DOI: https://doi.org/10.38027/ICCAUA2024IN0434

Assessing the Impacts of land Use Change on Carbon Sequestration: A Comprehensive Analysis for Kochi City, India

[1] Mr. **Thomas Mathew,** [2] Dr. **Shanmuga Priya Gnanasekaran**
[1] *M.Arch(Landscape Architecture) student, Department of Architecture, School of Planning and Architecture, Vijayawada*
[2] *Associate Professor, Department of Architecture, School of Planning and Architecture, Vijayawada*
E-mail [1]: 1220700087@spav.edu.in , E-mail [2]: shanmugapriya@spav.edu.in

Abstract
Land use typologies play a pivotal role in determining the carbon sequestration capacity of urban ecosystems. As human activities continue to reshape landscapes, understanding the impact of different land uses on carbon storage is crucial for developing effective climate change mitigation strategies for cities. This paper aims to analyse the relationship between land use typologies and carbon sequestration. Carbon sequestered in the selected city i.e., Kochi is quantified using the InVEST Carbon Storage and Sequestration model (Integrated Valuation of Ecosystem Services and Tradeoffs), coupled with remote sensing. The model uses input data on carbon pools including above-ground, below-ground, soil biomass, and dead carbon matter. The change in carbon sequestration with change in land use between 2003 and 2023 is calculated. The study reveals that there has been a reduction in wetland areas by 59 % which leads to 63% less sequestration of carbon highlighting the implication of land use on carbon sequestration.
Keywords: Landuse typology; carbon sequestration; remote sensing; InVEST-CSS model; Climate change mitigation.

1. Introduction

Land use typologies play a pivotal role in determining the carbon sequestration capacity of ecosystems. As human activities continue to reshape landscapes, understanding the impact of different land uses on carbon storage is crucial for developing effective climate change mitigation strategies. This is of even greater concern in coastal cities as wetlands are important components of the regional landscapes and serve as significant carbon sinks. However, very little research has been carried out on the impacts of land Use and Land Cover (LULC) changes on carbon storage in coastal areas, which plays a critical role in the conservation of blue carbon ecosystems. (Zheng, 2023). There is a lack of information about the magnitude of LULC change and its impact on carbon storage and sequestration in urbanized regions of Southeast Asia under different future scenarios (Kamarajugedda et al, 2023).

This paper aims to analyse and synthesise existing knowledge on the relationship between land use typologies and carbon sequestration through an analysis of Kochi City, India. The study determines the extent to which land use changes in Kochi City have affected carbon sequestration levels in different ecosystems, particularly wetlands. The analysis and findings in this study have been limited only to wetlands owing to their dominance in carbon sequestrating capacity in coastal landscapes. The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model is used to assess the carbon storage capacity of various land uses. Thus, it provides data-driven insights to policymakers, urban planners, and environmental agencies to support decision-making related to sustainable land use practices, conservation efforts, and climate change mitigation strategies (Amen, 2021; Amen et al., 2023). Suggestions related to specific mitigation measures and land management strategies that can help offset carbon losses, enhance carbon sequestration, and promote sustainable development in Kochi City have also been the intent of this paper.

1.1 Wetlands and carbon storage

Wetlands, like mangroves and salt marshes, are efficient carbon sinks. Conversion of wetlands for agriculture or urban development leads to significant carbon emissions. Preserving and restoring these ecosystems is crucial for maintaining their role in carbon sequestration and providing other benefits like flood control and habitat preservation. Wetlands are vital for biogeochemical processes; without them, water, carbon, and nutrient cycles would be affected. These systems remove CO_2 from the atmosphere and can store carbon for long periods. Due to their productivity and carbon potential, wetlands are an effective solution to reduce CO_2 density and mitigate climate change. Coastal blue carbon, the organic carbon stored by coastal plants like salt marshes, mangroves, and sea grasses, is a growing area of research. Studies worldwide have measured the carbon stored in sediments, showing that these ecosystems have a 10 times higher carbon sink capacity than terrestrial one (Rajaa Aitali, 2022).

For carbon accounting of a location, components namely, above- and below-ground, with changes in biomass and soil organic matter need to be considered (Watson et al., 2000). However, most of the analysis on carbon storage focuses on above-ground biomass (AGB), as it is more apparent during the process of land use change (FSI, n.d). However, potentials of soil biomass and dead biomass need to be included in the carbon sequestration analysis.

2. Material and Methods

This study combines remote sensing and modelling techniques for assessment of carbon storage for the years 2003 and 2023 for the Kochi city. The process involves data acquisition and processing, followed by mapping land use/land cover and carbon density. Further, carbon stocks are estimated using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model. The results reveal carbon stock dynamics over time and estimate sequestration potential. This study focuses on the value of carbon storage in wetlands due to their carbon sequestration potential. Figure 1 shows the steps in this approach.

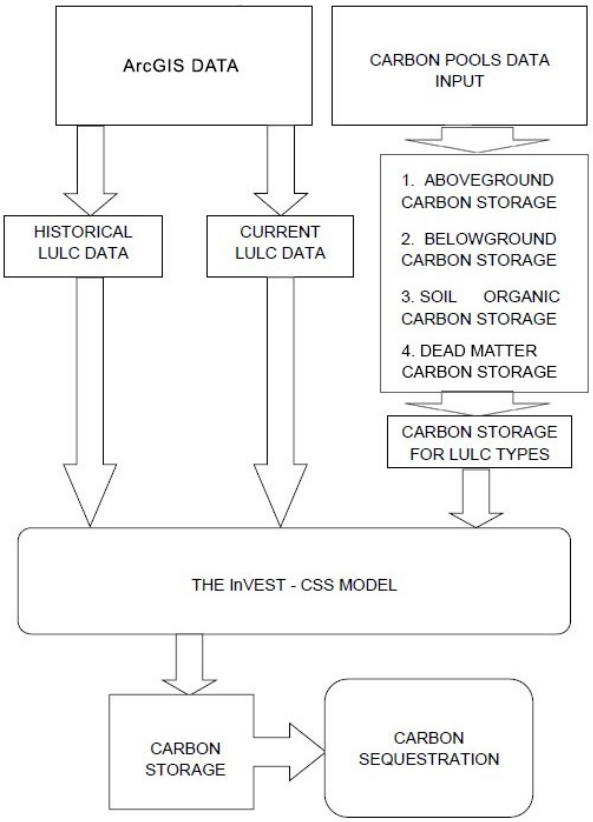


Figure 1 . Methodology of study

Figure 1 shows the various steps in the study. Data acquisition and processing is the first stage. In the next step land use/land cover and carbon density are mapped. The third and final step is the assessment of carbon storage using the InVEST model. These are described below.

Data Acquisition and Processing

As The InVEST model requires data on land use and land cover changes obtained from satellite images. Data on carbon in four carbon pools were also needed. The data was processed using ArcGIS software for the maps and Landsat images.

Mapping LULC Change

To achieve consistency, the landscape patterns were divided into six land use and land cover (LULC) categories: Water Bodies, Built-up Land, green areas, barren lands, wetlands and agricultural lands. Data on LULC changes for2004 and 2023 for the Kochi city was sourced from unpublished academic work (UEPS, 2023)

The InVEST-CSS Model

For estimating the volume of carbon sequestered in a given region, the InVEST Carbon Storage and Sequestration model (InVEST-CSS) is esternsively used. This primary advantage of this model is that it is an open-source software used to map and value the goods and service. Moreover, it is applicable across the globe, has a flexible scale and provides biophysical and economic outputs.

The InVEST-CSS Model is a geospatial tool developed by Stanford University to assess the impact of land use changes on carbon storage. It considers changes in atmospheric carbon dioxide due to human activities, affecting coastal ecosystems like wetlands. The model uses a simplified carbon cycle approach, summarizing carbon stored in different carbon pools and integrating carbon density data with LULC changes to quantify net changes in carbon stocks over time. The outputs show the dynamics of carbon stocks over time and estimate carbon sequestration potential. The

InVEST model also quantifies the value of carbon storage in wetlands and agricultural lands. The carbon pools in this study include aboveground biomass, belowground biomass, soil biomass, and dead carbon matter and the values applied in the assessment are shown in Table 1.

Table 1. Carbon Pool Table - Input feature for InVEST model (Source: Harishma et al., 2020)

TYPE	C_ABOVE	C_BELOW	C-SOIL	C_DEAD
WATERBODY	8.46	2.46	141.65	0.85
BUILT-UP	0.00	0.00	44.15	0.00
GREEN	1.19	2.37	63.42	0.06
BARREN	0.00	0.00	30.47	0.00
WETLANDS	8.5	1.95	131.61	0.95
AGRICULTURE	1.80	0.35	61.41	0.00

2.1 Study Area

Kochi, formerly known as Cochin, is a major port city located on the Malabar Coast of the Arabian Sea in the state of Kerala in southwestern India. It is considered the financial, commercial, and industrial capital of Kerala. Kochi spans an area of 94.88 km² (36.63 mile²) and is situated at the northern end of a narrow peninsula, approximately 19 km long and less than 1.6 km wide. The city has a coastline of 48 km and is surrounded by estuaries drained by perennial rivers from the Western Ghats.

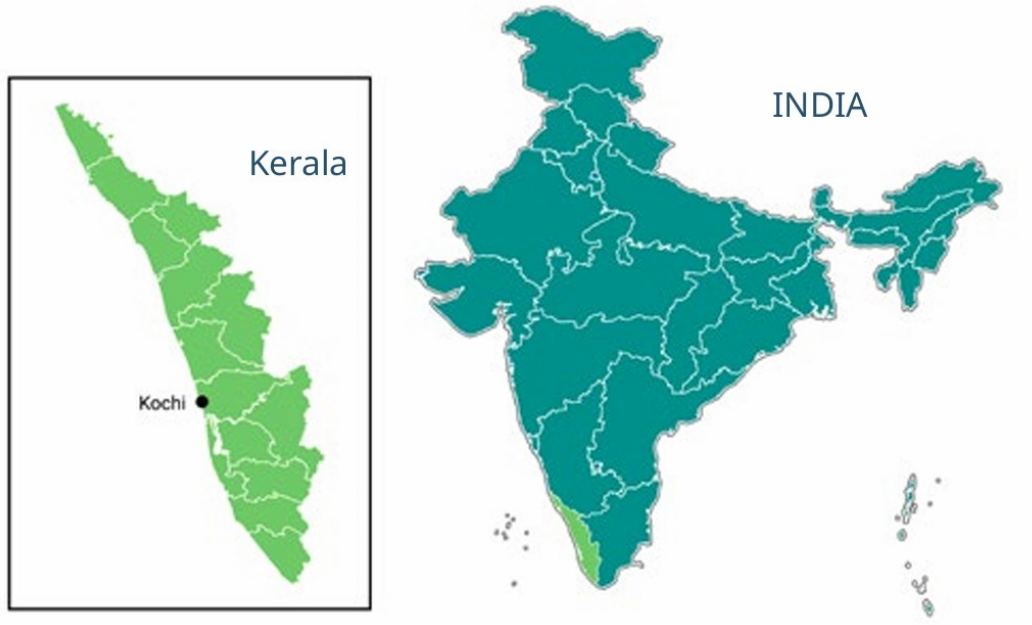


Figure 2. Map of study area location

Kochi City is experiencing rapid urbanization and development, which can lead to significant changes in land use patterns. These changes can result in the loss of natural habitats and the conversion of land from carbon-rich ecosystems to impervious surfaces, such as roads, buildings, and parking lots. This can significantly reduce the city's carbon sequestration capacity. (Minghao Lyu, 2023). Kochi's mangroves are a significant carbon sink, but they are heavily fragmented and under threat due to human activities like aquaculture and infrastructure development.

4. Results

LULC for the years 2003 and 2023 for Kochi city, India was taken adopting unsupervised classification method. Carbon pool data for paddy fields, wetlands and water bodies were taken and integrated into the InVEST interface. Land Use Land Cover map of Kochi city is shown in Figure 3 and Table 2 shows the decadal area change across land uses in Kochi city. The area of the wetlands has decreased from 45.03 sq. km to 18.5 sq. km. There is 58.8% reduction in the wetland area in 20 years. There is substantial increase in the built up area during the study period. It has increase from 29.78 sq.km to 65.99 sq.km. It is evident from the analysis that rapid urbanization is the major cause of the reduction in wetlands in Kochi.

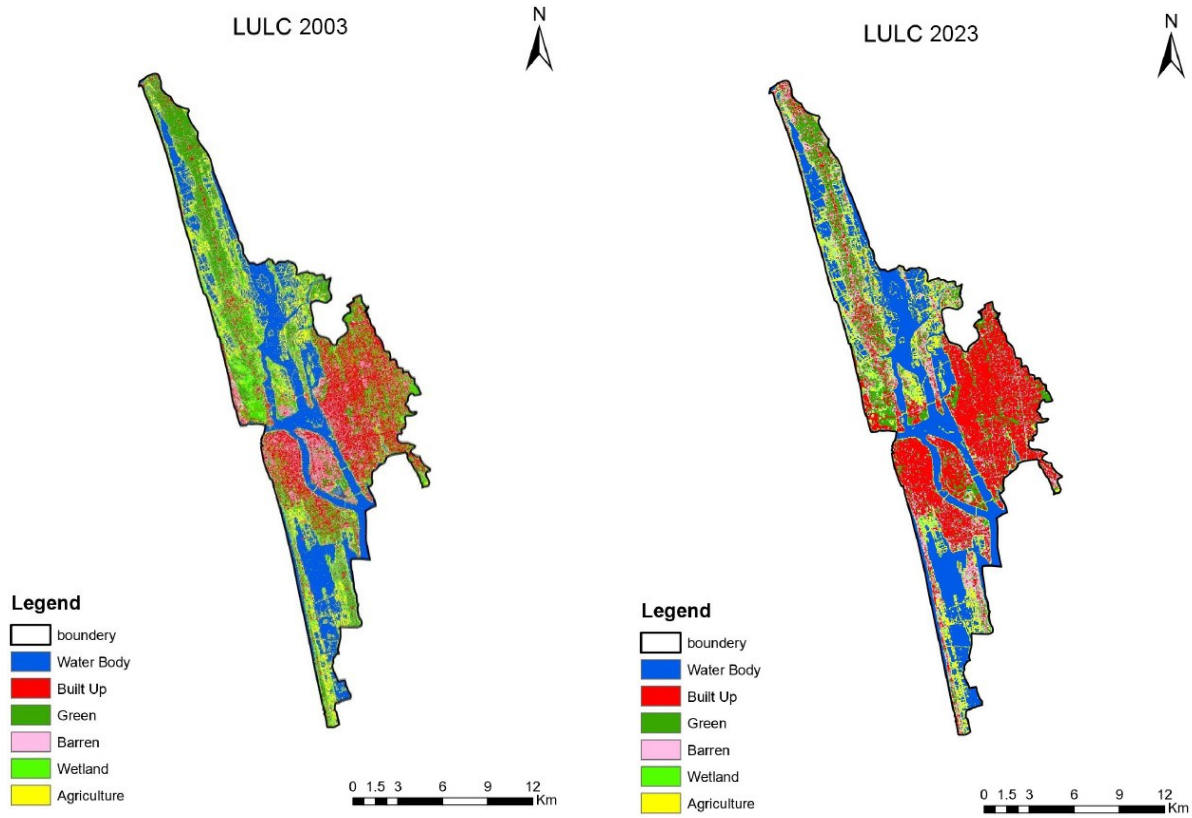
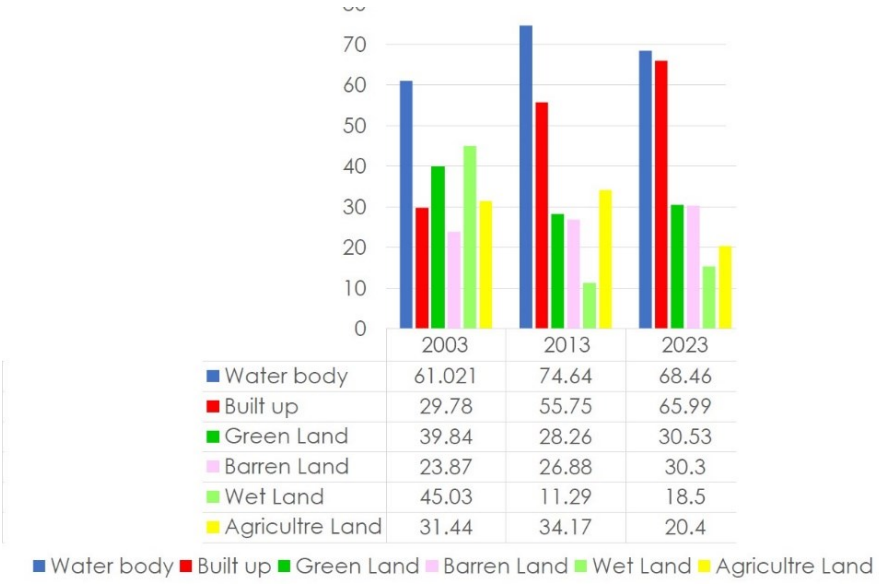


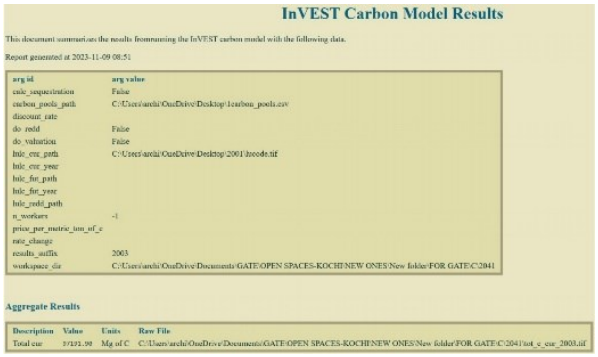
Figure 3. Land Use Land Cover map of Kochi city (source: UEPS, 2023**)**

Table 2 Decadal area change across landuses in Kochi city (Source: UEPS, 2023)



	2003	2013	2023
Water body	61.021	74.64	68.46
Built up	29.78	55.75	65.99
Green Land	39.84	28.26	30.53
Barren Land	23.87	26.88	30.3
Wet Land	45.03	11.29	18.5
Agricultre Land	31.44	34.17	20.4

The output of the analysis of carbon storage using InVEST model is shown in Figure 3.a. A total of 2,67,948 tonnes of carbon is sequestered in the year 2003 by the wetlands. However, this has been reduced to 97,191 tonnes in the year 2023 as shown in Figure 3.b. The 63.7% reduction in sequestration indicates colossal effects of rapid urbanization with alterations in land use. This clearly shows that the land use change is one of the largest sources of carbon emissions.


InVEST Carbon Model Results

This document summarizes the results from running the InVEST carbon model with the following data.

Report generated at 2023-11-09 08:51

arg id	arg value
calc_sequestration	False
carbon_pools_path	C:\Users\archi\OneDrive\Desktop\1carbon_pools.csv
discount_rate	
do_redd	False
do_valuation	False
lulc_cur_path	C:\Users\archi\OneDrive\Desktop\2001\lreclc.tif
lulc_cur_year	
lulc_fut_path	
lulc_fut_year	
lulc_redd_path	
n_workers	-1
price_per_metric_ton_of_c	
rate_change	
results_suffix	2003
workspace_dir	C:\Users\archi\OneDrive\Documents\GATE\OPEN SPACES-KOCHI\NEW ONES\New folder\FOR GATE\C2041

Aggregate Results

Description	Value	Units	Raw File
Total cur	97191.99	Mg of C	C:\Users\archi\OneDrive\Documents\GATE\OPEN SPACES-KOCHI\NEW ONES\New folder\FOR GATE\C2041\tot_c_cur_2003.tif

	2003	2023
Area of Wetlands in sq. km	45	18.5
Carbon sequestered in Tonnes	2,67,948	97,191

Figure 3: a) InVEST carbon model output. b) Carbon storage values in Wetlands in Kochi City

5. Discussion

Urbanization has had a significant negative impact on wetland ecosystems and has resulted in the permanent disappearance of wetlands. The chief threats to urban wetlands include draining and infilling for developments, solid waste disposal and wastewater pollution, channelization of rivers and streams, and loss of hydrological connection between the wetlands and water bodies. Urbanization has also led to a loss of biodiversity in wetlands by converting them into open public parks and recreational waterfronts. Understanding the impact of land use changes on these wetlands can inform conservation efforts and help protect these critical ecosystems.

The analysis of LULC for 2003 and 2023 in Kochi city reveals that the wetland area has reduced from 45.03 to 15.33 sq. kms. Rapid urbanization has resulted in a substantial reduction in wetland area and their sequestration capacity. The reduction of wetlands in Kochi by 58.8% is a result of complex issues driven by a combination of urbanization, infrastructure development, pollution, land use changes, and climate change. By understanding the impacts of land use changes on carbon sequestration in Kochi City, policymakers and urban planners can develop more effective strategies to reduce greenhouse gas emissions, increase carbon sequestration and contribute to global climate goals. (Ghosh, 2021)

A few recommendations that can be implemented to increase the carbon sequestration potential of wetlands are:

- To incorporate wetlands into urban planning and development strategies to ensure their protection and enhancement. This can include designating wetlands as protected zones and promoting nature-based solutions for climate change mitigation.
- To focus restoration efforts on areas that have experienced significant mangrove loss, such as those converted for aquaculture, as these habitats have low carbon sequestration potential. Restoring these areas can help increase the overall carbon storage capacity of Kochi's mangrove
- Engage local communities in wetland conservation and restoration efforts through education and awareness programs. This can foster a sense of ownership and stewardship, ensuring the long-term success of these initiatives.
- Explore funding opportunities through programs like the United Nations' Reducing Emissions from Deforestation and Forest Degradation (REDD) program to support wetland conservation and restoration efforts.
- Future research should focus on long-term monitoring of carbon sequestration in Kochi's mangrove habitats to understand the dynamics of carbon storage and burial rates over time. This can help assess the effectiveness of conservation efforts and restoration initiatives in maintaining and enhancing carbon sequestration potential.

6. Conclusions

Carbon sequestration is a critical component of climate change mitigation strategies. This study analysed the changes in one LULC typology i.e., wetland in a selected city due to its predominance in the landscape of south-western coast in India and its vulnerability to degradation and change. The study shows that due to multiples issues associated with urbanization in India, area of wetlands has been substantially reduced in the past 20 years i.e between 2003 an 2023. Thus, the findings of this study highlights the consequences of land use change on carbon sequestration. Efforts to conserve and restore remaining wetland areas are essential to maintain biodiversity, provide ecosystem services, and mitigate the impacts of urbanization and climate change on the environment and local communities. Thus, this study recommends the protection and enhancement of wetlands through various ways such as urban planning and development strategies, community involvement and monitoring of wetlands. Further, research can be carried out for various future scenarios of LULC change and their implications on carbon sequestration to develop effective climate change mitigation strategies.

Acknowledgements
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interests
The Author(s) declare(s) that there is no conflict of interest.

References
Forest Survey of India (n.d) Carbon Stock in India's forest, Ministry of Environment and Forest. Dehradun
Amen, M. A. (2021). The assessment of cities physical complexity through urban energy consumption. Civil Engineering and Architecture, 9(7). https://doi.org/10.13189/cea.2021.090735
Amen, M. A., Afara, A., & Nia, H. A. (2023). Exploring the Link between Street Layout Centrality and Walkability for Sustainable Tourism in Historical Urban Areas. Urban Science, 7(2), 67. https://doi.org/10.3390/urbansci7020067
Ghosh, S., (2021) Kochi's disappearing mangroves lock away significant carbon, Mongabay. [Online] Available at: https://india.mongabay.com/2021/04/kochis-disappearing-mangroves-lock-away-significant-carbon/
Harishma, K. M., Sandeep, S., & Sreekumar, V. B. (2020). Biomass and carbon stocks in mangrove ecosystems of Kerala, southwest coast of India. *Ecological Processes*, *9*, 1-9.
Kamarajugedda, S. A., Johnson, J. A., McDonald, R., & Hamel, P. (2023). Carbon storage and sequestration in Southeast Asian urban clusters under future land cover change scenarios (2015–2050). Frontiers in Environmental Science, 11, 1105759.
Minghao Lyu, Y. Z. Y. W. J. L. S. W., 2023. The Impact of Land Use Changes on Carbon Flux in the World's 100 largest cities. MDPI, Sustainability, 15(12497), p. 22.
Rajaa Aitali, M. S. A. S. K. B. O. N. M., 2022. Effects of Land Use/Land Cover Changes on Carbon Storage in North African Coastal Wetlands. Journal of Marine Science and Engineering, p. 22..
Urban Environmental Planning Studio (2023) Land use and land cover change, Resilient and sustainable development planning: A Case Of Kochi, Kerala, School of Planning and Architecture Vijayawada, Unpublished academic work.
Watson, R. T., Noble, I. R., Bolin, B., Ravindranath, N. H., Verardo, D. J., & Dokken, D. J. (2000). Land use, land-use change and forestry: a special report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
Zheng, H. Z. H., 2023. Assessment and prediction of carbon storage based on land use/land cover dynamics in the coastal area of Shandong Province. Elsevier, p. 12.