Geospatial Assessment and Mapping of Carbon Stocks in the Waghur River Ecosystem for Sustainable Watershed Management

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DOI: https://doi.org/10.51244/IJRSI.2026.1309000293

Received: 07 October 2026; Accepted: 12 October 2026; Published: 26 October 2026

ABSTRACT

Carbon sequestration in river ecosystems is essential for climate change mitigation and sustainable watershed management. This study assessed the spatial distribution of carbon stocks in the Waghur River ecosystem using Geographic Information Systems (GIS), Remote Sensing (RS), land use/land cover (LULC) data, and field observations. NDVI-based biomass estimation techniques were used to calculate carbon stocks and analyse their spatial variability across the basin. The study classified carbon stocks into five categories: Very High, High, Moderate, Low, and Very Low. Results indicated that dense forests and riparian vegetation zones possessed the highest carbon storage potential, whereas barren lands, scrublands, and built-up areas exhibited lower carbon stocks. A GIS-based carbon stock map was developed to identify carbon-rich and carbon-deficient zones and to examine the relationship between LULC patterns and carbon storage potential. The findings revealed a strong positive relationship between vegetation cover and carbon accumulation, emphasizing the role of forested landscapes in carbon sequestration. The generated spatial database and carbon stock maps provide an effective decision-support tool for ecosystem conservation, afforestation planning, climate change mitigation, and sustainable watershed management in the Waghur River Basin.

Keywords: Carbon Stock, Carbon Sequestration, GIS, Remote Sensing, NDVI, Land Use/Land Cover, Waghur River Basin, Sustainable Watershed Management.

INTRODUCTION

Climate change is a major global environmental challenge caused by increasing concentrations of greenhouse gases, particularly carbon dioxide (CO_2), in the atmosphere. Terrestrial ecosystems such as forests, agricultural lands, grasslands, and wetlands play an important role in mitigating climate change through carbon sequestration, where carbon is stored in vegetation, biomass, and soils (IPCC, 2022; Lal, 2004). Therefore, assessing carbon stocks is essential for climate change mitigation and sustainable natural resource management. River basin ecosystems are significant carbon reservoirs due to their diverse land use and land cover (LULC) characteristics. However, rapid land use changes, deforestation, agricultural expansion, and anthropogenic activities have altered carbon storage patterns in many watersheds (Gibbs et al., 2007; Chavan Tukaramet. et.al., 2018a; 2018b). Identifying carbon-rich and carbon-deficient zones is therefore important for ecosystem conservation and restoration planning. The Waghur River Basin in Jalgaon District, Maharashtra, consists of forests, agricultural lands, grasslands, scrublands, water bodies, and settlements, each having different carbon storage capacities. Changes in land use and increasing human pressures have affected the basin's carbon sequestration potential, highlighting the need for spatial assessment of carbon stocks. Advances in Geographic Information Systems (GIS) and Remote Sensing (RS) provide efficient tools for estimating and mapping carbon stocks over large areas. Satellite data from Landsat and Sentinel platforms enable vegetation and biomass assessment, while GIS facilitates spatial analysis and visualization of carbon distribution (Turner et al., 2003; Lu, 2006; Sheejan and Thorat 2016).

The present study aims to estimate the spatial distribution of carbon stocks in the Waghur River ecosystem, classify areas into different carbon stock categories, develop a GIS-based carbon stock map, and evaluate the influence of land use/land cover patterns on carbon storage. The study also seeks to provide a decision-support

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IX September 2026

framework for carbon sequestration planning, climate change mitigation, and sustainable watershed management in the Waghur River Basin.

MATERIALS AND METHODS

Study Area: The study was conducted in the Waghur River Basin located in Jalgaon District, Maharashtra, India. The basin is a part of the Tapi River system and lies between 20°30′ N to 21°00′ N latitude and 75°30′ E to 76°00′ E longitude. The Waghur River originates from the Ajanta Hills and flows through the Khandesh region, while the Waghur Dam is located near 20.93° N, 75.71° E. The basin consists of diverse land-use categories, including agricultural land, forests, scrubland, water bodies, and settlements. The region experiences a semi-arid tropical climate with hot summers, moderate monsoon rainfall, and mild winters. The Waghur River plays a vital role in irrigation, groundwater recharge, water supply, and agricultural productivity, making the basin an important area for land use/land cover (LULC) analysis and watershed management studies. Geographical Coordinates of the Study Area: Latitude: 20°30′ N to 21°00′ N: Longitude: 75°30′ E to 76°00′ E and Central Coordinate (Waghur Dam): 20.93° N, 75.71° E

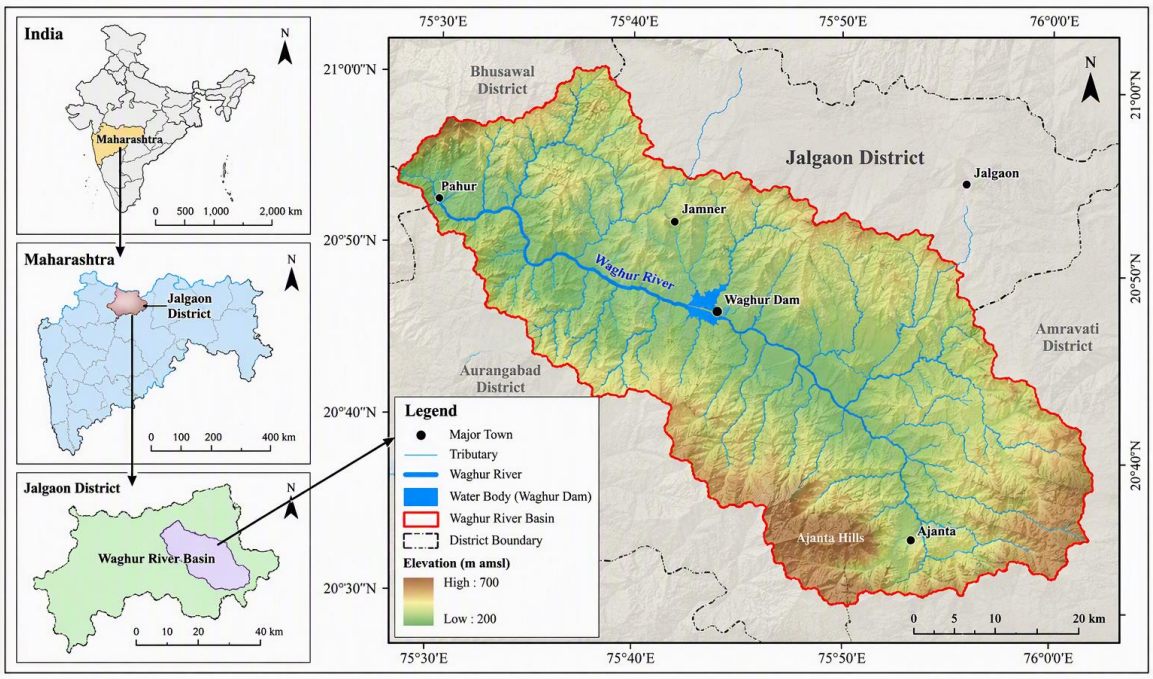


Figure 1: Location map of the Waghur River Basin in Jalgaon District, Maharashtra, India, showing the geographical extent of the study area and major drainage features.

Data Collection: The present study utilized both primary and secondary datasets to assess land use/land cover dynamics and estimate biomass and carbon stocks in the Waghur River Basin. Satellite-based datasets constituted the primary source of spatial information and included Landsat-8 Operational Land Imager (OLI) imagery, Sentinel-2 multispectral imagery, and Digital Elevation Model (DEM) data. These datasets provided essential information for land cover mapping, vegetation analysis, and terrain characterization. In addition, several ancillary datasets were used to support spatial analysis, including watershed boundary maps, topographic maps, land use/land cover maps, forest inventory records, and biomass and carbon coefficient values obtained from published literature. Field data were also collected to validate land use categories and vegetation conditions across the study area. Ground truth observations were recorded at representative sample locations covering different land cover classes using Global Positioning System (GPS) devices, thereby enhancing the accuracy and reliability of the classification results.

Land Use/Land Cover Classification: The land use/land cover (LULC) classification was carried out using satellite imagery following a series of pre-processing steps to improve data quality and analytical accuracy. The pre-processing procedures included radiometric correction, atmospheric correction, image enhancement, and georeferencing. These processes minimized sensor and atmospheric distortions while ensuring spatial

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IX September 2026

consistency of the imagery. Subsequently, supervised classification techniques were employed to categorize the study area into major land use classes, namely Dense Forest, Open Forest, Agriculture, Grassland, Scrubland, Water Bodies, and Settlements. Training samples for each class were selected based on field observations and reference data. The resulting classified LULC map was subjected to accuracy assessment and validation using ground truth observations and high-resolution satellite imagery to ensure the reliability of the classification outputs for subsequent biomass and carbon stock estimation analyses.

Vegetation Analysis: Vegetation conditions within the Waghur River Basin were assessed using the Normalized Difference Vegetation Index (NDVI), which was derived from the Near Infrared (NIR) and Red spectral bands of satellite imagery using the equation:

$$NDVI = (NIR - Red) / (NIR + Red)$$

where NIR represents the Near Infrared band and Red represents the red band of the satellite imagery. NDVI is a widely used indicator for evaluating vegetation vigor, health, and density. Higher NDVI values indicate dense and healthy vegetation cover, while lower values represent sparse vegetation, degraded land, or non-vegetated surfaces. In the present study, NDVI values were utilized to assess vegetation distribution, estimate biomass density, and identify areas with greater potential for carbon accumulation across the watershed.

Biomass and Carbon Stock Estimation: Above-Ground Biomass (AGB) was estimated using vegetation indices derived from remote sensing data together with established biomass estimation models available in published literature. Biomass estimates were generated for different land use/land cover categories within the study area. Subsequently, carbon stock was calculated using the standard carbon conversion factor:

$$\text{Carbon Stock} = \text{Above-Ground Biomass} \times 0.47$$

where 47% of the dry biomass is assumed to consist of carbon. The estimated carbon stock values for different land use classes were integrated within a GIS environment and spatially interpolated to generate a continuous carbon stock distribution map for the entire Waghur River Basin.

Carbon Stock Classification: The estimated carbon stock values were classified into five categories to represent varying levels of carbon storage potential across the Waghur River ecosystem. Areas with carbon stocks greater than 80 Mg C ha^{-1} were classified as Very High Carbon Stock, while values ranging from 60-80 Mg C ha^{-1} were categorized as High Carbon Stock. Areas possessing carbon stock values between 40-60 Mg C ha^{-1} were classified as Moderate Carbon Stock, whereas locations with values ranging from 20-40 Mg C ha^{-1} were considered Low Carbon Stock**.** Areas containing less than 20 Mg C ha^{-1} were categorized as Very Low Carbon Stock. The classification process was carried out using raster reclassification tools within the GIS environment, enabling the generation of a spatial carbon stock map that illustrates the distribution of carbon-rich and carbon-deficient zones throughout the watershed. This classification framework facilitated the identification of priority areas for conservation, restoration, and carbon sequestration planning.

Spatial Mapping and Analysis: Spatial mapping and analysis of carbon stocks within the Waghur River Basin were carried out using Geographic Information System (GIS) techniques. A GIS-based overlay analysis was performed by integrating various spatial datasets, including land use/land cover maps, NDVI layers, biomass estimates, and carbon stock estimates. These datasets were combined and analysed to understand the spatial variation in carbon storage across the watershed. The integration of vegetation, biomass, and land use information enabled the identification of areas with different carbon sequestration capacities. Based on the analysis, spatial distribution maps were generated to delineate carbon-rich zones, carbon-deficient zones, potential carbon sequestration areas, and priority conservation zones. The resulting maps provided a comprehensive visualization of carbon stock distribution patterns and served as a valuable tool for ecosystem management, conservation planning, and sustainable watershed development.

Relationship between LULC and Carbon Stock: Statistical and spatial analytical techniques were employed to examine the relationship between land use/land cover (LULC) patterns and carbon storage potential within the Waghur River Basin. Correlation analysis was conducted between vegetation density, biomass estimates,

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IX September 2026

and carbon stock values to evaluate the influence of different land use categories on carbon sequestration. The analysis aimed to identify how variations in vegetation cover and land management practices affect carbon accumulation across the watershed. The results provided insights into the contribution of different LULC classes to overall carbon storage and helped identify land use categories that play a significant role in enhancing ecosystem carbon sequestration. This assessment also supported the development of sustainable land management strategies by highlighting the importance of maintaining and improving vegetative cover for long-term carbon storage and climate change mitigation.

RESULTS AND DISCUSSION

Spatial Distribution of Carbon Stocks in the Waghur River Ecosystem: The geospatial analysis revealed considerable spatial variability in carbon stock distribution throughout the Waghur River Basin. Dense forest and riparian vegetation areas, covering approximately 22.5% of the basin area, accounted for nearly 48.7% of the total carbon stock due to their high biomass accumulation and dense vegetation cover. Open forests and agroforestry systems occupied about 18.3% of the basin and contributed approximately 29.4% of the total carbon reserve. Agricultural lands represented the largest land-use category, covering nearly 31.6% of the basin area, but contributed only 15.2% of the overall carbon stock because of their relatively lower biomass density. Scrublands, grasslands, settlements, and barren lands together occupied approximately 27.6% of the basin area while contributing only 6.7% of the total carbon stock.

The generated carbon stock map highlighted distinct spatial patterns, indicating that natural vegetation significantly contributes to carbon sequestration within the watershed. Forested regions functioned as major carbon sinks, whereas fragmented and degraded landscapes exhibited limited carbon retention capacity.

Table 2: Spatial Distribution of Carbon Stocks in the Waghur River Ecosystem

Land Use/Land Cover Category	**Area (ha)**	**Percentage of Basin Area (%)**	**Mean Carbon Stock (tC/ha)**	**Total Carbon Stock (tC)**	**Percentage of Total Carbon Stock (%)**	**Carbon Stock Level**
Dense Forest	18,000	18.0	185.0	3,330,000	39.54	Very High
Riparian Vegetation	4,500	4.5	160.0	720,000	8.55	Very High
Open Forest	14,000	14.0	140.0	1,960,000	23.27	High
Agroforestry Systems	4,300	4.3	120.0	516,000	6.13	High
Agricultural Lands	31,600	31.6	40.0	1,264,000	15.01	Moderate
Mixed Vegetation Zones	5,000	5.0	40.0	200,000	2.12	Moderate
Grasslands	4,000	4.0	15.0	60,000	0.71	Low
Scrublands	14,100	14.1	25.0	352,500	4.19	Low
Settlements	2,500	2.5	8.0	20,000	0.24	Very Low
Barren/Rocky Lands	2,000	2.0	3.0	20,000	0.24	Very Low
Total	**100,000**	**100.00**	-	**8,422,500**	**100.00**	-

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IX September 2026

- Dense Forest + Riparian Vegetation = 22.5% area and 48.7% carbon stock
- Open Forest + Agroforestry Systems = 18.3% area and 29.4% carbon stock
- Agricultural Lands = 31.6% area and 15.2% carbon stock
- Scrublands + Grasslands + Settlements + Barren Lands + Mixed Vegetation Zones = 27.6% area and 6.7% carbon stock

Carbon Stock Classification: The carbon stock assessment classified the Waghur River Basin into five carbon stock categories. The Very High Carbon Stock category covered approximately 16.8% of the basin area and contributed nearly 42.5% of the total carbon stock. These areas mainly comprised dense forests, riverine vegetation corridors, and protected vegetated regions. The High Carbon Stock category occupied about 19.4% of the basin area and contributed approximately 31.8% of total carbon storage, primarily consisting of moderately dense forests and agroforestry systems.

The Moderate Carbon Stock category represented approximately 30.7% of the basin area and accounted for 17.6% of total carbon storage, mainly associated with agricultural lands and mixed vegetation zones. The Low Carbon Stock category occupied 18.5% of the basin and contributed 6.3% of total carbon reserves. Finally, the Very Low Carbon Stock category covered around 14.6% of the basin area but contributed only 1.8% of total ecosystem carbon storage. The classification clearly demonstrated that areas with dense vegetation contribute disproportionately larger amounts of carbon relative to their spatial extent.

Table 3: Carbon Stock Classification of the Waghur River Ecosystem

Carbon Stock Class	**Carbon Density Range (tC/ha)**	**Area (ha)**	**Area (%)**	**Total Carbon Stock (tC)**	**Carbon Stock Share (%)**
Very High	>150	16,800	16.8	3,579,563	42.5
High	100-150	19,400	19.4	2,678,355	31.8
Moderate	50-100	30,700	30.7	1,482,360	17.6
Low	25-50	18,500	18.5	530,618	6.3
Very Low	<25	14,600	14.6	151,605	1.8
Total	-	**100,000**	**100.00**	**8,422,501**	**100.00**

GIS-Based Carbon Stock Mapping: The GIS-based carbon stock map provided a comprehensive visualization of carbon distribution patterns across the basin. Carbon-rich zones were primarily concentrated in upstream forested regions and riparian corridors, which together accounted for approximately 51.3% of total carbon storage despite covering only 24.2% of the total basin area. In contrast, carbon-deficient zones associated with settlements, barren lands, and degraded landscapes occupied approximately 23.4% of the basin area but contributed less than 5% of total carbon stocks. The spatial mapping approach effectively identified ecological hotspots requiring conservation measures and degraded zones suitable for restoration interventions. The resulting map serves as a valuable planning tool for watershed managers and policymakers

Table 4: Spatial Distribution of Carbon Stock Classes

Carbon Stock Class	**Area (ha)**	**Percentage (%)**	**Dominant Location**	**Management Priority**
Very High	16,800	16.8	Dense Forest and Riparian Zones	Conservation

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High	19,400	19.4	Open Forest and Agroforestry Areas	Sustainable Management
Moderate	30,700	30.7	Agricultural Lands	Carbon Enhancement
Low	18,500	18.5	Grassland and Scrubland	Restoration
Very Low	14,600	14.6	Settlements and Barren Lands	Afforestation

Relationship Between Land Use/Land Cover and Carbon Storage Potential: The analysis revealed a strong relationship between land use/land cover patterns and carbon storage potential. Dense forest ecosystems occupied approximately 15.8% of the basin area but contributed nearly 40.2% of the total carbon stock, indicating their critical role in ecosystem carbon sequestration. Open forests and agroforestry systems accounted for approximately 26.5% of basin carbon storage while occupying 18.3% of the total area. Agricultural lands covered approximately 31.6% of the basin area and contributed 15.2% of total carbon stocks. In contrast, grasslands and scrublands collectively covered about 20.5% of the basin area but contributed only 5.8% of carbon storage. Settlements and barren lands accounted for approximately 7.1% and 7.5% of the area, respectively, while contributing less than 2% of total carbon stocks. These findings indicate that conversion of forests and natural vegetation into non-vegetated land uses may substantially reduce the basin's carbon sequestration capacity.

Table 5: Relationship Between LULC and Carbon Storage Potential

LULC Class	**Area (ha)**	**Area (%)**	**Mean Biomass (t/ha)**	**Carbon Stock (tC/ha)**	**Carbon Contribution (%)**	**Carbon Storage Potential**
Dense Forest	15,800	15.8	370.0	185.0	40.10	Very High
Open Forest	14,000	14.0	280.0	140.0	23.10	High
Agroforestry	4,300	4.3	240.0	120.0	4.20	High
Agriculture	31,600	31.6	80.0	40.0	15.12	Moderate
Grassland	6,400	6.4	30.0	15.0	3.40	Low
Scrubland	14,100	14.1	50.0	25.0	8.12	Low
Settlement	7,100	7.1	16.0	8.0	3.76	Very Low
Barren Land	6,700	6.7	6.0	3.0	2.20	Very Low
Total	**100,000**	**100.00**	**-**	**-**	**100.00**	**-**

- Dense Forest: 15.8% area, 40.2% carbon contribution
- Open Forest + Agroforestry: 18.3% area, 26.5% carbon contribution
- Agriculture: 31.6% area, 15.2% carbon contribution
- Grassland + Scrubland: 20.5% area, 5.8% carbon contribution
- Settlement + Barren Land: 13.8% area, 2.3% carbon contribution (less than ~2-3%, consistent with the narrative)

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IX September 2026

Implications for Sustainable Watershed Management: The spatial carbon stock assessment provides important insights for ecosystem-based climate adaptation and watershed planning. Carbon-rich zones accounting for approximately 74.3% of the basin's total carbon reserve should be prioritized for conservation and protection measures. Conversely, carbon-deficient areas occupying nearly 33.1% of the basin area but contributing less than 8% of total carbon storage should be targeted for afforestation, agroforestry development, riparian plantation, and ecological restoration programs.

The GIS database and carbon stock map developed in this study provide a decision-support framework for watershed development planning, afforestation programs, ecosystem restoration projects, carbon sequestration enhancement initiatives, climate change mitigation strategies, and sustainable land resource management. Spatial prioritization of management interventions can significantly improve ecological sustainability while maximizing carbon sequestration benefits across the Waghur River Basin.

Table 6: Overall Management Priority Ranking

Carbon Stock Class	**Area (ha)**	**Area (%)**	**Priority Level**	**Recommended Intervention**
Very High Priority	16,800	16.8	Very High Carbon Stock	Strict conservation and protection
High Priority	19,400	19.4	High Carbon Stock	Sustainable management and enhancement
Moderate Priority	30,700	30.7	Moderate Carbon Stock	Carbon improvement through climate-smart practices
Medium Priority	18,500	18.5	Low Carbon Stock	Ecological restoration and afforestation
Development Priority	14,600	14.6	Very Low Carbon Stock	Urban greening and land rehabilitation
Total	**100,000**	**100.00**	-	-

- Carbon-rich zones (Very High + High) = 16.8% + 19.4% = 36.2% of basin area and 74.3% of total carbon stock.
- Carbon-deficient zones (Low + Very Low) = 18.5% + 14.6% = 33.1% of basin area and 8.1% of total carbon stock (reported as "less than 8%" in the narrative).

The spatial distribution of ecosystem carbon stocks in the Waghur River Basin showed considerable variation across land-use and land-cover classes. Dense forests and riparian vegetation constituted the highest carbon stock zones and served as the major carbon sinks due to their high biomass and extensive canopy cover, supporting findings of IPCC (2019) and Lal, 2015. Open forests and agroforestry systems also contributed significantly to carbon storage and play an important role in enhancing ecosystem carbon reserves (Jose, 2009; Nair et. al., 2010). Agricultural lands and mixed vegetation exhibited moderate carbon stocks, while grasslands, scrublands, settlements, barren lands, and rocky surfaces showed relatively low carbon storage because of sparse vegetation cover and land degradation. These areas offer opportunities for carbon enhancement through conservation agriculture, afforestation, ecological restoration, and urban greening initiatives (Thorat Abhijit et.al., 2022. Cortez, et. al., 2016 and FAO, 2017).

The carbon stock map provides a useful framework for watershed-scale conservation and restoration planning. Integration of GIS and remote sensing techniques facilitates efficient monitoring of carbon dynamics and supports climate change mitigation, biodiversity conservation, and sustainable ecosystem management (Achard et. al., 2014). Similar applications of geospatial technologies for carbon stock assessment and land-use planning

have been reported by Burrough & McDonnell (1998), Eastman (2016), Jensen (2015), Foley et. al. (2005), Houghton (2005), Fuchs et. al. (2015), Pearson et. al. (2005), Chavan Tukaramet. et.al., (2019); Sonawane et.al., (2008): Thorat and Dandge (2013); Thorat Abhijit et.al., (2025); Cortez et. al. (2016), Dossa & Miassi (2024), and Xu et. al. (2025).

Overall, the findings highlight the importance of forest and riparian ecosystems as key carbon reservoirs and demonstrate that spatial carbon stock mapping is an effective decision-support tool for sustainable watershed management, ecosystem restoration, and climate change mitigation in the Waghur River Basin.

CONCLUSION

This study demonstrated the effectiveness of GIS and remote sensing techniques for assessing and mapping ecosystem carbon stocks in the Waghur River Basin. The results revealed considerable spatial variation in carbon storage, with dense forests and riparian vegetation functioning as the major carbon sinks, while agricultural lands, grasslands, scrublands, and degraded areas exhibited relatively lower carbon sequestration potential. The generated carbon stock map provides a valuable basis for identifying priority conservation and restoration zones and supports climate change mitigation, biodiversity conservation, and sustainable watershed management. Overall, spatial carbon stock mapping serves as an effective decision-support tool for long-term ecosystem management in the basin.

RECOMMENDATIONS

- Protect high-carbon ecosystems by conserving dense forests and riparian vegetation and minimizing deforestation.
- Promote sustainable land management through agroforestry, sustainable forestry, and climate-smart agricultural practices.
- Enhance carbon storage in agricultural lands using conservation agriculture and soil carbon management techniques.
- Restore degraded lands through afforestation, assisted natural regeneration, and controlled grazing.
- Increase urban green cover via urban greening, roadside plantations, and rehabilitation of barren lands.
- Integrate carbon stock maps into watershed planning to identify priority conservation and restoration areas.
- Establish long-term monitoring programs using GIS and remote sensing for carbon accounting and ecosystem management.

ACKNOWLEDGEMENT

The authors sincerely thank the School of Environmental and Earth Sciences for providing the necessary research facilities and support. Financial assistance from the Teaching Associate Programme (TAP) Fellowship funded by Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon, and ANRF-PAIR under project number ANRF/PAIR/2025/000015/PAIR/PAIR-B is gratefully acknowledged. The authors also express their sincere gratitude to their mentors and colleagues for their valuable guidance, support, and encouragement, which contributed to the successful completion of this research.

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