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Urban expansion significantly impacts carbon stocks and sequestration, contributing to global climate change. This study analyzes the spatial dynamics of urban expansion and its effects on carbon stock depletion and sequestration potential in the Konkan division of Maharashtra, India. The conversion of forests, agricultural lands, and wetlands into urban and built-up areas has resulted in substantial carbon stock depletion in the region. This research aims to estimate the ongoing and future impacts of urbanization on carbon stocks by projecting land-use and land-cover (LULC) scenarios, and identifying strategies for enhancing carbon sequestration. The LULC data for the years 2017 to 2023 were analyzed to assess carbon pools across various land-cover types, including aboveground biomass, belowground biomass, soil, and dead organic matter using spatial analysis tools such as QGIS (Quantum Geographic Information System) Desktop 3.28.2, OSGeo4W (Open Source Geospatial for Windows) Shell, InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) 3.14.2 Workbench. The results highlight a significant reduction in carbon stocks due to urban sprawl, especially in green and agricultural areas. Future projections emphasize the importance of sustainable urban planning, with a focus on preserving green spaces and implementing carbon sequestration measures to mitigate the environmental impacts of rapid urbanization in the region. This study provides essential insights for policymakers aiming to balance urban growth with environmental sustainability.

Keywords: urban expansion, carbon stock, carbon sequestration, land-use change, Konkan division, Maharashtra, spatial analysis, QGIS, InVEST.

Introduction

The phenomenon of carbon stock depletion due to urban expansion has emerged as a critical concern in the context of global climate change. As of 2020, approximately 56.2% of the world's population resides in urban areas, which are a major contributor to greenhouse gas (GHG) emissions, with the Intergovernmental

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Introduction

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Panel on Climate Change (IPCC) reporting land-use and land-cover changes, especially urbanization, contribute approximately 23% of anthropogenic emissions globally, highlighting the urgent need for sustainable urban planning practices (Edenhofer et al., 2014; UNCTAD, 2021; World Bank Group, 2025; UN DESA, 2019). The expansion of cities often leads to the conversion of natural landscapes, such as forests, vegetations, croplands, and wetlands, into impervious surfaces or built-up areas, resulting in the loss of vital carbon sinks, decreasing carbon sequestration potential and exacerbating climate change (Seto et al., 2012). This study is anchored within the broader theoretical framework of urban ecology and ecosystem services. Urban expansion not only diminishes terrestrial carbon sinks but also undermines nature-based solutions (NbS), such as mangrove ecosystems, which act as globally recognized blue carbon reservoirs(Duarte et al., 2013; Mcleod et al., 2011). These ecosystems contribute substantially to climate regulation, biodiversity conservation, and disaster resilience, and their degradation jeopardizes progress toward carbon neutrality(Barbier, 2016; Mcleod and Salm, 2006). Situating the Konkan Division's urbanization within this discourse highlights the ecological trade-offs of rapid land-use change in biodiversity hotspots, directly linking local patterns to global sustainability commitments such as the Paris Agreement and the Sustainable Development Goals (SDGs 11 and 13). In Asia, urban expansion is occurring at an unprecedented rate, driven by rapid economic growth and population migration from rural areas to urban centers. The Asian Development Bank reported that Asia's urban population is expected to increase by 1.2 billion people by 2030, leading to significant land-use and land-cover changes and increased carbon emissions. Cities like Shanghai, Delhi, and Bangkok are experiencing extensive urban sprawl, often at the expense of agricultural lands and forests, resulting in substantial carbon stock depletion. The degradation of these ecosystems not only reduces their capacity to sequester carbon but also impacts biodiversity and local climate regulation, creating a cascade of environmental challenges. India, as a rapidly developing nation, exemplifies the challenges associated with urban expansion and carbon stock depletion. The country's urban population is projected to reach 600 million by 2031, necessitating substantial infrastructure development and land conversion (Kumar and Gupta, 2018). A study published in Environmental Science and Policy indicated that urbanization in India has led to significant losses in forest cover and agricultural land, directly affecting the carbon stock. The carbon emissions resulting from these land-use and land-cover changes are particularly alarming, as urban areas contribute approximately 70% of the nation's total GHG emissions (World Economic Forum, 2025). The interplay between urban expansion at an expense of ecological regions and carbon stock depletion presents a significant challenge globally, regionally in Asia, nationally in India, specially in ecologically diverse regions like Western And Eastern Ghats, Sunderbans, Himalayas, Sundalands, Indo-Burma Region, and many more. Addressing these issues requires a multifaceted approach that integrates sustainable urban planning, preservation of green spaces, and restoration of degraded ecosystems to mitigate the impacts of urban growth on carbon stocks and climate change.

After conducting, an exhaustive literature review of 169 documents on the assessting impacts of urbanization of carbon storage and sequestration capacity it was observed that these studies are carried under two broad themes, i.e. impacts of land-use and land-cover (LULC) change on carbon storage and sequestration capacity at national/regional level/city level and at ecologically diverse region level. Across Asia and other global regions, more than 40 studies consistently show that LULC transitions from forests or agricultural land to built-up areas lead to significant carbon declines. Additionally, research from Myanmar, Manipur, Nanjing, Northeast China, and Mizoram demonstrates that urban expansion or land-use changes reduce aboveground biomass, soil carbon, and overall sequestration capacity, while sustainable land-use strategies can mitigate these impacts(Ahirwal et al., 2023; Helen et al., 2019; Momo and Devi, 2022; Peng et al., 2024; Song et al., 2023; Xu and Li, 2024). Similarly, more than 60 studies were conducted in ecologically diverse regions such as Zambia, the Haihe River Basin, the Tianshan North Slope, the Amazon, and Indian dry tropical forests confirm that hotspots of biodiversity face sharp carbon stock depletion when forests, mangroves, or wetlands are converted for agriculture or infrastructure (Budak et al., 2023; Feitosa et al., 2023; Lin and Li, 2024a; Liu et al., 2024; Nunes et al., 2022). These works highlight that carbon losses in ecologically fragile regions not only reduce sequestration but also undermine ecosystem services and resilience.

It can be seen that while many studies are focusing on discussing the carbon stock and sequestration in ecologically diverse areas like tropical forests, mangroves, Himalayas, plains, etc., only two studies have examined the Western Ghats region despite its global recognition as a biodiversity hotspot. These limited works explored carbon fluxes, black carbon dynamics, and biomass distribution of endemic species, leaving a major research gap on how urbanization shapes carbon storage and sequestration in the Western Ghats.

However, translating findings from broader regional or national scales to micro-level landscapes remains one of the biggest challenges. While the results of many existing studies are applicable to larger areas, bringing them down to a localized scale such as the Konkan Division requires methodological innovation and fine-grained data integration. To bridge this gap, this paper targets a specific and ecologically diverse region in the Western Ghats of India: the Konkan Division, which is known for its unique coastal ecosystems and high biodiversity. Understanding the effects of urban expansion on carbon dynamics here is critical but underexplored. The paper contributes to the localized understanding of how urban growth affects carbon storage and sequestration in Indian coastal and transitional zones. Additonally, this study utilizes Quantum Geographic Information System (QGIS - An open-source geographic information system used for spatial data visualization, mapping, and geospatial analysis), OSGeo4W (Open Source Geospatial for Windows - A Windows-based open-source geospatial software environment that provides command-line access to various GIS tools and libraries) Shell and the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST - modeling tool developed by the Natural Capital Project that quantifies ecosystem services, including carbon storage and sequestration, under different land-use scenarios) model to assess carbon stocks and sequestration. While these tools are widely used for environmental assessment, their combined application to analyze urban impacts on carbon dynamics in this specific context adds methodological value. The study demonstrates how open-source tools like QGIS, paired with InVEST, can be effectively employed to create accessible and replicable carbon stock assessments for regions with similar ecological and socio-economic profiles.

This study aims to assess the impact of urban expansion on carbon stock and sequestration across Konkan using spatial analysis tools, specifically QGIS and the InVEST model. By quantifying the effects of LULC changes driven by urbanization, the study targets to inform sustainable urban planning strategies that can preserve Konkan's ecological integrity and carbon storage functions amidst ongoing development pressures. Overall, this paper offers a unique contribution by combining spatial analysis tools with ecosystem service modeling in a lesser-studied region of India, providing localized insights into the challenges of balancing urban development with carbon storage and sequestration efforts.

Methodology

Study area

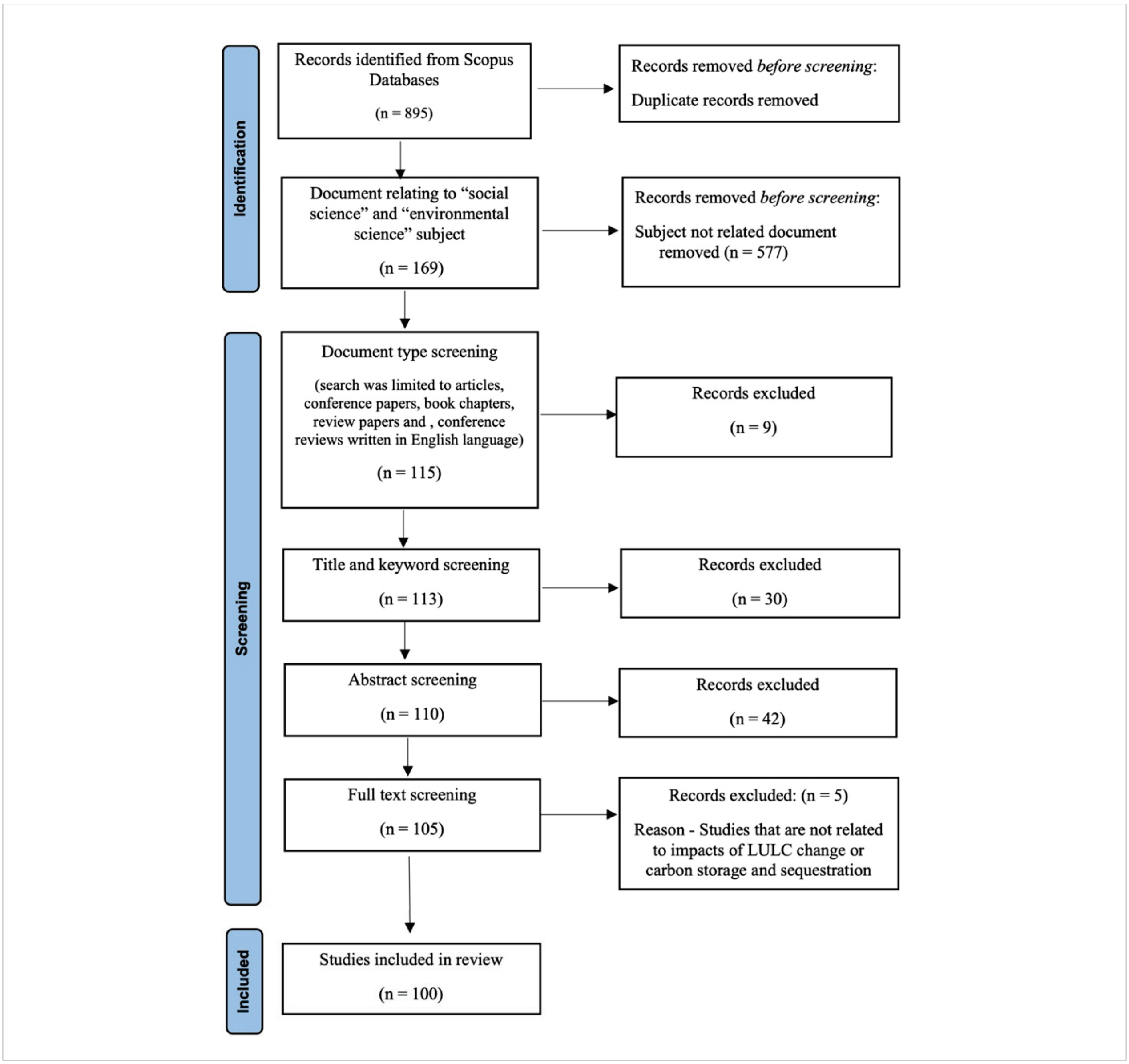
The Konkan Division, located along the western coast of Maharashtra, India, encompasses a diverse landscape that includes coastal plains, river valleys, and the Western Ghats' foothills. Spanning approximately 30,746 square kilometers and comprising the districts of Mumbai, Mumbai Suburban, Thane, Palghar, Raigad, Ratnagiri, and Sindhudurg, Konkan is bounded by the Arabian Sea to the west and the Sahyadri range to the east, which separates it from the Deccan Plateau. The region's tropical monsoon climate, characterized by high humidity and an annual rainfall exceeding 3,000 mm in certain areas, supports lush vegetation and contributes significantly to carbon sequestration, particularly within its forested and mangrove-rich zones. The area's topography, marked by lateritic and alluvial soils, is conducive to diverse vegetation but susceptible to erosion when the native cover is removed, making LULC patterns critical in carbon dynamics.

Ecologically, Konkan is part of the Western Ghats, a globally recognized biodiversity hotspot and UNESCO World Heritage Site, which hosts tropical rainforests, mangroves, and evergreen forests that are home to various endemic and endangered species. These ecosystems not only enhance biodiversity but also play a crucial role in regional carbon sequestration. Socio-economically, the region includes a mix of urban and rural populations, with cities like Mumbai and Thane experiencing rapid urbanization. Primary economic activities include agriculture, fishing, tourism, and industry. However, the urban sprawl, especially around Mumbai, has accelerated infrastructure development, deforestation, and changes in land-use, all of which impact carbon stock and sequestration potential.

Literature review

We have conducted a Systematic Literature Review (SLR) on assessting impacts of urbanization of carbon storage and sequestration capacity to outline a complete research agenda. The methodology is used to ensure that only relevant literature is included and bias is avoided in choosing sources. The quality assurance of SLR depends on the clarity and comprehensiveness of the reporting procedure; hence the study follows "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) criteria in doing the literature review. According to PRISMA, an SLR consists of three phases: identification, screening, and eligibility, as presented in *Fig. 1*. The initial search using keywords (*"carbon stock" AND "land-use and land-cover"*) yielded 895 documents, of which those pertaining to the "social science" and "environmental science" disciplines were selected, resulting in 169 documents. Further refinement based on document type, focusing on articles, conference papers, book chapters, and review papers written in English, reduced the count to 115 documents.

Fig. 1. *PRISMA analysis for systematic literature review*



The subsequent screening process involved three stages: keywords screening, title screening, abstract screening, and full-text screening, in which studies were three categories:

1. Impacts of LULC change on carbon storage and sequestration capacity at national/regional level/city level – 40 studies.
2. Impacts of LULC change on carbon storage capacity and sequestration at at ecologically diverse region level – 60 studies.
3. Studies that are not related to impacts of LULC change or carbon storage and sequestration capacity – 5 studies.

Thus, the studies that are irrelevant to the studied topic, i.e. studies that are not related to decarbonization or greenhouse gas emissions were excluded. Accordingly,100 documents were selected to be included in this study, of which impacts of LULC change on carbon storage capacity and sequestration at ecologically diverse region level.

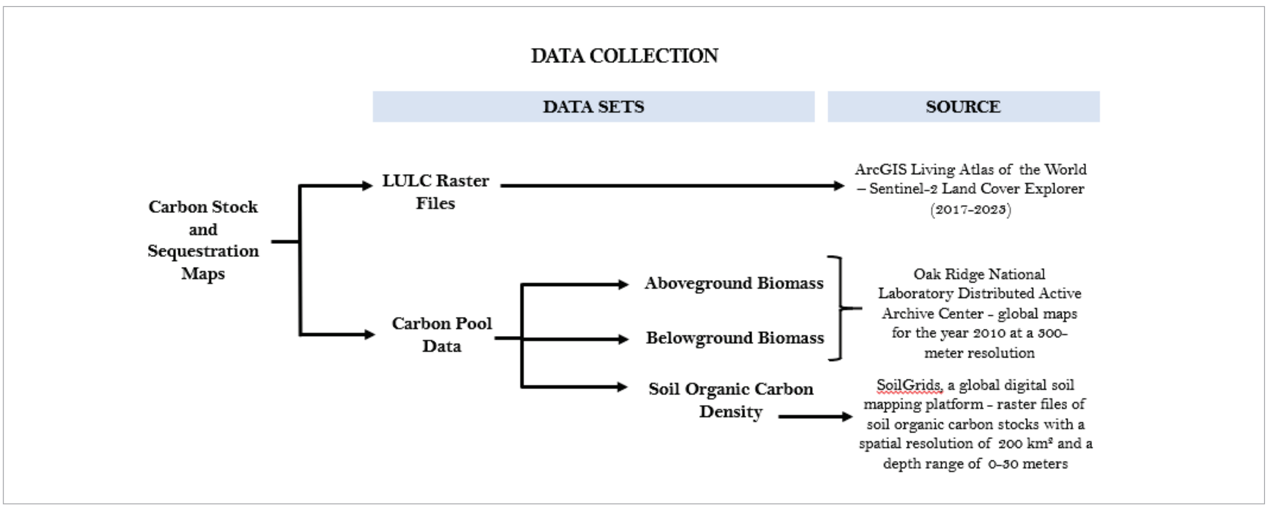
Map preparation

The LULC and carbon stock maps for the Konkan Division were generated using QGIS Desktop 3.28.2, OSGeo4W Shell, and the InVEST 3.14.2 Workbench. These maps were created using datasets such as LULC raster files and carbon pool data for aboveground biomass, belowground biomass, soil, and dead organic matter. The LULC rasters covering the 2017–2023 period were sourced from the ArcGIS Living Atlas of the World – Sentinel-2 Land-cover Explorer. Soil organic carbon density data was obtained from SoilGrids, a global digital soil mapping platform that combines global soil profile data (WoSIS - World Soil Information Service) with environmental layers, providing raster files of soil organic carbon stocks with a spatial resolution of 200 km² and a depth range of 0-30 meters. Biomass carbon density data for aboveground and belowground biomass, available as global maps for the year 2010 at a 300-meter resolution, were sourced from the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC).

A key limitation arises from the reliance on the ORNL DAAC 2010 dataset, as it does not fully reflect current vegetation and land-use dynamics. To improve representativeness, these values were cross-validated with European Space Agency's Climate Change Initiative (ESA CCI) Biomass (2023) products and Maharashtra Remote Sensing Centre (MRSC) inventories. Nonetheless, the temporal mismatch may introduce some degree of uncertainty in estimating present-day carbon stocks.

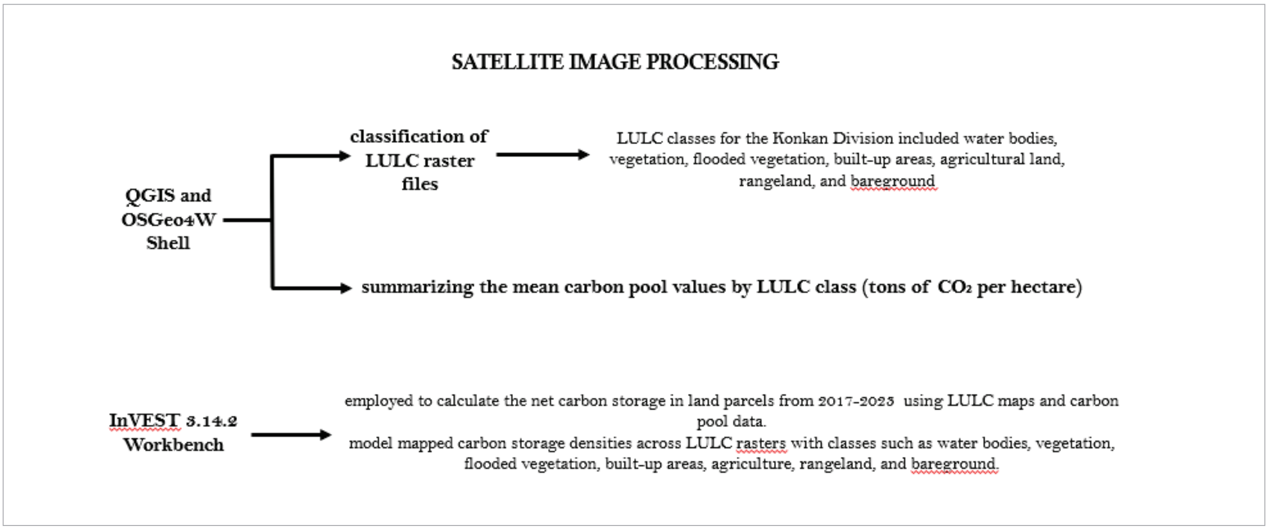
QGIS and OSGeo4W Shell facilitated the classification of LULC raster files and enabled summarizing the mean carbon pool values (aboveground biomass, belowground biomass, soil, and dead organic matter) by LULC class, expressed in tonne of CO_2 per hectare. The identified LULC classes for the Konkan Division included water bodies, vegetation, flooded vegetation, built-up areas, agricultural land, rangeland, and bareground. Subsequently, the InVEST 3.14.2 Workbench

Fig. 2. *Data collection methodology (Sources of Datasets)*



was employed to calculate the net carbon storage in land parcels from 2017–2023 using LULC maps and carbon pool data. The model mapped carbon storage densities across LULC rasters with classes such as water bodies, vegetation, flooded vegetation, built-up areas, agriculture, rangeland, and bareground.

Fig. 3. *Satellite image processing methodology using QGIS, OSGeoW Shell, and InVEST*



Results

The assessment of LULC change impacts on carbon storage in Kokan Division, Maharashtra, using data from 2017 to 2023, illustrates how the dynamics of urban expansion influence carbon storage and sequestration. This study leverages quantitative data from two dimensions: the area of each LULC class and the percentage of carbon stock within each land-use type as shown in *table 1* and *table 2*. Together, these insights reveal substantial trends, primarily highlighting the pressures of urbanization on carbon-rich land-covers and the resulting implications for total carbon storage in the region.

In summarizing the mean values of carbon pools (including aboveground biomass, belowground biomass, soil, and dead organic matter) across various LULC classes in the Kokan Division, it was observed that flooded vegetation serves as the most significant carbon sink, with a storage capacity of 14,286.63 tonne of CO_2 per hectare. This is followed by built-up areas (13,477.70 tonne of CO_2 per hectare), bare ground (11,002.26 tonne of CO_2 per hectare), agricultural land (986.44 tonne of CO_2 per hectare), natural vegetation (749.58 tonne of CO_2 per hectare), rangeland (592.49 tonne of CO_2 per hectare), and water bodies (0.03 tonne of CO_2 per hectare).

The data indicates that flooded vegetation plays a critical role in carbon storage within the Kokan Division, likely due to the accumulation of organic matter in wetland environments, where anaerobic conditions significantly slow the decomposition of plant materials. Interestingly, agricultural areas exhibit a higher carbon storage capacity compared to natural vegetation, a phenomenon attributable to effective agricultural practices, such as cover cropping and the application of organic amendments, which enhance soil carbon storage. The specific crop types cultivated may also contribute to increased carbon sequestration. Conversely, natural vegetation may experience degradation or disturbances that diminish its carbon storage potential, underscoring the importance of sustainable agricultural practices and the preservation of natural vegetation for optimal carbon sequestration and overall ecological health. Additionally, bare ground presents a noteworthy carbon storage capacity of 11,002.27 tonne of CO_2 per hectare, likely due to carbon sequestered in the soil. However, similar to built-up areas, bare ground does not actively store or sequester carbon through photosynthesis, limiting its effectiveness for long-term carbon management. Rangelands contribute to carbon storage with a potential of 592.49 tonne of CO_2 per hectare, albeit at a lower

Table 1. *Land-use land-cover change 2017–2023*

LULC	2017, %	2018, %	2019, %	2020, %	2021, %	2022, %	2023, %
Water bodies	4.09	4.08	3.90	4.12	4.12	4.12	4.13
Vegetation	39.41	36.48	28.61	33.78	36.20	36.20	38.08
Flooded vegetation	0.60	0.48	0.55	0.51	0.54	0.54	0.42
Agriculture	11.44	11.04	11.49	10.92	10.32	10.32	11.04
Builtup area	4.98	5.95	6.29	6.34	6.04	6.04	7.28
Bareground	0.04	0.04	0.04	0.03	0.02	0.02	0.03
Rangeland	39.43	41.93	49.12	44.29	42.76	42.76	39.02

Footnote: Values in Table 1 represent the percentage share of each LULC class in the total study area.

Table 2. *Total and change in carbon storage 2017–2023*

Year	Total carbon stored (in tonne CO_2)	Change in carbon storage (in tonne CO_2)
2017	2,276,832,863	-
2018	2,164,627,826	–112,205,037.09
2019	2,172,365,973	7,738,146.45
2020	2,116,501,860	–55,864,112.57
2021	2,132,373,569	15,871,709.19
2022	2,132,373,569	0.00
2023	2,082,432,029	–49,941,540.50

Footnote: Values in Table 2 represent the total estimated carbon stored across all LULC classes, expressed in metric tonne of CO_2 (tCO_2). The "Change in Carbon Storage" column indicates year-on-year variation relative to the previous year.

capacity compared to densely vegetated areas. Water bodies, while essential for biodiversity and ecosystem services, represent the least carbon storage potential at only 0.03 tonne of CO_2 per hectare, primarily due to a lack of aboveground biomass. Surprisingly, built-up areas demonstrate a significant carbon storage capacity of 13,477.70 tonne of CO_2 per hectare.

However, this value is misleading because it reflects embedded carbon locked in construction materials such as concrete and asphalt rather than active biological sequestration. Although built-up areas appear to hold substantial carbon, these pools are inert and do not contribute to ongoing carbon absorption. Hence, for ecological accounting purposes, built-up carbon storage is considered negligible.

The analysis of carbon storage capacity in the Konkan Division over several years reveals significant fluctuations in LULC that have impacted regional carbon sequestration potential. In 2018, a reduction of 0.112 billion tonne of CO_2 was observed, coinciding with a decline in vegetation cover from 39.41% to 36.48%, and a decrease in flooded vegetation, a key carbon sink, from 0.60% to 0.48% as shown in *Fig. 5* and *Fig. 12.* Although agricultural land saw a slight reduction from 11.44% to 11.04%, the increase in rangeland-cover from 39.43% to 41.93% was insufficient to offset the losses in high-carbon-storage areas like flooded vegetation and forests, leading to an overall decrease in carbon storage capacity. The rise in built-up areas and the expansion of bare land, potentially due to urban encroachment, deforestation, or soil degradation, further diminished the region's ability to store carbon.

In 2019, the Konkan Division saw a modest increase in carbon storage capacity, rising by 0.0077 billion tonne of CO_2, despite a continued reduction in vegetation cover, from 36.48% to 28.61% as shown in *Fig. 6* and *Fig. 13.* The growth of rangeland from 41.93% to 49.12% contributed to this increase, although rangeland has lower carbon sequestration potential compared to flooded vegetation and forests. The expansion of built-up areas from 5.95% to 6.29%, likely at the expense of vegetation and agricultural lands, suggests an ongoing trend of urbanization. Despite the increase in carbon storage in 2019, the continuing decline in high-capacity carbon sinks, such as flooded vegetation, raises concerns about the long-term sequestration potential in the region.

The 2020 data presented a contrasting picture, with a reduction of 0.056 billion tonne of CO_2 in carbon storage capacity. This decline occurred even as vegetation cover increased from 28.61% to 33.78%, highlighting the critical role of other LULC factors in determining overall carbon storage as shown in *Fig. 7* and *Fig. 14*. A slight decrease in flooded vegetation (from 0.55% to 0.51%) and reductions in both agricultural land (from 11.49% to 10.92%) and rangeland (from 49.12% to 44.29%) contributed significantly to the decrease in carbon storage. The increase in built-up areas (from 6.29% to 6.34%) further encroached upon valuable carbon sinks, exacerbating the overall reduction in carbon sequestration capacity.

In 2021, carbon storage capacity improved by 0.016 billion tonne of CO_2, corresponding with a rise in vegetation cover from 33.78% to 36.20% as shown in *Fig. 8* and *Fig. 15*. However, this increase was counterbalanced by a slight decrease in flooded vegetation, which continued to be a vital carbon sink, and reductions in agricultural land and rangeland. The slight decrease in built-up areas from 6.34% to 6.04% suggests a possible stabilization in urbanization, although the shifts in other land-uses still pose a threat to the long-term carbon storage potential of the region.

In 2022, the region experienced stable carbon storage capacity with no significant changes in LULC or carbon sequestration as shown in *Fig. 9* and *Fig. 16*. While this stability indicates a halt in degradation, it also suggests missed opportunities to enhance the region's carbon storage potential. The lack of significant improvements in land-use practices or restoration efforts likely limited the region's capacity to increase its carbon sink.

In 2023, carbon storage capacity again declined by 0.050 billion tonne of CO_2, despite an increase in vegetation cover from 36.20% to 38.08% as shown in *Fig. 10* and *Fig. 17*. This decline was primarily due to the reduction in flooded vegetation (from 0.54% to 0.42%), a crucial carbon sink in the region. Additionally, the shift from rangeland (which saw a decrease from 42.76% to 39.02%) to agricultural land (which increased from 10.32% to 11.04%) and built-up areas (which rose from 6.04% to 7.28%) further diminished the carbon storage potential. The increase in bare land, though minimal, also contributed to this trend. These shifts underscore the critical need to preserve and restore high-capacity carbon sinks, such as flooded vegetation and rangelands, to mitigate the impact of urbanization and agricultural expansion on carbon sequestration

Fig. 4. *LULC 2017*

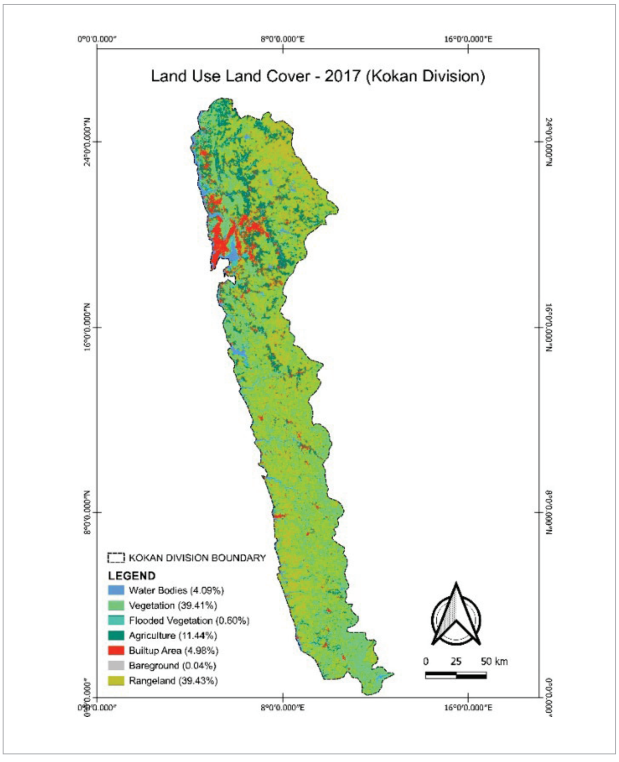


Fig. 5. *LULC 2018*

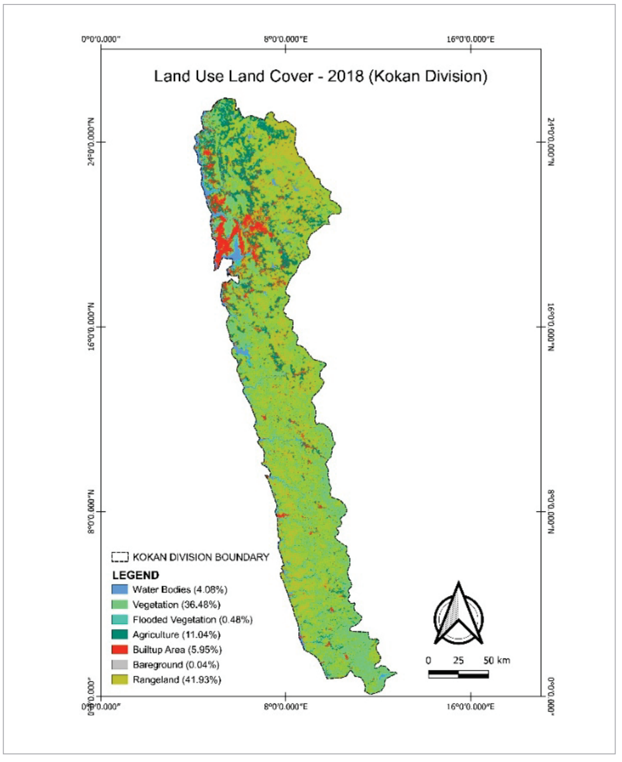


Fig. 6. *LULC 2019*

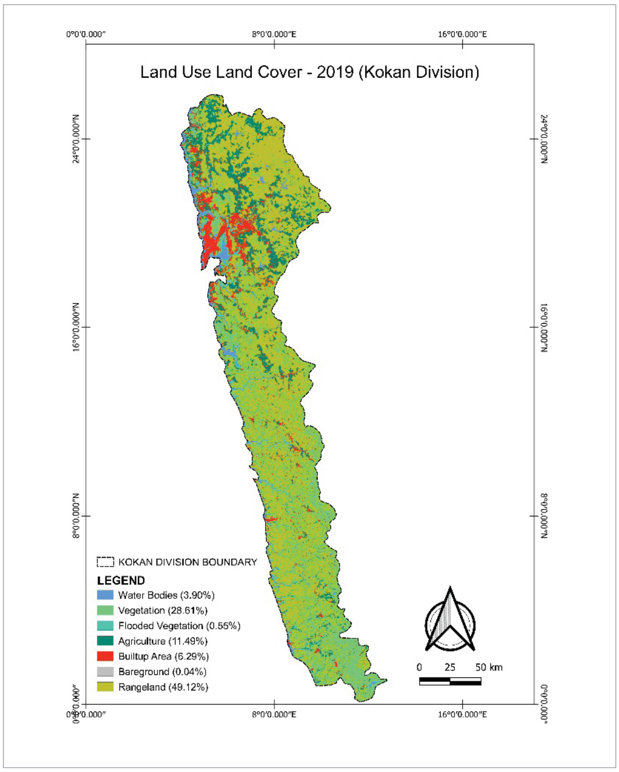


Fig. 7. *LULC 2020*

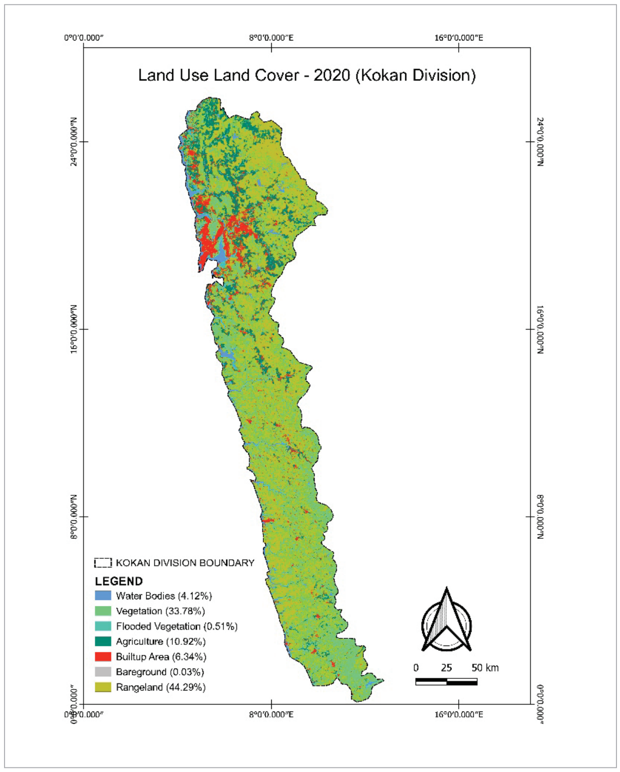


Fig. 8. *LULC 2021*

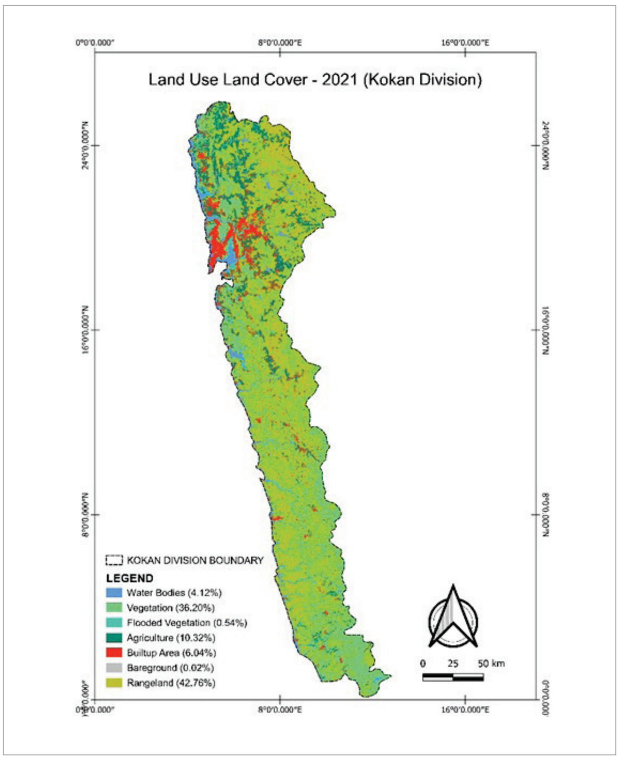


Fig. 9. *LULC 2022*

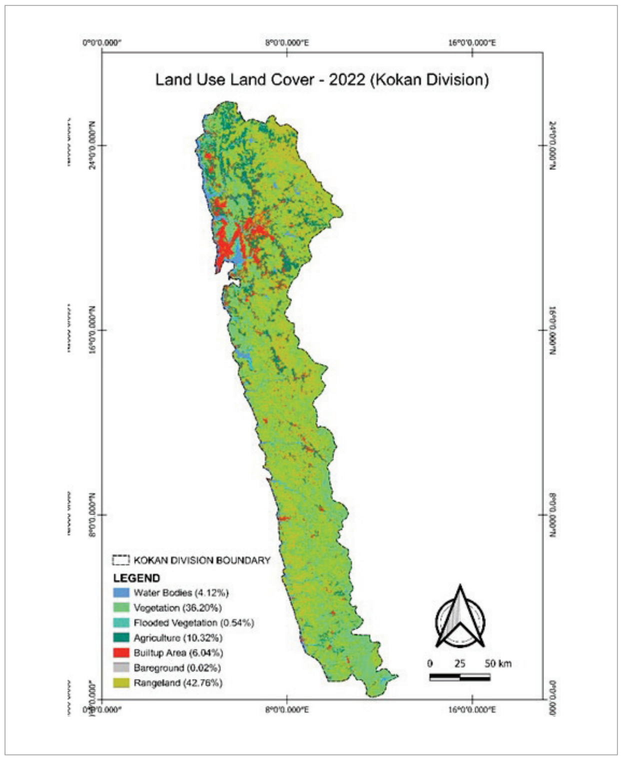


Fig. 10. *LULC 2023*

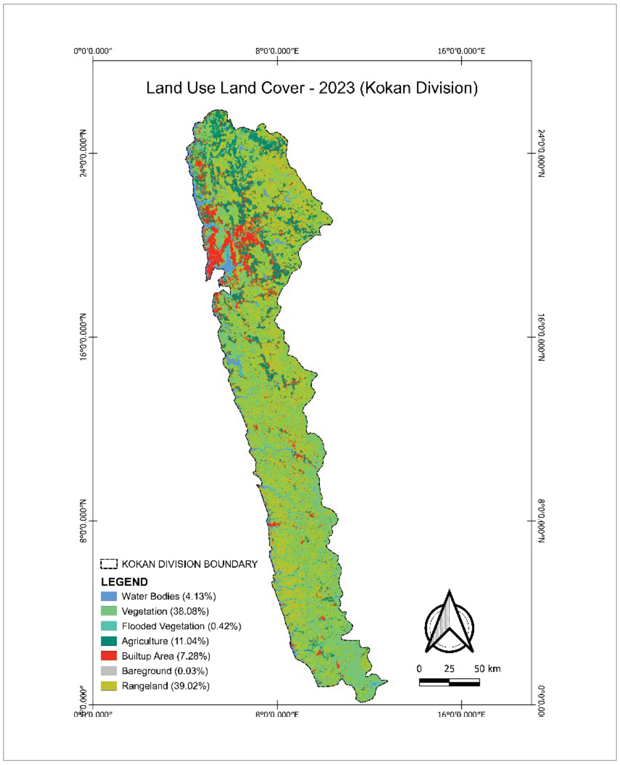


Fig. 11. *Carbon stock 2017*

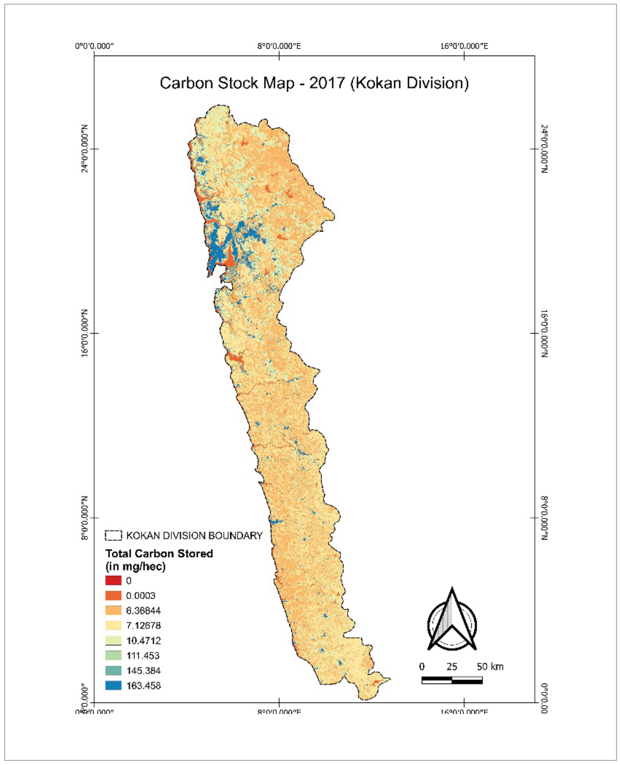


Fig. 12. *Carbon stock 2018*

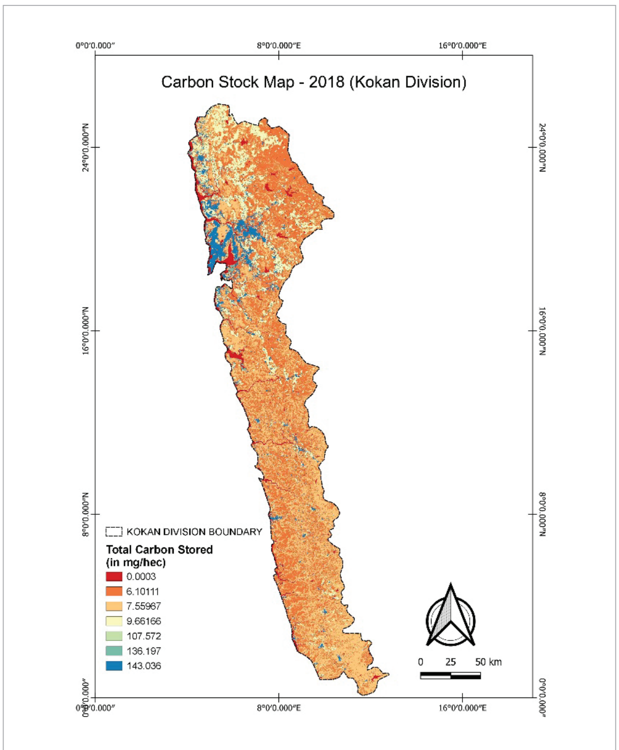


Fig. 13. *Carbon stock 2019*

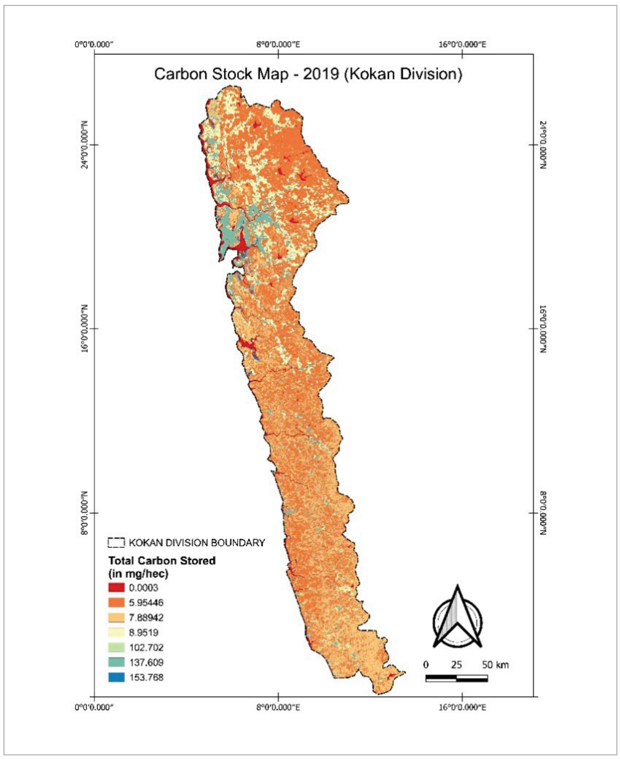


Fig. 14. *Carbon stock 2020*

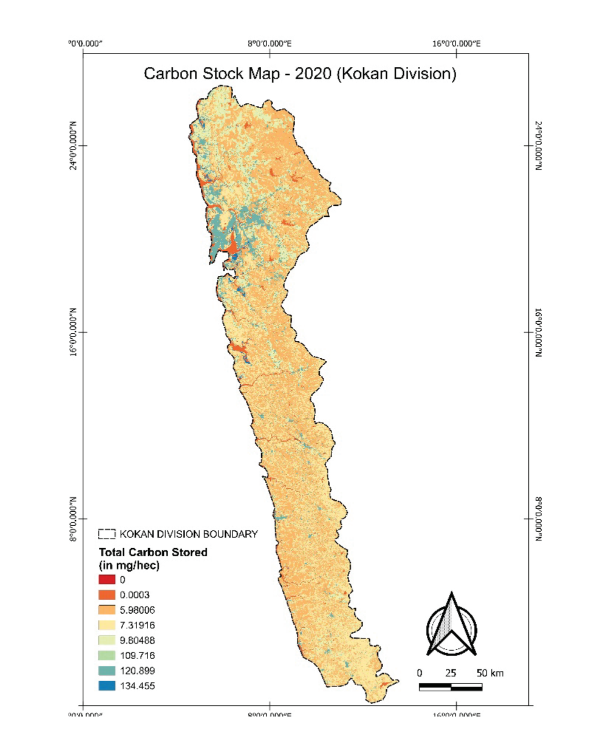


Fig. 15. *Carbon stock 2021*

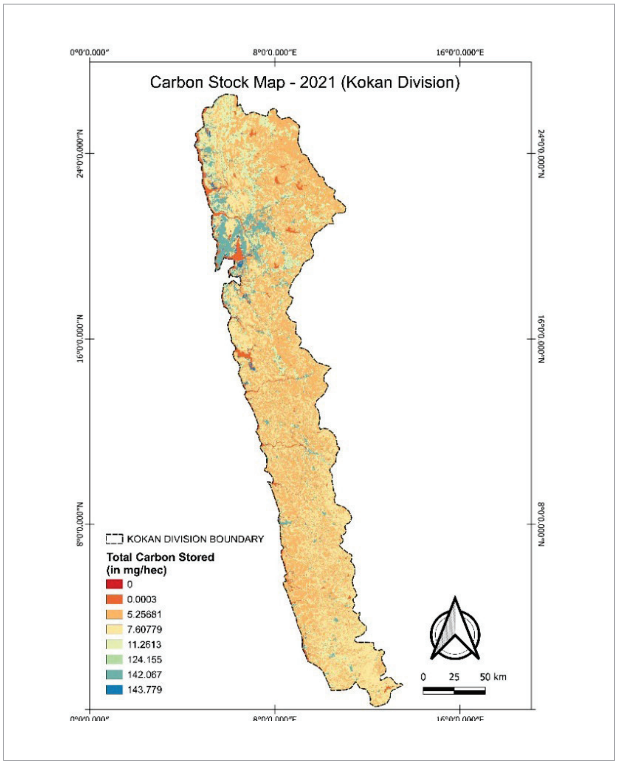


Fig. 16. *Carbon stock 2022*

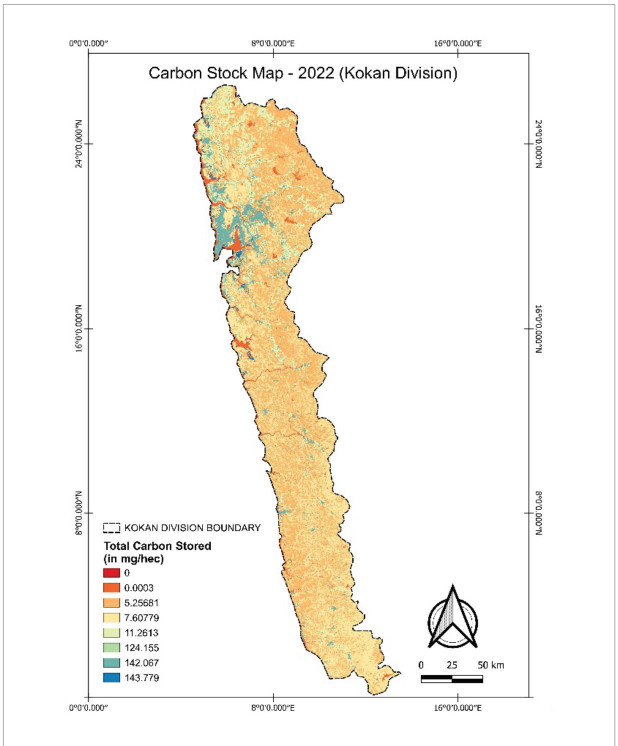
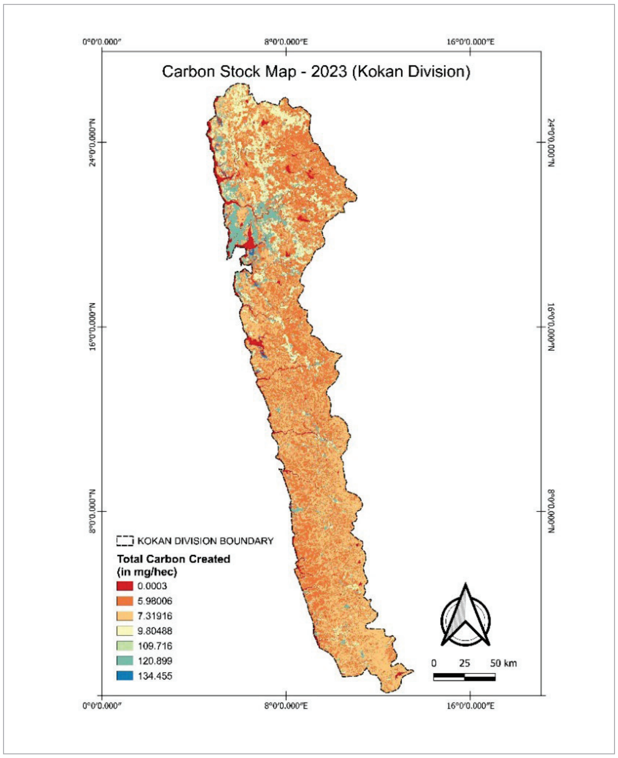


Fig. 17. *Carbon stock 2023*



Discussion

The assessment of urban expansion's impact on carbon stock and sequestration in the Konkan Division, Maharashtra, reveals critical insights into how LULC changes influence regional carbon dynamics. Utilizing QGIS and the InVEST model to evaluate the period from 2017 to 2023, this study highlights how expanding urban areas are reshaping the landscape and affecting carbon storage potential across various LULC classes. Flooded vegetation, a key carbon sink due to its high organic matter accumulation in waterlogged conditions, demonstrates the highest carbon storage capacity per hectare but has seen a notable decline in coverage over the study period. This reduction is particularly concerning, as it directly compromises the region's carbon sequestration potential. Wetland and flooded vegetation ecosystems accumulate large amounts of aboveground biomass and soil organic carbon under anaerobic conditions, which slow decomposition and enhance long-term carbon retention. Their reduction therefore risks releasing disproportionately high carbon stocks and undermining ecological resilience.

Agricultural lands, unexpectedly, show relatively high carbon storage capacities, which may stem from sustainable land management practices such as crop rotation, organic amendments, and soil management techniques that enhance soil carbon retention. These findings suggest that implementing further sustainable agricultural practices could enhance the region's overall carbon storage. In contrast, built-up areas, while demonstrating carbon storage due to construction materials, do not contribute to active carbon sequestration. The high storage values recorded in built-up areas reflect embedded carbon locked in cement, steel, and asphalt, which are static pools rather than dynamic sinks. Although these figures appear large in quantitative terms, they are ecologically negligible because such materials do not absorb additional carbon over time. This distinction is critical to avoid misinterpreting built-up environments as functional carbon sinks. The steady increase in built-up areas highlights the growing pressures of urbanization, which has resulted in a reduction of natural vegetation and other high-capacity carbon sinks, such as flooded vegetation. This expansion indicates the need for urban planning policies that minimize conversion of carbon-rich land types to built-up areas, as such conversions disrupt the natural carbon sequestration capacity of the region. The fluctuations in carbon storage observed across different years also demonstrate the complex interplay between LULC changes and sequestration potential. For instance, although vegetation cover saw an increase in certain years, the loss of flooded vegetation and declines in agricultural land suggest that total carbon storage capacity cannot be maintained solely by expanding vegetation cover but requires preservation of high-carbon-density land types.

Conclusions

The study's findings illustrate that urban expansion is exerting a significant and often negative influence on carbon stock and sequestration potential in the Konkan Division. While there are short-term fluctuations, the overall trend reveals a decline in carbon storage capacity driven by reductions in high-density carbon sinks like flooded vegetation and increasing encroachment of built-up areas. Given flooded vegetation's role as a crucial carbon sink, its diminishing area represents a pressing environmental concern that affects long-term carbon sequestration and ecosystem stability.

To mitigate the impact of urban expansion on carbon dynamics, the region would benefit from strategic urban planning that protects carbon-rich land-covers, such as flooded vegetation and natural vegetation, while promoting sustainable agricultural practices to enhance soil carbon retention. Restoration of rangelands and natural vegetation, alongside targeted conservation of high-carbon-density areas, could help balance the effects of urban growth on the region's carbon sequestration potential.

It is also important to acknowledge that part of the analysis relied on biomass datasets from 2010, which, despite being cross-validated with ESA CCI Biomass (2023) and MRSC inventories, may introduce temporal uncertainty. This limitation underlines the need for future research that incorporates higher temporal-resolution and field-validated biomass datasets for improved accuracy. Policy interventions should include designating urban growth boundaries around rapidly expanding cities like Mumbai and Thane, embedding carbon offset mechanisms that require developers to contribute to ecological restoration, and scaling up mangrove restoration and afforestation programs in districts such as Raigad and Ratnagiri. Furthermore, integrating LULC – carbon monitoring into Maharashtra's Climate Action Plan would institutionalize long-term tracking of carbon dynamics and ensure that urban expansion is aligned with ecological resilience and climate mitigation targets.

The use of QGIS and InVEST in this assessment underscores the value of spatial analysis and modeling tools in informing land management strategies, highlighting that proactive policies not only serve regional priorities but also contribute to global sustainability commitments under the Paris Agreement and the United Nations Sustainable Development Goals (SDGs 11 and 13).

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