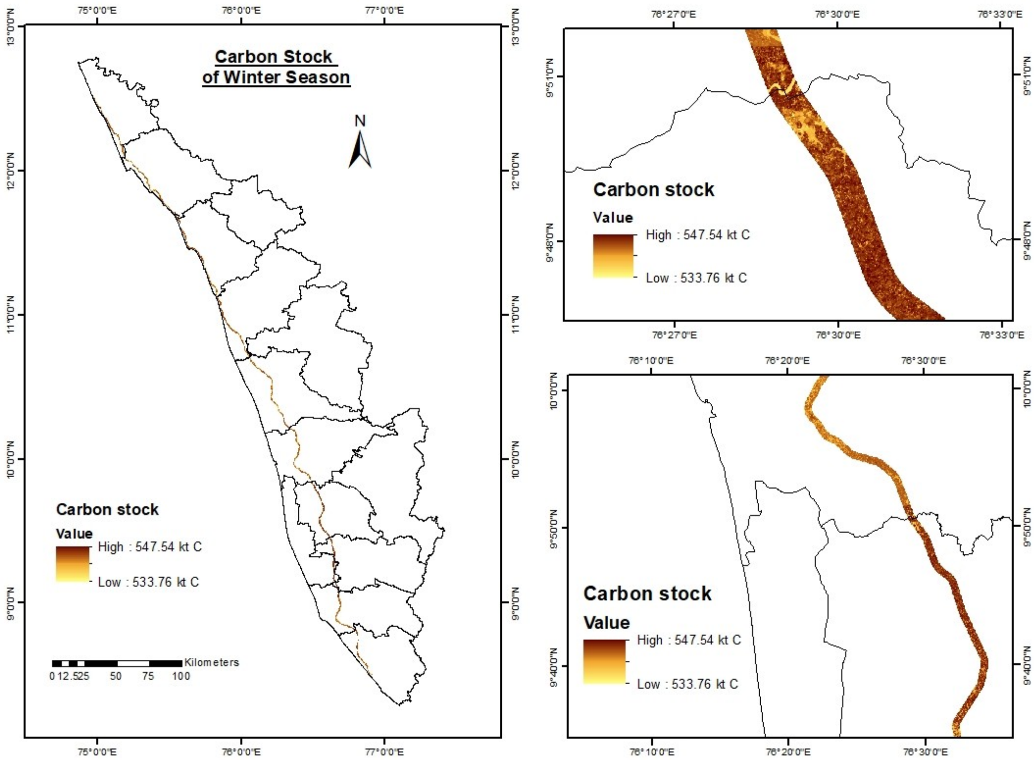

Fig. 9. Carbon stock of the winter season.

4.3.4. Carbon Dioxide Estimation

The study area has been clipped from the processed and merged output of carbon dioxide that would escape from terrestrial sequestration due to the removal of the vegetation cover for both the summer and winter seasons. As per the study, in the summer

Table 7. District zonation of carbon stock in summer.

Sl.No.	District	Area (km^2)	Average (ktC)
1	Kasaragod	52.672	56.8959
2	Kannur	61.286	66.1738
3	Kozhikode	74.130	80.1195
4	Malappuram	54.154	58.4153
5	Thrissur	67.214	72.5959
6	Ernakulam	51.885	56.1291
7	Alappuzha	18.886	20.4788
8	Kottayam	49.114	53.2496
9	Pathanamthitta	21.636	23.4700
10	Kollam	41.997	45.5084
11	Thiruvananthapuram	39.269	42.5047

Table 8. District zonation of carbon stock in winter.

Sl.No.	District	Area (km^2)	Average (ktC)
1	Kasaragod	52.672	56.9401
2	Kannur	61.286	66.2028
3	Kozhikode	74.130	80.1461
4	Malappuram	54.154	58.5386
5	Thrissur	67.214	72.6231
6	Ernakulam	51.885	56.0701
7	Alappuzha	18.886	20.4506
8	Kottayam	49.114	53.1971
9	Pathanamthitta	21.636	23.4462
10	Kollam	41.997	45.4309
11	Thiruvananthapuram	39.269	42.4712

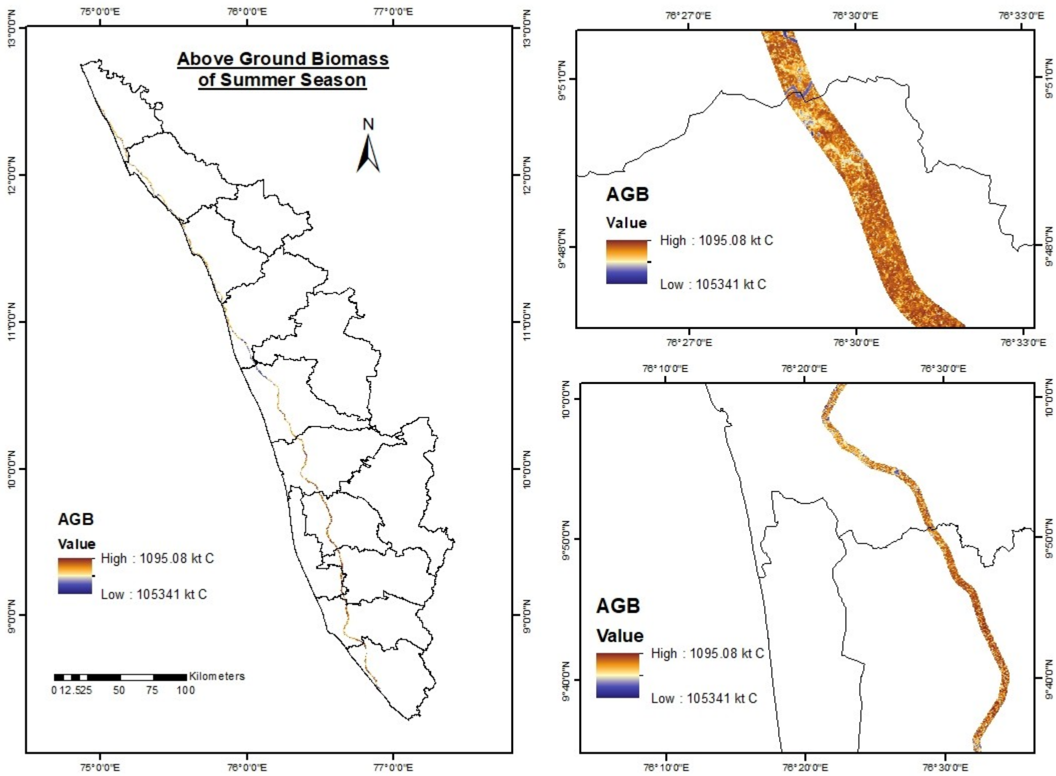

Fig. 10. Above-ground biomass of the summer season.

season, the range of carbon dioxide that would escape from terrestrial sequestration due to the removal of the vegetation cover lies between 2009.47 ktCO_2e and 1932.99 ktCO_2e (Fig. 12) and in the winter season, between 2009.47 ktCO_2e and 1958.92 ktCO_2e (Fig. 13).

The carbon dioxide that would escape from terrestrial sequestration due to the removal of the

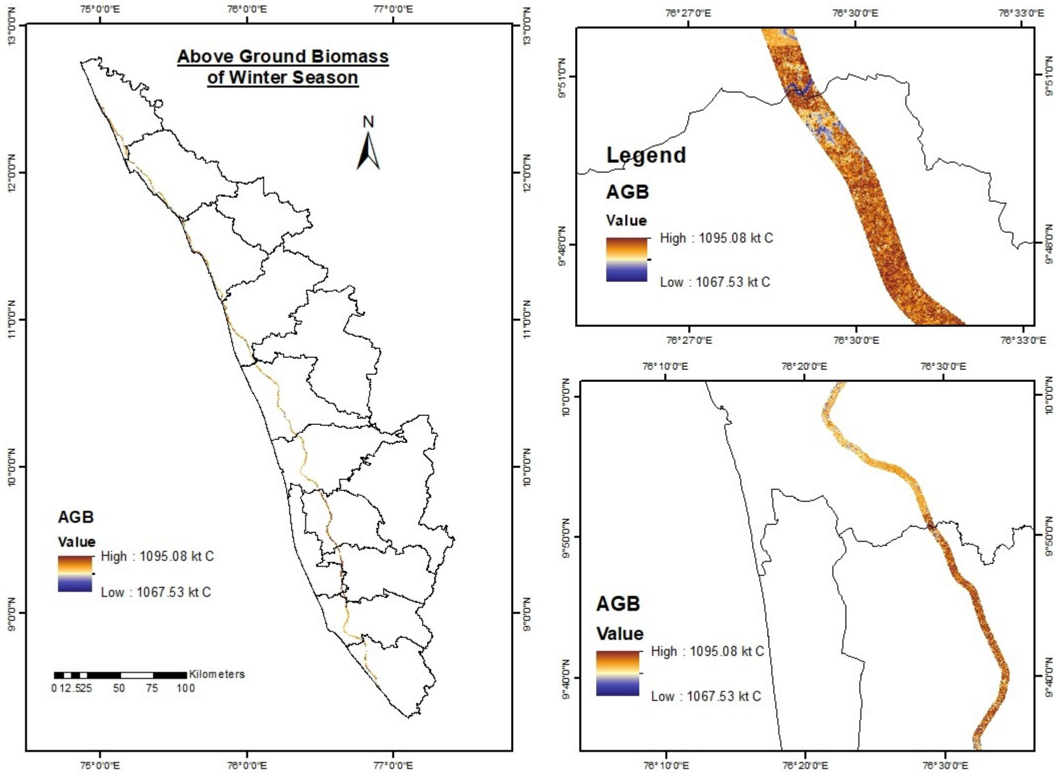

Fig. 11. Above-ground biomass of the winter season.

Table 9. District zonation of above-ground biomass in summer.

Sl.No.	District	Area (km^2)	Average (ktC)
1	Kasaragod	52.672	113.7918
2	Kannur	61.286	132.3477
3	Kozhikode	74.130	160.2391
4	Malappuram	54.154	116.8306
5	Thrissur	67.214	145.1920
6	Ernakulam	51.885	112.2584
7	Alappuzha	18.886	40.9576
8	Kottayam	49.114	106.4991
9	Pathanamthitta	21.636	46.9400
10	Kollam	41.997	91.0168
11	Thiruvananthapuram	39.269	85.0094

Table 10. District zonation of above-ground biomass in winter.

Sl.No.	District	Area (km^2)	Average (ktC)
1	Kasaragod	52.672	113.8802
2	Kannur	61.286	132.4055
3	Kozhikode	74.130	160.2922
4	Malappuram	54.154	117.0772
5	Thrissur	67.214	145.2462
6	Ernakulam	51.885	112.1402
7	Alappuzha	18.886	40.9011
8	Kottayam	49.114	106.3943
9	Pathanamthitta	21.636	46.8925
10	Kollam	41.997	90.8618
11	Thiruvananthapuram	39.269	84.9424

vegetation cover for a 10m buffer zone from the proposed Silver Line comprising an area of 10.678 km^2 is estimated as 42.3879 $ktCO_2e$ in summer and 42.3801 $ktCO_2e$ in winter. Also, for a 30m buffer zone with an area of 21.356 km^2, carbon dioxide that would escape from terrestrial sequestration due to the removal of the vegetation cover estimated is 84.7530 $ktCO_2e$ in summer and 84.7524 $ktCO_2e$ in winter. Similarly, the

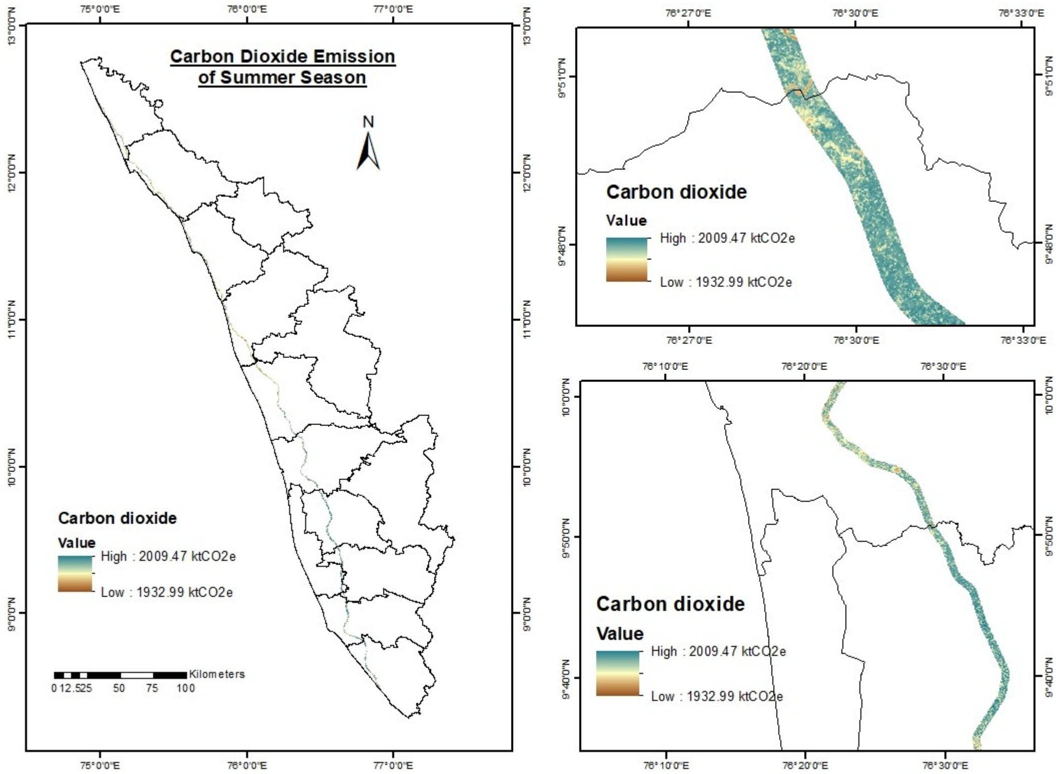

Fig. 12. Carbon dioxide of the summer season.

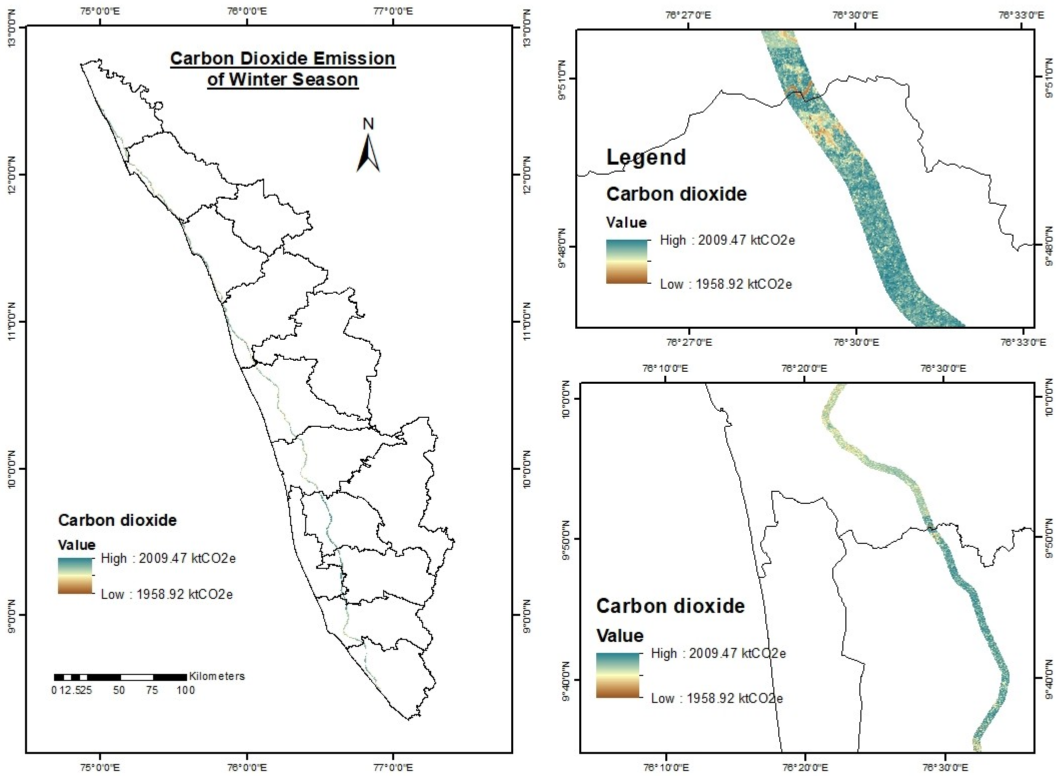

Fig. 13. Carbon stock of the winter season.

estimated carbon dioxide that would escape from terrestrial sequestration due to the removal of the vegetation cover for a 500 m buffer zone with an area of 500.952 km^2 is 1987.9726 $ktCO_2e$ in the summer season and 1987.9000 ktCO_2e in the winter season. The district-wise variation in the carbon dioxide that would escape from terrestrial sequestration due to the removal of the vegetation cover is given in Table 11, Table 12, for the summer season and winter season respectively.

The average variation in carbon stock after the completion of the Silver Line project is estimated as 11.54 ktC in 10 m buffer, 23.09 ktC in 30 m buffer and 541.68 ktC in 500 m buffer. Similarly, the average variation in above-ground biomass is estimated as 23.09 ktC in 10 m, 46.18 ktC in 30 m and 1083.36 ktC in 500 m buffer. Also, the average variation in CO_2 that would escape from terrestrial sequestration due to the removal of the vegetation cover is estimated as 42.38 ktCO_2e in 10 m, 84.75 ktCO_2e in 30 m and 1987.97 ktCO_2e in 500 m buffer. Thus, there is a noticeable change or variation in carbon stock, above-ground biomass and CO_2 that would escape from terrestrial sequestration in the K-Rail corridor after the completion of the project. As per the EIA report of the Silver Line project, the annual average greenhouse gas emission reduction is estimated to be 287.99ktCO_2e/year (Centre for Environment and Development, 2020) and thus, the carbon to be sequestrated will be available in the atmosphere as CO_2 but it would be overlooked as per the estimation of emission reduction due to promotion of public transport.

The study area passes through 11 districts of Kerala state and the largest area is covered in Kozhikode district, with 74.130 km^2, while the least area is covered in Alappuzha district, with 18.886 km^2. Even though the highest average NDVI value is determined in Pathanamthitta district as 0.5583 and 0.6105 in winter and summer seasons respectively, due to larger area coverage in Kozhikode district, the average carbon stock in ktC, above-ground biomass in ktC and CO_2 that would escape from terrestrial sequestration due to removal of the vegetation cover in ktCO_2e is higher in Kozhikode district as a whole when compared with other districts. Similarly, the least average NDVI value is determined as 0.3939 in the winter season in the Kannur district and 0.3208 in the summer season in the Malappuram district. But, due to the least area coverage in the Alappuzha district, the average carbon stock in ktC, above-ground biomass in ktC and CO_2 that would escape from terrestrial sequestration due to the removal of the vegetation cover in ktCO_2e are least in the Alappuzha district as a whole when compared with other districts of Kerala state.

As a result of the removal of 5282.14 ha of vegetation in a 500 m buffer zone, the carbon content of 576.3 ktC will be reduced, i.e, 10.91 tC/ha on an average, 1152.6 ktC of above-ground biomass will be reduced, i.e, 21.82 tC/ha on an average and 2115 ktCO_2 will be escaped from sequestration, i.e, 40.05 tCO_2/ha on an average. Considering the 30 m buffer with the vegetation of 318.10 ha, the carbon content of 34.64 ktC will be reduced, i.e, 10.88 tC/ha on an average, 69.29 ktC of aboveground biomass will be reduced, i.e, 21.78 tC/ha on an average and 127.13 ktCO_2 will be escaped from sequestration, i.e, 39.96 tCO_2/ha on an average.

4.4. Assessment of Change in Terrestrial Carbon Sequestration

The spatio-temporal change in terrestrial carbon sequestration is determined in ton C. For 10m buffer zone from the proposed Silver Line comprising an area of 10.678 km^2 is estimated as 1.1172 tons C. Also, for a 30m buffer zone with an area of 21.356 km^2, the change in terrestrial carbon sequestration estimated is 0.0542 ton C. Similarly, the estimated change in terrestrial carbon sequestration for a 500m buffer zone with an area of 500.952 km^2 is 10.4899 ton C. The district-wise variation of change in terrestrial carbon sequestration is given in Table 13.

The spatio-temporal change in the terrestrial carbon sequestration shows a negative change in northern districts from Kasaragod to Thrissur with a maximum negative change of -61.6447 ton C in the Malappuram district. Similarly, it showed a positive change in southern districts from Ernakulam to Thiruvananthapuram with a maximum positive change of 38.7532 ton C in the Kollam district. This may be due to the micro climatic changes faced by the state showing a higher summer rainfall intensity in the southern states in the year 2021 than that in the northern districts. Thus the lush greenery in the summer season has increased the NDVI value of southern districts in the summer season more than the values of those districts in the winter season, showing a positive change in the carbon.

5. Conclusion

In the present study, the spatio-temporal changes in terrestrial carbon sequestration for the two seasons, summer and winter of the year 2021 have

Table 11. District zonation of carbon dioxide in summer.

Sl.No.	District	Area (km^2)	Average ($ktCO_2e$)
1	Kasaragod	52.672	208.8079
2	Kannur	61.286	242.8602
3	Kozhikode	74.130	294.0363
4	Malappuram	54.154	214.3842
5	Thrissur	67.214	266.4273
6	Ernakulam	51.885	205.9941
7	Alappuzha	18.886	75.1572
8	Kottayam	49.114	195.4259
9	Pathanamthitta	21.636	86.1350
10	Kollam	41.997	167.0159
11	Thiruvananthapuram	39.269	155.9922

Table 12. District zonation of carbon dioxide in winter.

Sl. No.	District	Area (km^2)	Average ($ktCO_2e$)
1	Kasaragod	52.672	208.9702
2	Kannur	61.286	242.9642
3	Kozhikode	74.130	294.1363
4	Malappuram	54.154	214.8367
5	Thrissur	67.214	266.5268
6	Ernakulam	51.885	205.7772
7	Alappuzha	18.886	75.0536
8	Kottayam	49.114	195.2335
9	Pathanamthitta	21.636	86.0478
10	Kollam	41.997	166.7314
11	Thiruvananthapuram	39.269	155.8693

Table 13. District zonation of changes in terrestrial carbon sequestration.

Sl. No.	District	Area (km^2)	Average (ton C)
1	Kasaragod	52.672	-22.1024
2	Kannur	61.286	-14.4623
3	Kozhikode	74.130	-13.2916
4	Malappuram	54.154	-61.6447
5	Thrissur	67.214	-13.5617
6	Ernakulam	51.885	29.5464
7	Alappuzha	18.886	14.1191
8	Kottayam	49.114	26.2179
9	Pathanamthitta	21.636	11.8833
10	Kollam	41.997	38.7532
11	Thiruvananthapuram	39.269	16.7357

been assessed with special reference to the proposed Silver Line project in Kerala State, as the study area taken under consideration is the 500 m zone of influence. Sentinel-2 satellite data with 10 m resolution has been used for the study. The results indicated a negative change in northern districts from Kasaragod to Thrissur and a positive change in southern districts from Ernakulam to Thiruvananthapuram. The maximum negative change of -61.6447 tons C is recorded in the Malappuram district, while the maximum positive change of 38.7532 tons C is recorded in the Kollam district.

The seasonal changes or variations in carbon stock, AGB and carbon dioxide that would escape from terrestrial sequestration due to the removal of the vegetation of the study area, for summer and winter in the year 2021, have been estimated for 10 m, 30 m and 500 m buffer zones. The average variation in carbon stock is estimated as 11.54 ktC in 10 m buffer, 23.09 ktC in 30 m buffer and 541.68 ktC in 500 m buffer. Similarly, the average change in AGB is estimated as 23.09 ktC in 10 m, 46.18 ktC in 30 m and 1083.36 ktC in 500 m buffer. Also, the CO_2 that would escape the terrestrial sequestration as a result of the removal of vegetation cover is estimated as 42.38 $ktCO_2e$ in 10 m, 84.75 $ktCO_2e$ in 30 m and 1987.97 $ktCO_2e$ in 500 m buffer. The present study area passes through 11 districts of Kerala state and also, and the seasonal variations of carbon stock, AGB, and carbon dioxide that would escape from terrestrial sequestration due to the removal of the vegetation in the study area have been estimated for each of those 11 districts. Thus, from the results, it is evident that there is a noticeable difference in carbon stock, Above Ground Biomass, and CO_2 that would escape from terrestrial sequestration due to the removal of the vegetation cover in the K-Rail corridor after the completion of the project.

Removal of vegetation cover in the study area after the completion of the Silver Line project would lead to an average reduction in carbon content and above-ground biomass of 10.91 tC/ha and 21.82 tC/ha respectively. The average amount of CO_2 that would escape from sequestration is 40.05 tCO_2/ha.

6. Recommendations

The current study made use of Sentinel-2 satellite data of 10m resolution from an open data source and thus of coarse resolution as compared to cadastral level mapping. Where the cadastral level maps are of high resolution showing the property boundaries and ownerships of the land parcel under consideration. Thus, to get the actual and more realistic or more accurate results of carbon mapping, cadastral level mapping is required. It includes making use of Unmanned Aerial Vehicles (UAV) such as drones and GPS-based surveying techniques, for the estimation of land parcel-based carbon mapping. In this study, the current situation of the study area comprising the Silver Line route is analyzed and the carbon mapping is done. Further, once the Silver Line project is completed, the exact reduction in tree cover could be analyzed and exact changes in the carbon footprints could be mapped.

7. Limitations

This study is based exclusively on satellite-derived data and remote sensing analyses. No field-based measurements or ground-truthing were conducted. As such, the results and interpretations presented herein are subject to the limitations and uncertainties inherent in satellite data. Users are advised to consider these limitations when applying or referencing the findings of this study.

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

CRediT

SS & SSS: Conceptualization, Data curation, Formal analysis, Visualization, Writing – original draft – review & editing

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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