MODELLING AND PREDICTION OF THE IMPACT OF CLIMATE CHANGE ON "BLUE CARBON " ECOSYSTEM SERVICES PROVIDED BY TROPICAL MANGROVES, EAST COAST OF INDIA

By

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(2018-20-020)

THESIS

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DECLARATION

I, Sreelekshmi M (2018-20-020) hereby declare that this thesis entitled **"Modelling and prediction of the impact of climate change on 'blue carbon' ecosystem servicesprovided by tropical mangroves, East Coast of India"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"Modelling and prediction of the impact of climate change on 'blue carbon' ecosystem services provided by tropical mangroves, East Coast of India"** is a record of research work done independently by Ms. Sreelekshmi M, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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SYMBOLS AND ABBREVATIONS

AR 6	Sixth Assessment Report
CBC	Coastal Blue Carbon
DBH	Diameter at Breast Height
ERDAS	Earth Resource Data Analysis System
ES	Ecosystem services
ESV	Ecosystem service valuation
ETM	Enhanced Thematic Mapper
EUA	European Emission Allowances
GIS	Geographical Information System
GMSL	Global Mean Sea level
GST	Global Surface Temperature
GtC	Gigatonnes of carbon
InVEST	Integrated Valuation of Ecosystem services and Trade-off
IPCC	United Nations Intergovernmental Panel on Climate Change
LULC	Land use and Land cover
MISHTI	Mangrove Initiative for Shoreline Habitats & TangibleIncomes
MOEFCC	Ministry of Environment, Forest and Climate Change
MSSRF	M. S. Swaminathan Research Foundation
NAMAs	Nationally Appropriate Mitigation Actions
NCC	No Carbon Change
OLI	Operational land imager
RCP	Representative Concentration Pathway
REDD	Reducing emissions from deforestation and forest degradation
SCC	Social Cost of Carbon
SLR	Sea Level Rise
TEEB	The Economics of Ecosystems and Biodiversity

UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS 84	World Geodetic System 1984
ρ	Wood density

CHAPTER 1

INTRODUCTION

Blue carbon refers to carbon from atmospheric carbon dioxide that has been absorbed and fixed in the ocean. and blue carbon in this case, it is comparable to the "green carbon" fixed by the Earth's ecosystems. Carbon sequestered by coastal plants such as marshes, mangroves and sea grasses has been called coastal blue carbon (Mcleod et al., 2011; Zhang et al., 2015; Howard et al., 2017). Globally, blue carbon sequestration accounts for approximately 1.3% (38.5 ± 19 TgC y-1) of the Earth's total carbon sequestration, but covers less than 0.4% of terrestrial land (Taillardat et al. 2018). Bluecarbon sequestration in marshes is the highest at 24226 gC m2a-1 (Ouyang and Lee 2014), followed by mangroves (16836 gC m2y-1 (Alongi, 2012) and seagrasses (83 gCm2a-1 (Duarte et al. 2005).

Ecosystem services (ES) are the convenience, advantages, and a variety of services and goods derived from natural ecosystems or natural capital that are essential for human well-being, livelihood, and survival (Coastana et al., 1997; Braat et al., 2012). Ecosystem service valuation (ESV) denotes the monetary worth of various ecosystem services given by the ecosystem as well as the natural environment. Mangroves provide a wide range of ecosystem services to humanity, both locally and globally (Millennium Ecosystem Assessment, 2005; Russi et al., 2013). The costal mangrove region is a completely different ecosystem region that can extensively provide various regulatory services (waste treatment, protection from storm surges and tropical cyclones, habitat provision etc.), provisional services (fish, timber and non-timber product, honey etc.), supporting services (biomass production) and cultural services (De Groot et al., 2002). Although the majority of these benefits are not recognised in current markets, they havedemonstrated to have a significant economic worth. Salem and Mercer (2012), estimate mean economic values for services including entertainment and tourism ($37,927/ha/yr), fisheries ($23,613 ha^{-1} yr^{-1}), coastal preservation ($3,116 ha^{-1} yr-1), and carbon sequestration ($967 /ha/yr). According to other research, the overall economic value of mangroves ranges from $13,819 ha^{-1} yr^{-1} (UNEP/GPA, 2003) to $22,526 /ha/yr (Chong,2006). Mangrove loss has an ecological impact on the landscape as a result of thelossof physical structure, as well as a socioeconomic impact as a result of the loss of benefits offered to local populations (e.g., food, coastal protection) and the world population asa whole (eg. Climate regulation).

Mangroves are a type of unique vegetation that mostly consists of Rhizophoraceae species that live in the tidal zone of tropical and subtropical coastlines. Mangroves are found in coastal wetlands between 32° S and 32° N. Mangroves cover roughly 132000 km^2 globally, accounting for 0.4% of the total land surface. Mangroves, which have a robust root structure, are the first line of defence for coastal shelterbelts and vital habitats for seabirds, fish, and shrimp, helping to preserve coastal ecological balance (Lin, 2001). The global carbon sequestration capability of mangrove wetlands has been reported to be 0.18 Pg C per year with the average soil carbon storage in tropical mangrove wetlands up to 3 metres in depth in Southeast Asia reaching 102.3 kg C per m^2 (Donato et al., 2011). The most recent data from the United Nations Intergovernmental Panel on Climate Change (IPCC AR6, 2022) February 2022 showed that global temperatures have increased by 1.09°C. The state of world mangrove 2022 report by the Global Mangrove alliance puts, the total mangrove cover of the world at 147000 Sq. Km (14.7 million hectors). Urbanization, economic development and socio-cultural factors are dramatically changing natural habitats around the world. The most productive and biodiverse coastal habitats, including mangrove forests, are vulnerable to these changes (Dou et al. 2021; Kadaverugu et al. 2021a). According to Alongi et al., mangroves can store organic carbon up to 900 Mg ha^{-1}, which is almost four times more than swamps (600 Mg ha^{-1}) and seagrass meadows (200 Mg ha^{-1}). Presently, several primary and secondary driving factors such as biophysical (climate change, changes in soil properties, plant inherent structure, composition etc.) and anthropogenic (land degradation, land use change etc.) are more responsible for the devaluation of ecosystem services (Chen et al., 2019; Marx et al., 2019). Climate change has significant impacts on blue carbon stocks and fluxes in mangrove forests. Extreme weather events, increasing temperatures, and sea-level rise can result in carbon stock losses and declines in carbon cycling and export. However, mangrove reforestation and restoration could be a potential solution for ameliorating CO_2 emissions in climate mitigation projects. Among the driving factors, human induced land use change is the most eventual factor for the reduction of ESVs (Wang et al., 2018). The worldwide restoration of ecosystems and their services will be critical to attaining the UN 2030 Agenda for Sustainable Development's Sustainable Development Goals.

Mangroves in India are one of the richest biodiverse mangroves in Asia. Their existence is threatened by increasing anthropogenic and climatic factors. According to Chowdhury et al. (2019), the Sundarbans mangrove forest can sequester around 4.71-6.54 Mg C ha^{-1} $year^{-1}$ carbon. The Sundarbans region has two eco-regions: wetlands and mangroves, although these fresh water swamps have been extinct in recent years due to the rapid growth of agricultural lands and fisheries (Ghosh and Mondal, 2016). The current assessment shows that mangrove cover in India is 4992 sq.km which is 0.19 % of the country's total geographical area. Very dense mangroves comprise 1475 sq. km of the mangrove cover moderately dense mangroves is 1481 sq.km while open mangroves constitute area of 2036 sq.km. There has been a net increase of 17 sq.km in the mangrove cover in country as compared to 2019 assessment. The Convention on Wetlands (Ramsar Convention), signed in 1971, provides a framework for the preservation and responsible use of wetlands, including mangroves. By designating wetlands of international importance and adopting measures for their conservation and management, the parties of the convention aim to preserve these important ecosystems. Mangroves play a role in mitigating the effects of climate change by serving as a sink for carbon dioxide. As a result, the UNFCCC includes provisions for conserving and enhancing carbon sinks, including mangroves, through initiatives such as REDD+. Finance minister of India, announced 'MISHTI', a new scheme for mangrove plantation along India's coasts, in her Union Budget speech on February 1, 2023. An initiative like MISHTI is in line with India's Nationally Determined Contributions announced by MOEFCC to create an additional carbon sink of 2.5-3 billion tons of carbon dioxide CO_2 equivalent, through additional more forest and tree cover by 2023. India joined h mangrove alliance for climate, at 27th conference of parties in Egypt.

Management operations that alter the cover of coastal vegetation, such as seagrass restoration and mangrove forest cutting, alter the potential of coastal and marine ecosystems to store and absorb carbon. The InVEST (Integrated Valuation of Ecosystem services and Tradeoff). Coastal Blue Carbon model seeks to forecast the quantity of carbon stored and sequestered across a coastal zone at specific times in time as a result of land cover changes. InVEST Coastal Blue Carbon model measures the marginal value of storage and sequestration by using an estimate of the monetary social value or, if available, a market price for stored and sequestered carbon. The model is particularly suitable for decision-makers and researchers to compare multiple development scenarios and their trade-offs for ecosystem services. Results of the InVEST Coastal Blue Carbon model can be used to compare current and future scenarios of carbon stock and net sequestration, as well as identify locations within the landscape where degradation of coastal ecosystems should be avoided and restoration of coastal ecosystems should be prioritized in order to preserve and enhance these carbon storage and sequestration services.

Under these circumstances objective of this study is to predict the changes in mangrove regulatory services in Bapatla district Andhra Pradesh. Also estimate the carbon stock of planted and natural mangroves in the study area

CHAPTER 2

REVIEW OF LITERATURE

2.1 COASTAL BLUE CARBON

Global climate change is one of the greatest concerns confronting people in the 21st century. Main reason is the large emissions of greenhouse gases (GHGs) from human activity, particularly CO_2 created by burning fossil fuels during the previous century. According to Nellemann et al. (2009), ocean blue carbon refers to the carbon from atmospheric CO_2 that has been absorbed and fixed in the ocean. The "blue carbon" in this case is comparable to the "green carbon" that fixed by the terrestrial ecosystems. The carbon retained by coastal plants, such as salt marshes, mangroves, and seagrasses, has been referred to as coastal blue carbon in recent years (Mcleod et al., 2011; Zhang et al., 2015; Howard et al., 2017). The salt marshes, mangroves, and seagrasses' high production and controllability are the fundamental causes of this restrictive definition. Large productivity refers to the fact that these three coastal ecosystems have a carbon sequestration capability that is around ten times greater than that of terrestrial ecosystems (Mcleod et al., 2011). The term "high productivity" pertains to the fact that these three coastal ecosystems may sequester 10 times more carbon than terrestrial ecosystems (Mcleod et al., 2011). Despite accounting for only 0.2% of the ocean's surface area, these ecosystems store more than half of the total carbon deposits in marine sediments (Duarte et al., 2013).

The goal of the United Nations Decade on ecological Restoration 2021-2030, proclaimed in March 2019 by Resolution 73/284, is to prevent, stop, and reverse global ecological decline. All UN Decade projects are aimed at both maintaining and restoring ecosystems (UNEP, 2020).

Tropical forest zones contribute significantly to the global carbon cycle and equilibrium, accounting for around 40% of terrestrial NPP (net primary production) (Clark et al., 2001).Mangrove forest communities are especially common in tropical and subtropical climates' coastal and estuarine regions, and these forests play an important role in the region's socioeconomic and ecological patterns by contributing coastline development and protection, acting as a nutrient filter, and providing a variety of material services (Costanza et al., 1997; Vermatt and Tampanya, 2006).Landward range expansion is the primary element that might have a positive impact, with a possible increase in net global carbon storage of 1.5 GtC by 2100 (Lovelock and Reef, 2020) under the high emissions scenario, RCP 8.5. The worst-case scenario projected losses of 3.4 GtC by 2100 if such a landward expansion is not feasible. All three Working Group reports for the IPCC AR6 cycle expressly address CBCEs, with WG II coverage highlighting their co-benefits and sensitivity to climate change and direct human consequences (Parmesan et al., 2022; Cooley et al., 2022).

The AR6 WG III report evaluates the status and function of "blue carbon management in coastal wetlands" and "peatland and coastal wetland restoration" as independent methods in a NET summary table.

2.2 MANGROVES

In the tidal zone of tropical and subtropical coasts, mangroves are a type of unique flora made up primarily of Rhizophoraceae species. Mangroves are inherently capable of adapting to sudden variations in anoxia, temperature, salinity, freshwater intake, and tides. These drives impose structural and functional limits, promote physiological processes for adaptation, and make it easier to withstand in a harsh saline, low-oxygen environment (Alongi et al., 2016). Mangrove ecosystems are distinguished by a diverse range of marine, estuarine, and semi-terrestrial organisms that create distinctive food webs and perform a variety of functions in the coastal zone by connecting food webs and the flow of energy, inorganic and organic materials, geochemical cycles, and biogeochemical cycles from the shoreline to the nearby coastal ocean. Mangrove wetlands have been the subject of studies on carbon storage and sequestration in recent years. Some of these studies also looked into the mechanisms that regulate carbon cycling in mangrove wetlands in order to make scientific recommendations for the protection and utilization of mangrove wetlands. The average soil carbon storage in tropical mangrove wetlands up to 3 meters in depth in Southeast Asia was as high as 102.3 kg C m^2 (Donato et al., 2011). Mangrove wetlands have been claimed to have a worldwide carbon sequestration potential of 0.18 Pg C yr^{-1}.

Mangrove deforestation was mostly caused by coastal erosion, the establishment of cities, the production of commodities (such as aquaculture and agriculture plots), mangrove clear-cutting operations, or death due to harsh weather occurrences (Goldberg et al.,2020).

2.2.1 Ecosystem services of Mangroves

Mangroves provide many valuable ecosystem services that contribute to human well- being, including provisioning (e.g. timber, firewood and charcoal), regulation (e.g. control of floods, storms and erosion; prevention of saltwater intrusion), habitat and cultural services (eg recreation, aesthetics, non-use) (Spaninks and van Beukering, 1997;UNEP,2006;TEEB,2010).

Many of these ecosystem services have the characteristics of 'public goods,' in that the people who benefit from them cannot be excluded from receiving the service provide d (e.g., habitat and nursery services supporting fisheries); and the level of consumptio n by one beneficiary does not reduce the level of service received by another (e.g., coa stal protection and storm buffering). These qualities restrict the ability for private incentives to manage the mangrove ecosystem services sustainably, and there are no marketplaces for such services. In other words, there is a "market failure" as the market system is unable to adequately supply the ecological services provided by mangroves. Mangroves are hence typically given insufficient consideration in both private and governmental decision-making pertaining to their usage, protection, and restoration. Using a meta-analysis of the economic valuation literature and the estimated value function, Brander et al. (2012) determined the value of mangroves in Southeast Asia. Under a baseline scenario of mangrove loss over the years 2000–2050, the meta-analytic value function is used to calculate the change in value of mangrove ecosystem services in Southeast Asia. With a projection range of US$1.6-2.8 billion, the anticipated yearlybenefits lost are $2.2 billion in 2050.

Spatially explicit valuation, transfer, and modelling are shown to be beneficial to its cost and time advantages as geospatial research and technology improve in the field of ESs studies. The market pricing and benefit transfer methodologies are just two of the many methods that have been developed for the precise estimate of ecosystem services. Blue carbon, which is predominantly absorbed by mangroves and tidal marshes in coastal locations, has drawn considerable attention from environmentalists. Regarding the decline in carbon storage and changes to the ecosystem services values for the mangrove ecosystem of the Indian Sundarbans, certain pertinent theories have been taken into account. Such a fast decline in carbon storage and ecosystem service values may be caused by natural (coastal storm, sea level rise, increase in sea surface temperature and salinity, etc.) as well as anthropogenic (human encroachment and loss in sediment and sweet water supply) reasons.

2.3 CLIMATE CHANGE IMPACT ON MANGROVES

2.3.1 Sea level rise

Rising sea levels caused by warmed seas and melting glaciers are probably the major threat to the longevity of mangrove forests. According to Global Sea level (GMSL) rise 0.2 m between 1901 and 2018, increasing at a 1.7 mm per year rate between 2006 and 2018, and rising beyond 2300. SLR-induced submergence will probably have a significant effect on mangrove carbon stores and fluxes. An increase in peat deposits will lead to a net increase in the carbon burial of significant amounts of dissolved and particulate carbon once the available nutrients and oxygen are depleted and the trees are dead. As the dying aboveground biomass decomposes, a significant amount of forest litter will initially be exported to the nearby rising sea. Initial necromass (a large, dynamic and persistent component of soil organic carbon) will decompose and release CO_2 and CH_4 to the atmosphere and tidal water. Until all the bioavailable nutrients are depleted, volatile soil carbon will continue to be mineralized. Live belowground roots of trees that have been submerged will progressively start to rot as well, killing the trees and causing peat and soil to collapse right below the root zone. In subtropical and tropical regions, warm temperatures and SLR are promoting the latitudinal spread of mangroves into salt marsh habitat. Increased soil carbon concentrations and blue carbon build-up in the newly colonised mangroves have been reported as a result of the invasion of mangroves into previously dominated marsh habitat. (Kelleway et al, 2016; Rogers et al 2019). Buffington et al., 2021 used empirical data from soil elevation, accretion rates, forest inventories, water-level monitoring, and differential levelling elevation surveys to undertake modelling research to determine which locations and mangrove ecosystems are most vulnerable to SLR. Mean elevation and community composition responses were examined under four SLR scenarios (37, 52, 67, or 117 cm by 2100). Through 2060, the model predicted mangrove survival in comparison to the 37 and 52 cm scenarios, with minimal relative gains in more flood-tolerant species. *Sonneratia alba* and *Rhizophora stylosa* will gain relative dominance for 30-40 years before dropping, but *Bruguiera gymnorrhiza, Xylocarpus granatum, and Rhizophora apiculata* will decrease in most circumstances.

2.3.2 Rising Temperatures, Increased Storms, Extreme Weather Events, and Precipitation Changes

Since 1850-1900, the increase in global surface temperature (GST) was 1.09 (range: 0.95-1.20) ◦C from 2011 to 2020, with a further projected 1.5 ◦C increase between 2021- 2400 and a very likely breaking of the 2 ˚C threshold during the 2040-2060 a period of time. In most situations, mangroves will respond favourably to expected increases in air and sea temperatures, up to a critical threshold. According to Alongi et al., 2021, Warmer temperatures have an impact on mangroves by (1) changing species composition, (2) modifying physiological processes, and (3) enhancing primary productivity and ecosystem respiration to critical levels, and (4) expanding Species ranges to higher latitudes where range is limited by temperature but not by other factors (Alongi et al., 2021). Temperature increases may also reduce survival in dry and semi-arid environments. (2) increased water vapour deficit, (3) enhanced secondary production, and (4) changes in species dominance and diversification. The continuing expansion of mangroves into higher latitudes in the Gulf of Mexico, Florida, New Zealand, Australia, southern China, and southern Africa may compensate for blue carbon losses caused by temperatures above the critical threshold (Cavanaugh et al., 2015). Obviously, new mangroves increase biomass and soil carbon, though the latter is dependent on freshwater availability, soil moisture, hydrologic regime, salt marsh, and mangrove species and productivity, as well as the presence of well-developed soils prior to replacement by larger mangrove forests (Yando et al., 2016). Many regions where mangroves are replacing less productive or marginal salt marshes, particularly in dry areas, have high increases in soil carbon stores with mangrove invasion, although major growth of mangrove soil carbon stocks may take time (Raw et al., 2019). Carbon fluxes differences between salt marshes and invading mangroves are poorly understood, with studies revealing varying findings across the ecotone (Simpson et al., 2019; Lewis et al., 2014). While mangrove expansion into salt marshes appears to be predominantly driven by rising temperatures and a decrease in the frequency of extreme cold events, changes in precipitation patterns and an increase in storm frequency cannot be ruled out as co-factors.

Hansen et al., 2012 point out that Extreme weather phenomena such as droughts, hurricanes, and cyclones have become more often and intense as temperatures have risen. The growing prevalence of such catastrophes, particularly more frequent instances of mass mortality, is having a severe impact on mangroves. The clearest illustration of such an event is the huge dieback of mangroves in Australia's Gulf of Carpentaria, when 6-10% of the forests died back along 1000 km of shoreline during the summer of 2015-2016 (Lovelock et al., 2017). According to the study of Abhik et al., 2021 and his co-workers an unusually long severe drought, along with a brief reduction in sea level caused by the 2015-2016 El Nino, contributed to the mass mortality. In terms of mangrove carbon cycling, cyclones have similar effects because they cause broken trees, canopy gaps, large amounts of downed woody debris, and irregular surface soil distributions with alternating areas of smothering and scouring of the forest floor, as well as increased soil anoxia (Krauss and Osland, 2020). According to Krauss and Osland, worldwide forest mortality due to cyclone damage averages 40% (range: 13-67%). Rainfall patterns are altering in the subtropics and tropics, with weaker monsoons but more frequent and heavy rainfall in portions of Africa, South Asia, and Southeast Asia. High rainfall often results in more luxuriant and productive mangroves, and hence more blue carbon, because mangrove canopy height is directly related to rainfall, temperature, and cyclone frequency globally (Simard et al., 2019).

2.3.3 Rising Atmospheric CO_2

Mean atmospheric CO_2 concentrations have risen from 326 ppm to 416 ppm in the last 50 years and continue to rise (IPCC, 2021). CO_2 increases mangrove photosynthesis, growth, respiration, and leaf chlorophyll concentrations, with species-specific and complex responses due to interactions with other factors like as salinity, temperature, nutrient availability, and water-use efficiency [Adame et al., 2021; Alongi et al., 2021). Most mangrove species will respond positively to rising CO_2 levels, while others will respond poorly or show little or little change. In greenhouse trials, for example, growth of *Avicennia germinans* seedlings was boosted only under higher CO_2 and high nutritional circumstances, whereas root growth quadrupled under low nutrient and elevated CO_2 conditions (Reef., 2016).

2.4 CHALLENGES OF CONSERVATION

The emphasis on protecting and restoring wetlands for their function in carbon sequestration and storage has increased along with the body of information on mitigating climate change (Crooks et al. 2011). The political context in which conservation occurs still presents a number of challenges, including institutional challenges (Buckley 2015), funding challenges (McCarthy et al. 2002), opportunity costs (Adams et al. 2010), and challenges in linking socio-ecological systems involving governmental organisations, for-profit businesses, and community stakeholders to ecosystems, functions, and services. Human decisions have contributed to the issues of habitat loss and degradation, but they also hold the key to successful conservation. The traditional biological conservation method has recently given way to a more community-based and people-centered approach to conservation (Brown 2003). Through more integrated management approaches, governments and scientists are progressively adopting novel conservation measures (Arkema et al. 2015). These coordinated initiatives (Tallis et al. 2008; Ruckelshaus et al. 2013) have highlighted the importance of research and policy in preserving ecosystem services that support human socioeconomic well-being and have addressed the conservation and development objectives. First-order analysis is frequently what decision makers require to direct research to policy decisions, even if there are many methods available to employ ecosystem services techniques to support decision making (Ruckelshaus et al. 2013).

Today, a variety of governmental instruments, consumer and business options, and international processes are available to potentially improve conservation outcomes in terms of blue carbon conservation. These include financial incentives, carbon markets, offsets, and payments for ecosystem services (Wunder 2014), in addition to non-market options like international multi-lateral mechanisms like the United National Framework Convention on Climate Change (UNFCCC), "Nationally Appropriate Mitigation Actions" (NAMAs), and Reducing Emissions from Deforestation and Degradation (REDD) (Ullman et al. 2013). Because these strategies might be more or less applicable in different settings, it is necessary to develop and share a portfolio of blue carbon policy and conservation choices. This will provide decision-makers with the tools and data they need to use this information to effectively fulfil their objectives.

2.5 InVEST COASTAL BLU CARBON

InVEST Coastal Blue Carbon model attempts to estimate amount of carbon that will be stored and sequestered in coastal areas for a specific period of time as a result of changes in land cover. Coastal Blue's Carbon InVEST model also calculates the relative benefits of storage and distribution using estimates of social value or, in some cases, market value for stored and sequestered carbon. Results from the InVEST Coastal Blue Carbon model can be used to compare current and future carbon stocks and net emissions, and to identify areas where it is necessary to prevent damage to coastal ecosystems. and lead to their restoration so that he can restore them. to support and improve these carbon storage and sequestration projects. InVEST is used to assess how human activity and climate change have affected coastal ecosystems, according to Harley et al. (2006). Analysis of these disturbances is necessary to choose responses to climate change based on the protection and management of essential ecological services. Many river management strategies (Duarte et al. 2013b; Karim et al. 2019; Sutton-Grier and Sandifer 2019; Wu et al. 2020) have been developed worldwide to protect (restoration and protection) coastal environments in response to Article 4.1 d) United Nations Framework Convention on Climate Change (1992 UN Framework Convention). These concepts can be effectively incorporated into the yet-to-be-developed financial and legislative framework for effective ocean management. The economic benefits of blue carbon in coastal areas were identified in a study by Kacem et al. (2022) in the Moulay Bouselham Lagoon (MBL), Morocco, examines changes in carbon storage over 49 years in response to land-cover and land-cover (LULC) changes. Based on the results, there are 94 different types of LULC changes between 1971 and 2020, most of which include the conversion of wetlands and juncus to grasslands and the expansion of non- water areas, especially dunes region, in the absence of aquatic habitat. Contributing to these changes is the ability of coastal ecosystems to sequester and store carbon dioxide, estimated at 1.47 Mt C CBCS in 2020. Based on the current calculation of European emission Allowances (EUA), Social cost of carbon (SCC) and CO2, the economic valueof CBCS could between $371,053 and $3,803,295 per year, and the loss would be between $371,053 and $3,803,295(10,127 and 103,806 per year). According to this study, CBCS payments can accelerate wetland restoration with positive effects on climate change.

According to research by R. Kadaverugu et al. (2021), the mangrove ecosystem services (ES) in Odisha State, on India's east coast, were quantified. Additionally, they used scenario analysis to forecast the changes in ES based on probable future changes in land use. On the basis of key informant interviews and participatory surveys with the region's stakeholders, realistic future scenarios (by 2030) have been generated. The possibilities include climatic change, socioeconomic development, infrastructure expansion, and agriculture and aquaculture growth. The InVEST (Integrated valuing of ecosystem services and trade-offs) model was used to calculate the amount of coastal blue carbon sequestration, sediment retention and export, and nutrient export. The findings suggest that by 2030, disturbances to the mangrove forests in Odisha could emit 2.16 Tg C into the atmosphere. Mangroves have the potential to absorb up to 1.55 Tg C of carbon dioxide from the atmosphere. A maximum reduction in sediment and nutrient export of 24.9% and 7.6%, respectively, has been achieved by increasing mangrove and green cover.

The capacity of ecosystems to store carbon has been considerably impacted by changes in land use and land cover (LULC), which may ultimately have a large impact on global climate change.

The interactions between coastal wet lands and land reclamation can be fully revealed by LULC change, driving process, and response of essential ecosystem services, even though little is known about them in coastal regions (Costanza et al., 2017; Quintero- Gallego et al., 2018; Rindfuss et al., 2008). A previous study (Minta et al., 2018) examined the evolution of various LULC types across time. It may be more beneficial to take into account the cumulative transformation across LULC kinds at all times to comprehend their gain and loss throughout the LULC transformation spanning numerous time periods throughout the entire research period (Mallinis et al., 2014). The social cost of carbon ranged from $12 to $60 per tonne, with a mean value of $26 (converted from the original price in 1995) (Plambeck and Hope, 1996), and additional results from the PAGE2002 model, which gave a range of $4 to $51 per tonne, with a mean value of $19 (in year 2000 prices) (Hope, 2011). These results were published results from the PAGE95 model.

CHAPTER 3

MATERIALS AND METHODS

3.1 STUDY AREA

The (i) landward boundary and (ii) coastal alongshore boundary were used to determine the study boundaries. The research area's landward limit for the Baptala stretch extends up to the composite hazard line marked in the report on the Andhra Pradesh Coastal Zone Management Plan As Per CRZ Notification, 2011 report. The hazard line drawn by the MoEFCC through the Survey of India (SOI) taking into consideration tides, waves, sea level rise, and shoreline alterations has been used to identify coastal areas likely to be affected over the long term. The hazard line marks the boundaries of land regions that are vulnerable to coastal floods and erosion (the flood line). The "Composite Hazard Line" would display the flood and erosion lines that are furthest from the coast. The administrative border of the Baptla District in Andhra Pradesh served as the only limit for the coastal alongshore boundary.

Krishna Delta's 74 km of shoreline in the Bapatla region (15.896622o N, 80.460434o E) was deemed to be somewhat risky. The Bapatla region, with its 405 sq km of forest cover and 67.97 sq km of mangrove forests, is renowned for its abundant biodiversity. 1600 Sq. km is the size of the study's area. For the study, dense mangroves in the Kothapalem region and planted mangroves in the Nizampatnam region were both taken into consideration.

The Nizampatnam Reserve Forest (RF), which spans 800 38 to 800 40 E and 150 52 to150 54 N, is the largest reserve forest area in Andhra Pradesh. Backwater canals and the influent canal of the Krishna River, which drains into the Bay of Bengal, are reticulated throughout the entire region.

Kothapalem RF: This R.F. has a total area of 1553.91 ha, of which only 285 ha are covered with robust mangroves. Near Vasalsinkkalava, large tracts of degraded patches have been transformed for aquaculture. Along the canals of Kothapalem R.F., dense vegetation may be found. This vegetation includes Avieennia marina, Rhizophora apieulata, R. mucronata, Bruguiera eylindriea, B. gymnorrhiza, and Xyloearpusgranatum.

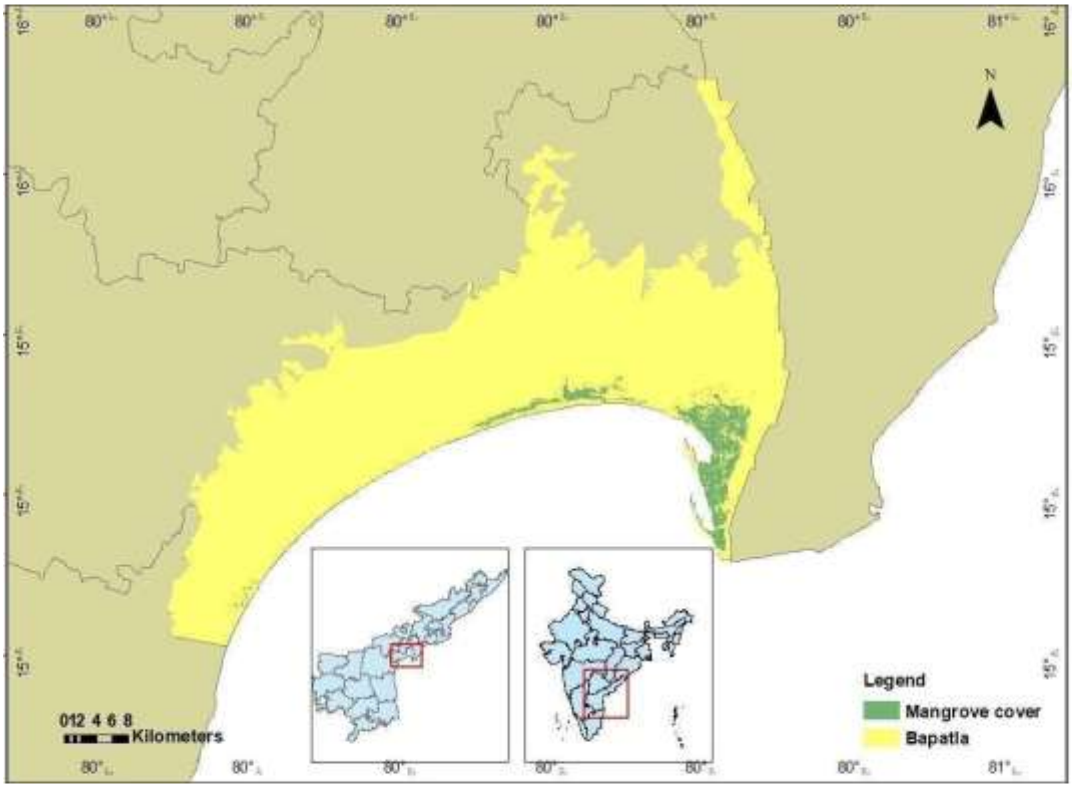


Fig.3.1: Map showing the study area with Mangrove cover

3.2 FIELD SAMPLING AND MEASUREMENT

3.2.1 Field sampling:

A non-destructive stratified random quadrat sampling technique was used to create a total of 9 sampling plots, each measuring 10 m × 10 m, in order to assess the carbon stock, tree density, and mangrove type. Using a Global Positioning System, GPS (Garmin GPS map), each sampling site's precise location was marked, and the location of each quadrat was recorded spatially.

Table 3.1. Study station and Geo spatial location

Sectors	Number of Quadrat	GPS Location
Poguru	1	15°51' 6.84"N 80° 31' 52.29" E
Kothapalem	1	15°52' 35.27"N 80° 48' 31.20" E
	2	15°52' 35.27"N 80° 48' 31.20" E
	3	15°51' 34.08"N 80° 49' 48.72" E
	4	15°51' 21.36"N 80° 48' 12.06" E
Nizampatnam	1	15°53' 48.36"N 80° 38'33.60" E
	2	15°53' 4.03"N 80° 38' 33.76" E
	3	15°53' 2.34"N 80° 38' 33.90" E
	4	15°53' 48.54"N 80° 39' 17.40" E

Fig 3.2: Sampling location of Bapatla

3.2.2 Tree measurements

All the mangrove plants/trees of each study quadrat were measured for their tree girth. The tree girth measurements were taken at breast height, which is approximately 1.3 m above the ground; and the girth measurements were converted into diameter at breast height (DBH) measurement by dividing by π (Frontier Madagascar, 2005). All adult trees as well as saplings greater than 1.3 m height were considered for measurement of DBH. The plants greater than 4 cm girth at breast height and taller than 1 m were classified as adults. The plants lesser than 4 cm girth at breast height but taller than 1 m were classified as saplings while the plants less than 1 m tall were classified as seedlings(Frontier Madagascar, 2005).

Plate 3.1: Identification of mangrove species

3.2.3 Collection of Sediment samples

Sediment core samples were collected aseptically using a hand-held stainless steel from 1 meter depth with 5 cm interval from 8 sites of mangrove area in Bapatla district. The samples were collected in a zip lock bags and sealed. This samples were stored at 4^{o}C in the dark and transferred to the laboratory for analysis.

Plate 3.2: Sediment core sample collection

3.2.4 Estimation of biomass and carbon stock

Three pools of carbon were taken into consideration for the measurement of carbon stored in mangrove ecosystem viz., i) above-ground biomass, ii) below-ground biomass (root) and iii) sediment.

The allometric equations developed by Komiyama et al. (2005) for mangroves of south-east Asia were used for the estimation of above-ground biomass (W_{top}) and below-ground biomass (W_R). The allometric equations are:

$$\mathbf{W_{top} = 0.251\rho D^{2.46} \quad W_R = 0.199\rho^{0.899}D^{2.22}}$$

Where W_{top} is the above-ground biomass (kg), W_R is the below-ground biomass (root), ρ is the wood density of the respective species and D is the diameter at breast height (DBH). The value of above-ground and below-ground biomass was summed up to get the total biomass for all the plots which were then averaged to get the mean total biomass and finally converted to tons per hectare. The carbon values were estimated as50% of the biomass (Komiyama et al., 2005).

3.2.5 Determination of species diversity

Shannon Weaver diversity was calculated as follows:

$H_s = -\Sigma (P_i) (\ln P_i)$

Where,

H_S= diversity in a sample of the speciesS= The number of species

P^i = The relative abundance of i^{th} species or kinds,

N = The total number of individuals,

n_i = The number of individuals of i^{th} species,

ln = log base

2. Simpson's Diversity Index

Measure of species diversity, used to quantify the biodiversity of a habitat. It takes into account the richness (number of species present), as well as the evenness (relative abundance) of each species. A high value for D is ‘good’ and means the habitat is diverse, species rich, and low value for D is ‘poor’ and means the habitats low in species. The value of D ranges between 0 & 1; 1 represents infinite diversity and 0, no diversity. It was calculated by using the formula,

$D = 1 - (\sum n(n-1) / N(N-1))$

n = The total number of organisms of a particular species

N = The total number of organisms of all species

3.2.6 Importance value index

The importance value index (IVI) which indicates the structural importance of each species in the community was obtained by adding the percentage values of relative frequency (RF), relative dominance (RDom) and relative density (RD) (Widyastuti et al., 2018).

- Relative frequency = (Frequency of a species / Sum of frequency of all species)× 100
- Relative density = (Density of a species / Sum of density of all species) × 100
- Relative dominance = (Dominance of a species /dominance of all species) × 100
- Importance Value Index (IVI) = Relative Frequency + Relative Density + Relative Dominance

3.3 LABORATARY ANALYSIS

3.3.1 Soil Organic carbon analysis

Walkley Black Method

To evaluate the role served by the organic fraction of sediments in the transport, deposition, and retention of trace metals, organic carbon is measured. Jackson (1958) adapted and improved the Walkley-Black method (1947) to determine the rapidly oxidizable organic content.

Procedure

Place 0.5 µg of dried and sieved (200 µm sieve) sediment sample in a 500 ml Erlenmeyer flask. Add exactly 10 ml of 1N $K_2Cr_2O_7$ solution by burette and 20 ml of concentrated H_2SO_4 with Ag_2SO_4 and mix gently rotating the flask for about 1 min. A standardization blank without sediment should be run with each new batch of samples. After 30 min, add 200 ml distilled water, 10 ml 85% H_3PO_4 and 0.2 g NaF. Add 15 drops of diphenylamine indicator to the sample flask. Back titrate the solution with the 0.5 N ferrous ammonium sulphate solution to a one -drop end point (brilliant green).

Plate 3.3: Analysis of organic carbon (Walkley Black Method)

Calculation of results

% organic carbon = 10(1-T/S) × F

Were,

S = Standardization blank titration, ml of ferrous solution

T= Sample titration, ml of ferrous solution

F= Factor, which is derived as follows:

F= (1 N) × 12/4000 × 100/sample weight

3.4 SATELITE IMAGE AND PROCESSING

Estimated the spatio-temporal changes in the Bapatla Landscape using time series satellite images of the period from 1993 to 2022. Landsat Thematic Mapper (TM) images (1993) and Enhanced Thematic Mapper (ETM) images (2003), the operational land imager (OLI) images for the years 2013and 2022 extracted from USGS Earth Explorer. The specifications of the images used are provided in Table 3.2

3.4.1 Specifications of the Satellite Imagery used in the study

The metadata of the multi-temporal Landsat images used for this study is provided in Table 3.2

Table 3.2. Details of Landsat images used in the study

Satellite	Sensor	Path/Row	Date of pass	Spatial resolution (m)
Landsat-5	TM	142/049	11-06-1993	30
Landsat-7	ETM	142/049	30-05-2003	30
Lansat-8	OLI_TIRS	142/049	18-06-2013	30
Lansat-8	OLI_TIRS	142/049	02-06-2022	30

3.5 LAND USE/ LAND COVER (LU/LC)

The Landsat images for the years 1993, 2003, 2013 and 2022 were used to prepare the land use-land cover map of Bapatla District. The study area was extracted from the satellite imagery from the Krishna delta region. The selection of the satellite images dates was influenced by the quality of the image especially for those with limited cloud cover. Images are georeferenced to WGS_84 and UTM zone is 44N. Specifications of the images used are provided in Table 1 and Table 2. Images was then processed in ERDAS IMAGINE 2014 Software. Each band's satellite image was stacked in ERDAS. Subset tool was then used to extract the study region image from the stacked satellite image. Satellite images for all four years were used LU/LC supervised classification. Nine LULC classes have been determined for classification purposes. The supervised classification technique used in the study utilises a maximum likelihood classifier.

3.6 InVEST MODEL

A collection of free, open-source software models called InVEST is used to map and value the natural resources that provide human life with sustenance and fulfilment

These services include the creation of commodities (like food), life- supporting activities (like water purification), opportunities for recreation and beauty, and the preservation of options (like genetic diversity for future use). This natural capital is underappreciated, rarely monitored, and, in many situations, rapidly deteriorating and disappearing despite its significance. All organisations that manage natural resources for numerous purposes—governments, corporations, non-profits, and international lending institutions—inevitably have to weigh trade-offs. The multi-service, modular architecture of InVEST is a useful instrument for striking a balance between these many organisations' financial and environmental objectives. With the aid of InVEST, decision makers may evaluate the quantifiable trade-offs linked to various management options and pinpoint opportunities for investing in natural capital to advance both the preservation of the environment and human development. Eighteen different ecosystem service models for freshwater, marine, terrestrial, and coastal ecosystems are currently included in the toolbox. A variety of "helper tools" are also included to help with input data processing and retrieval, as well as output comprehension and visualisation.

3.6.1 Coastal Blue Carbon Model

The InVEST CBC model, version 3.12.1, analyses changes in carbon storage over time in response to LULC changes and compares this across multiple management scenarios in order to evaluate the value of carbon storage and sequestration services offered by coastal ecosystems. In the form of a transition matrix, these LULC changes are then categorised as either accumulation or disturbance. According to Sharp et al. (2014), this model generates spatially explicit outputs on net sequestration, net present value of averted emissions, carbon stock, and gain/loss data on the landscape that is being studied over time.

The InVEST Blue Carbon model measures the evolving value of carbon storage and sequestration services offered by coastal ecosystems by assessing changes in carbon storage over time and comparing these across alternative management scenarios. One of the first coastal blue carbon models allows users to contribute spatially precise information about vegetation disturbances brought on by human activity (such as hardening the shoreline or emptying a marsh) and climate change (such as rising sea levels). The value of averted emissions and the locations of net carbon gains or losses over time on land or in the ocean can also be determined using the Blue Carbon model. The CBC model is useful for analysing vegetative disturbances brought on by human activity and climate change, which is crucial for allocating priorities for conservation efforts and resource management.

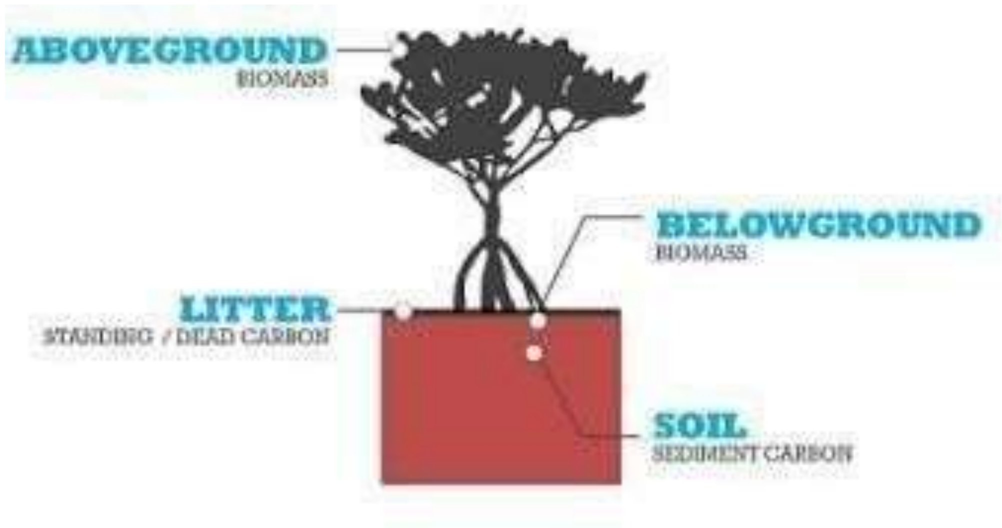


Fig. 3.3: Three carbon pools for marine ecosystems in the InVEST Coastal Blue Carbon model

3.6.2 CBC Pre-Processor Tool

The CBC pre-processor tool used the LULC input maps (1993,2003,2013 and 2022) and LULC lookup table to map LULC classes to their values in a raster, and to identify whether an LULC class is a coastal blue carbon habitat. The cells of the 'Accumulation' matrix indicated that an LULC class with carbon storage potential persisted between 1993 and 2022. The 'Disturbance' matrix indicated that an LULC class with carbon storage potential was changed from a vegetated LULC class to a non-vegetated LULC class. The "None" matrix indicated that the transition between

LULC types did not occur on any of the LULC maps. The tool generated a carbon pool table for LULC classes, a carbon pool transition variables table, and an LULC transition table.

3.6.3 Identifying LULC Transitions with the Pre-processor

The inputs that promote carbon accumulation and emissions in the model are the LULC maps, which offer snapshots of a changing landscape. A series of maps of coastal and marine habitats must be created initially using a land change model, a scenario assessment tool, or manual GIS processing. The model must get the LULC maps in the following chronological order: s0, s1... sn. To determine the set of all LULC transitions that take place, the pre-processor tool compares LULC classes between the maps. After that, it creates a transition matrix that shows if a transition happens between two habitats (for example, from a mangrove forest to an area devoid of vegetation) and whether carbon builds up, is disrupted, or stays the same after that transition.

The Land Cover Transition types can be:

- Other LULC class ⇒ Coastal Blue Carbon class (Carbon Accumulation
- Coastal Blue Carbonclass ⇒ CoastalBlue Carbonclass (CarbonAccumulation)
- Coastal Blue Carbon class ⇒ Other LULC class (Carbon Disturbance)
- Other LULC class ⇒ Other LULC class (No Carbon Change)

Input

Inputs As previously indicated, the inputs are:

- Workspace: The chosen folder is used (needed).
- suffix (optional): to aid distinguish outputs from several runs, this text stringwill be added to the end of the result file names.

- Lookup Table (required): a Comma Separated Value table that shows whether or not a LULC class is a coastal blue carbon habitat and maps LULC classes totheir values in a raster.Table 3.4 provides the table format that is utilised for this purpose.

Table 3.3 Look up table for InVEST model

LULC Class	**Code**	**Is coastal blue carbon habitat or not**
Agriculture	1	False
Aquaculture	2	False
Built up	3	False
Mangroves	4	True
Plantation	5	False
Sandy area	7	False
Uncultivated area	8	False
Vegetation	9	False
Waterbody	10	False

Where all the columns are essential and are defined as follows:

- Lulc-class: a text string that describes each LULC class (land use/land cover).
- Code: each LULC class's integer value. All LULC classes in the user-supplied Land Use/Land Cover Rasters must be included in this LULC Lookup Table, and these integer values must match those in the Land Use/Land Cover Rasters.
- Is_coastal_blue_carbon_habitat: Returns 'FALSE' if the LULC type is not coastal blue carbon habitat (e.g., stable other vegetation) and 'TRUE' if it is (e.g., mangrove forest). Class 1, "mangrove forest," is the sole class in this study

that represents a Coastal Blue Carbon Habitat; all other classes have input valuesof "FALSE."

Outputs

The pre-processor's output files are found in the Workspace folder that was previously established. The optional user-defined Suffix input is indicated by the term "Suffix" in the following file names.

- Parameter log: A.txt file will be created in the main Workspace folder each time the model is run. The file, which will have a name based on the service, the date, and the time, will list the parameter values and output messages for that run.
- Transitions_[Suffix].csv: a transition matrix indicating whether accumulation or disruption happens in a transition from one LULC class to another, presented in a Comma Separated Value format table. There won't be any such transition between the input Land Use/Land Cover Rasters if the cell is left blank. The source LULC class is shown by the leftmost column (lulc-class), and thedestination LULC classes are shown by the top row. A cell's pre-population will depend on the sort of transition: empty (meaning no transition occurs), "NCC" (meaning no carbon change), "accum" (meaning accumulation), or "disturb" (meaning disturbance) (High, low, and medium). Table 3.5 displays the LULC Transition table for the designated study area.

Table 3.4 Land cover transition table for InVEST model

2022 / 1993	Agriculture	Aquaculture	Built up	Mangroves	Plantation	Sandy area	Uncultivated area	Vegetation	Waterbody
Agriculture	NCC	NCC	NCC	Accum	NCC	NCC	NCC	NCC	NCC
Aquaculture	NCC	NCC	NCC	Accum	NCC	NCC	NCC	NCC	NCC
Built up	NCC	NCC	NCC	Accum	NCC	NCC	NCC	NCC	NCC
Mangroves	High-disturb	High-disturb	High-disturb	Accum	Low-disturb	Med-disturb	Med-disturb	Med - disturb	Low-disturb
Plantation	NCC	NCC	NCC	Accum	NCC	NCC	NCC	NCC	NCC
Sandy area	NCC	NCC	NCC	Accum	NCC	NCC	NCC	NCC	NCC
Uncultivated Area	NCC	NCC	NCC	Accum	NCC	NCC	NCC	NCC	NCC
Vegetation	NCC	NCC	NCC	Accum	NCC	NCC	NCC	NCC	NCC
Water body	NCC	NCC	NCC	Accum	NCC	NCC	NCC	NCC	NCC

Biophysical Table (CSV, necessary): Biophysical characteristics for every LULC class listed in a table. The pre-processor creates a template for this table and includesit with the model's sample data.

Information about the transport of carbon into and out of coastal blue carbon pools is included in this table. It is assumed that as a result of change, all non-coastal blue carbon habitat LULC classifications will neither emit nor sequester carbon. The half- life is expressed in integer years, the accumulation units are (Megatons of CO_2 e (ha yr) -1), and the "disturbance" must be expressed as a decimal percentage of stock disturbed when a transition away from a specific LULC happens. The numbers for "yearly-accumulation" must be expressed in Megatons of CO_2 e (ha yr) -1. The values for the "half-life" must be expressed in whole years.

Table 3.5 Percent carbon loss and habitat-specific decay rates as a result of low (LI), medium (MI) and high (HI) impact activities disturbing Mangroves (Murray et al., 2011)

% carbon loss from biomass	Low Impact/Medium Impact: 50%biomass loss High impact: 100% biomass loss
% carbon loss from soil	Low Impact: 30% loss Medium impact: 50% loss High impact: 66% loss (up to 1.5 m depth)
Rate of decay (over 25 years)	Biomass half-life: 15 years, but assume 75% is released immediately from burning; Soil half-life 7.5 years

Table 3.6 Carbon stock values and accumulation rates used in InVEST coastal blue carbon model

Parameter	Value	Unit	Reference
Standing carbon stock in mangrove biomass	39.81876	Mg C/ha	Field data
Standing carbon stock in litter in mangrove forests	0.76	Mg C/ha	Field data
Standing carbon stock in the sedimentsof mangrove forests	109.21	Mg C/ha	Field data
Half-life of C decomposition from biomass	15	Year	Murray et al.(2011)
Half-life of C decomposition from sediments	7.5	Year	Murray et al.(2011)
Accumulation rate of C by mangrove forests	1.789	Mg C/ha/y	Sahu et al., (2015)
Accumulation rate of C by sediments	3.35	Mg C/ha/y	Mackenzie et al., (2016)

The edited tables are used as input to the main Coastal Blue Carbon model as the LULC Transition Effect of Carbon Table, the Carbon Pool Initial Variables Table and the Carbon Pool Transient Variables Table

3.6.4 The Main Model - Coastal Blue Carbon

The main Coastal Blue Carbon model calculates carbon stock and sequestrationover time, based on the transition and carbon pool information generated by the pre- processor. It can also calculate the value of sequestration if economic data are provided.

Input

- Workspace (directory, required): The folder containing all of the output files generated by the model.
- File Suffix: An optional text suffix that will be added to the names of all outputfiles. helpful in distinguishing across model runs.

- Land cover Snapshots Table (CSV, required): A table that associates LULC maps with snapshot years.
- Biophysical Table (CSV, necessary): Biophysical characteristics for every LULC class listed in a table.
- Land cover Transitions Table (CSV, required): A matrix of transitions that illustrates the kind of carbon activity that occurs when a certain LULC type changes into another.
- Analysis Year (number, optional): This is an additional year that can be utilisedto carry out the analysis after the previous snapshot. When using the model, it is assumed that carbon would either accumulate or continue to be released following the last year of snapshots until the year of analysis. This number needs to exceed the year of the last snapshot.
- Calculate Net Present Value of Sequestered Carbon (optional): for calculate the monetary value of sequestration.

  The following calculates the value of carbon sequestration over time:

  Prices per tonne of CO2 are used to describe the value of sequestered carbon.A price schedule covering the relevant time horizon or a base year carbon priceplus an annual inflation rate might be used to input this number. The net present value equation's discount rate, or d, represents time preferences for current advantages over benefits in the future. Monetary values are not discounted when the rate is set to 0%. If the box labelled "Calculate Net Present Value of Sequestered Carbon" is ticked, the following valuation data is also required.

  Price table use is optional. If a table with carbon costs for several years can besupplied, tick this box.

  Price: the cost per milligramme of CO2 at the baseline year (necessary for valuation if the Price Table is not utilised). Currency used for the floating pointvalue might be any.

  Interest Rate: the annual compound interest rate on the price per megaton of CO2 e, necessary for valuation in the event that the Price Table is not employed. Value of floating point percentage (%)

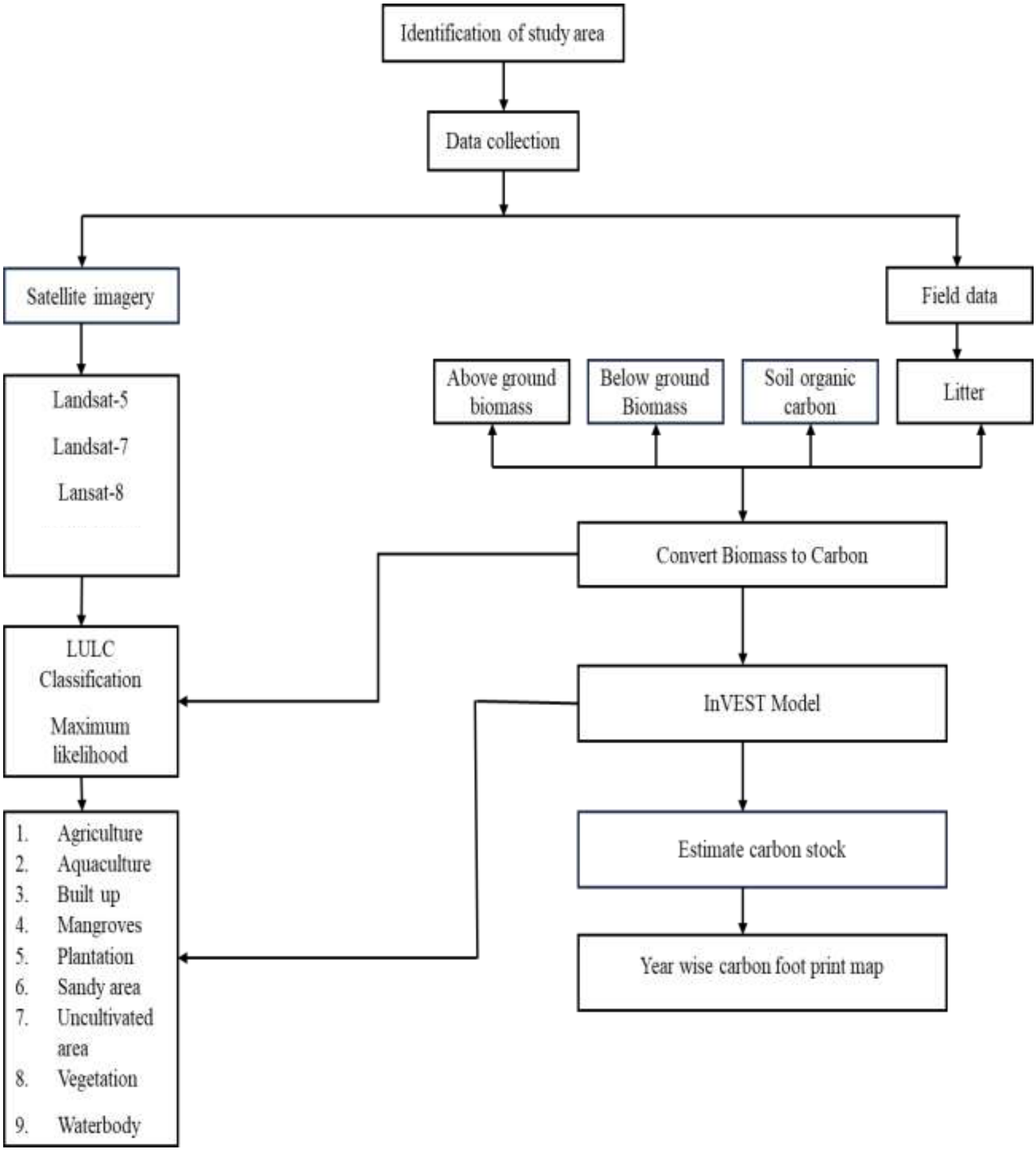


Fig 3.4: Schematic representation of the methodology

CHAPTER 4

RESULTS AND DISCUSSION

4.1 TEMPORAL CHANGES IN LAND USE

4.1.1 Analysis of Land use Land cover map

The distribution and functioning of vegetation and soil are directly impacted by significant variations in the capacity of various LULC types to sequester carbon as well as the transformation between LULC types (Li et al., 2020b; Ni, 2013). Additionally, the primary expression of terrestrial ecosystem carbon storage is seen in flora and soil, which have greater potential to store carbon. Therefore, variations in ecosystem carbon storage will directly result from changes in vegetation growth and soil types brought on by the spatial structure of LULC dynamics. Particularly, the reduction in regional carbon storage has been brought on by the modification of LULC type from non- construction land to building land. Additionally, several recent studies have shown that LULC dynamics are responsible for the 1.5 Pg/yr carbon release to the atmosphere. This indicates that LULC change has had a significant impact on the carbon cycle of terrestrial ecosystems around the world (Landman, 2010).

The entire study area was designated under nine major classes according to NRSC level 2 LU/LC classification. The classes are Agriculture, Aquaculture, Built-up, Mangrove, Plantation, Sandy area, uncultivated area, Vegetation, Waterbody. Analysis of satellite imagery has revealed the changes in the extent of mangrove vegetation in the entire Bapatla Landscape. According to the analysis (Fig.4.4), the predominant land use in the study area is Agriculture, followed by Built-up area, Vegetation, Waterbody, Uncultivated area, plantation, aquaculture, Mangroves and sandy area as of 2022 (Table 4.1). Also, it shows that changes in the extent of LULC classes in the entire study area. LULC map during the period 1993-2022 reveals that there was a change in the mangrove cover of the Bapatla Land scape. The mangrove cover had decreased initially from 4809.02 ha in 1993 to 3849.16 ha by 2003. During this period most of the mangroves are converted into aquaculture (269.9 ha), vegetation (100.8 ha) and Agriculture (52 ha) which shows in fig.4.5 However, it increased thereon to 5698.44 ha and 6767.98 ha for the years 2013 and 2022 respectively (Table 4.1). LULC map and statistics shows that there was an increase in the aquaculture (4809.02 ha to 10309.47 ha) and Agriculture (18758.93 ha to 37821.88 ha) in the study area from 1993 to 2022.During this period there was an increase in mangrove cover. During At this period mangroves are converted in aquaculture at an extend of 212 ha and agriculture is about 94.1 ha. Built-up area continuously expanded in the whole time period. There was an increase in the mangrove cover for the regions like Nizampatnam and Kothapalem RF during the years 2003 to 2022.

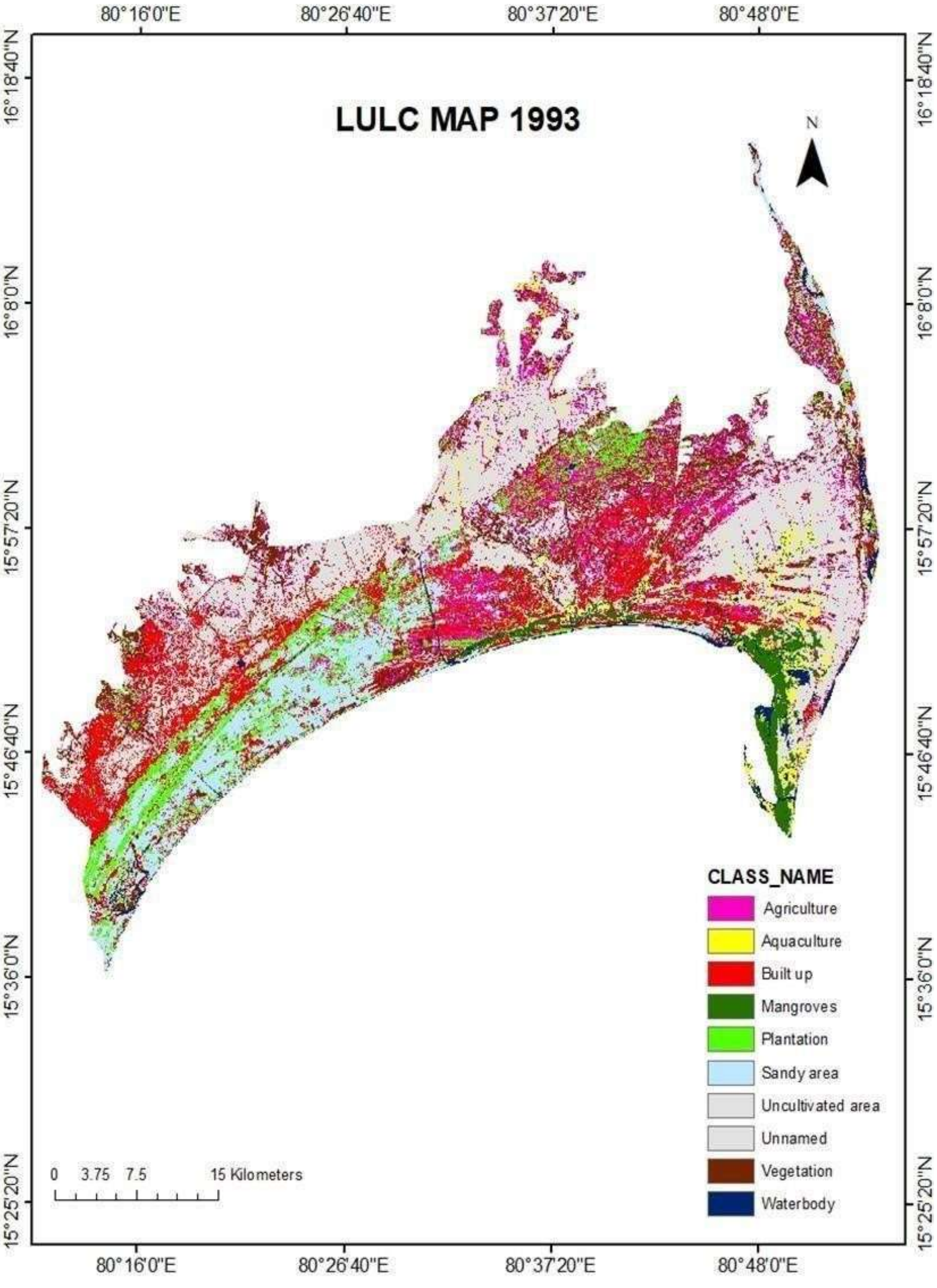


Fig. 4.1: Map of LULC for the study area during 1993

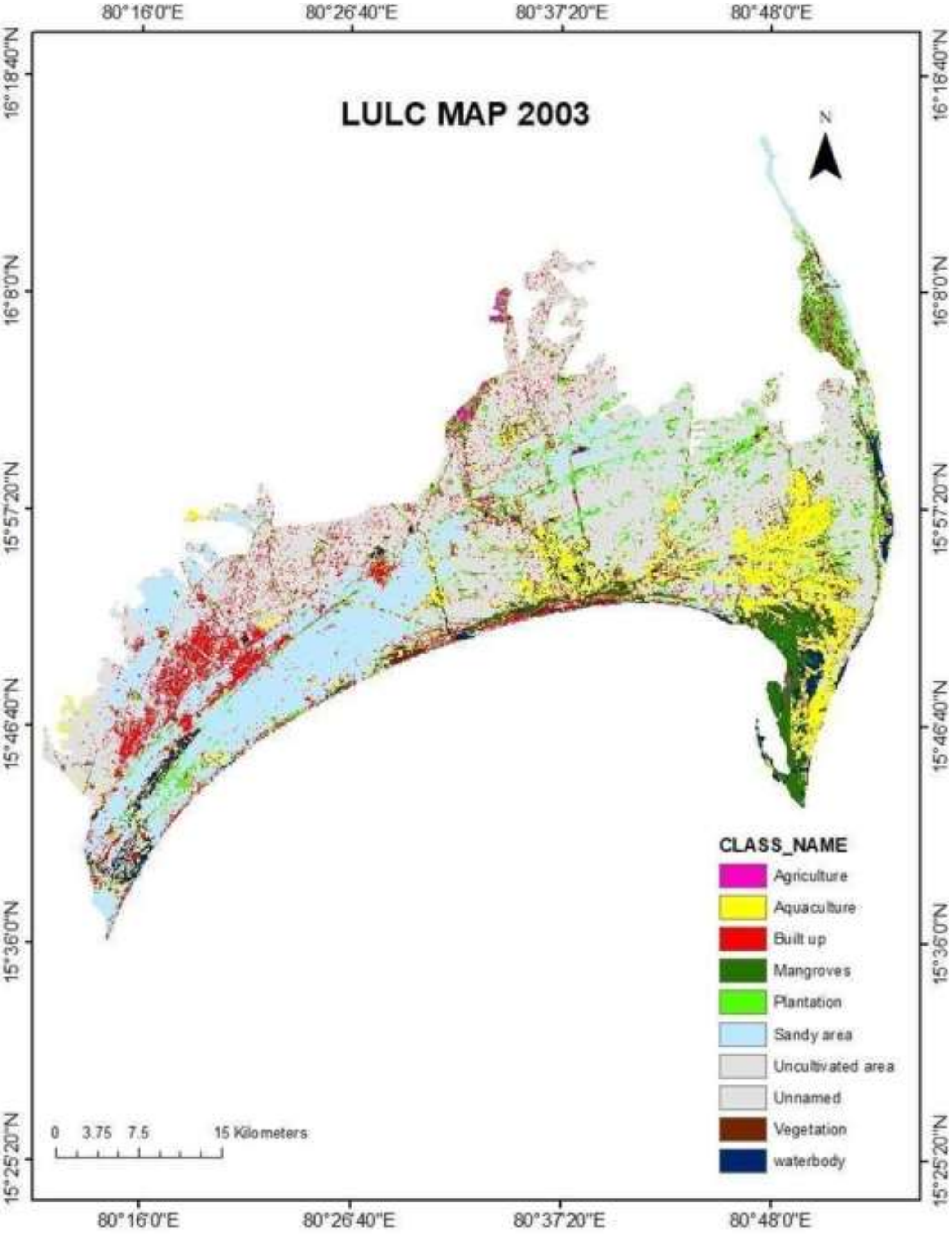


Fig. 4.2: Map of LULC for the study area during 2003

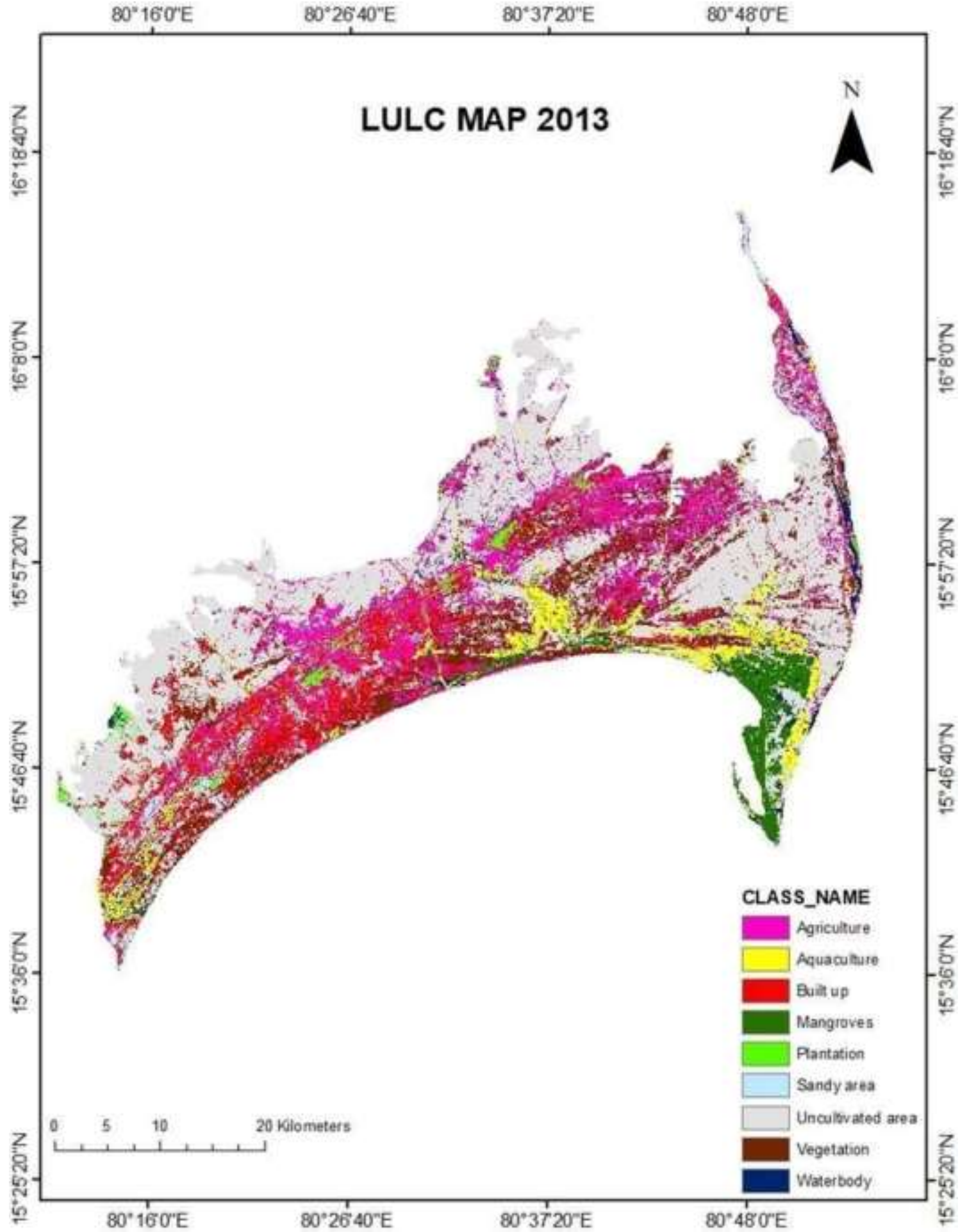


Fig. 4.3: Map of LULC for the study area during 2013

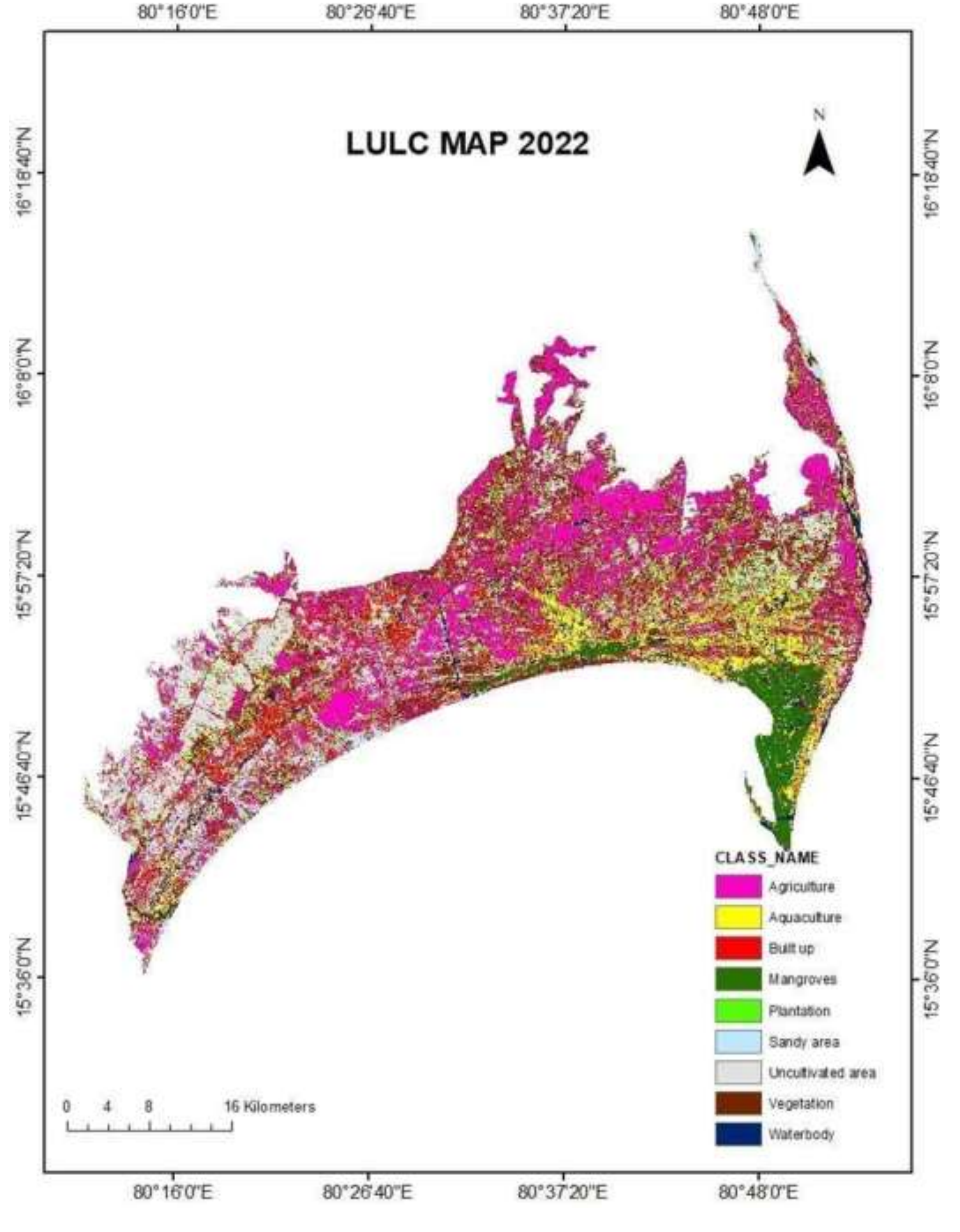


Fig. 4.4: Map of LULC for the study area during 2022

Table 4.1 Data on temporal change in LULC for the study area

Code	LULC-class	1993 (ha)	2003 (ha)	2013 (ha)	2022(ha)
1	Agriculture	18758.93	1401.47	24728.09	37821.88
2	Aquaculture	4809.02	14797.97	8711.22	10309.47
3	Built-up	22935.2	24734.46	26670.11	32935.25
4	Mangroves	4207	3849.16	5698.44	6767.98
5	Plantation	14109.8	10479.49	5010.26	14738.31
6	Sandy area	18352.37	33413.73	8048.53	6186.4
7	Uncultivated area	53434.17	62507.63	56600.73	20425.05
8	Vegetation	18206.87	6395.02	21469.64	28659.86
9	Waterbody	3527.35	5196	4157.99	28659.86
	Total	**158340.8**	**162774.9**	**161095**	**164372.2**

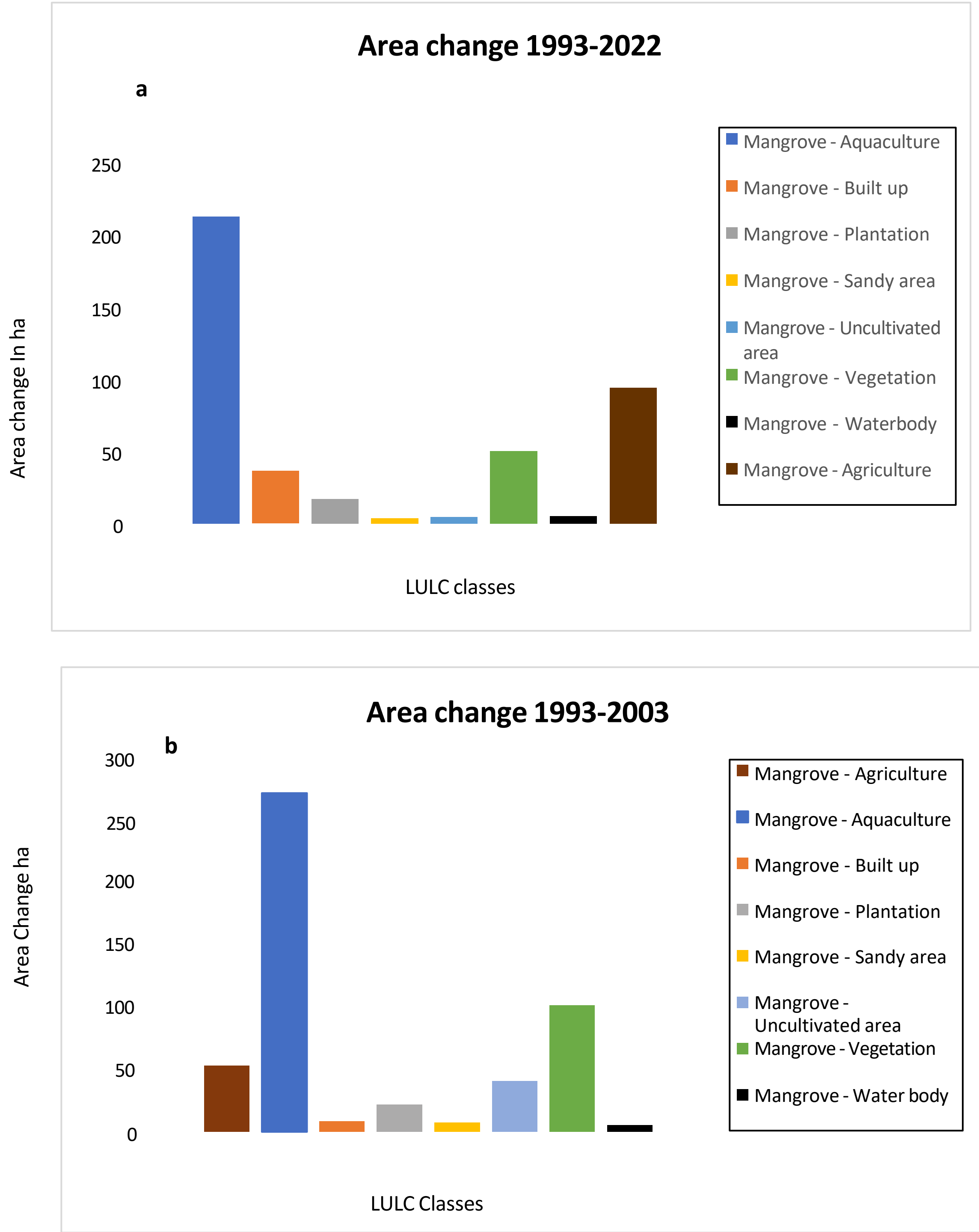


Fig.4.5: Graphical representation of change in mangroves to different classes during the period, a- 1993-2022 and b- 1993-2003

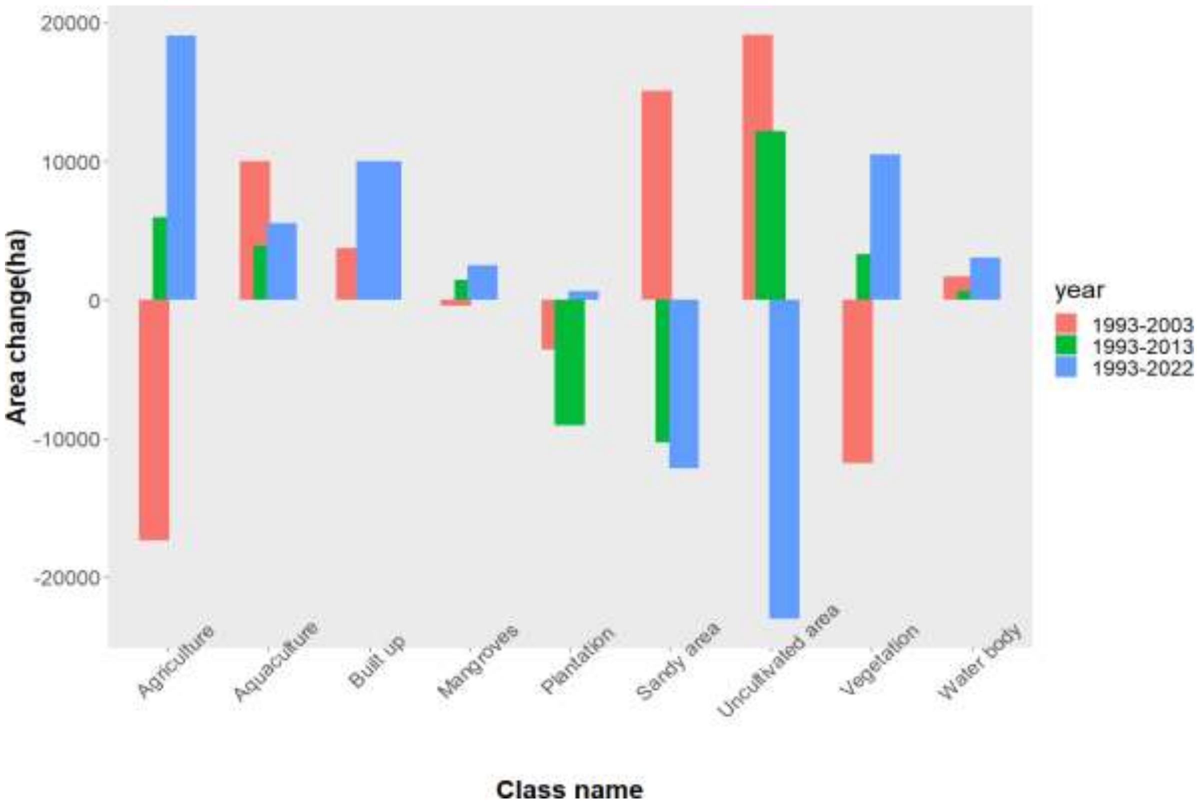


Fig. 4.6: Graphical representations of LULC change for 30 years

4.2 MANGROVE DEFORESTATION AND DECLINE

Mangrove forests, which are extremely dynamic communities with a productive ecosystem that has long been valued, have recently come to be understood as endangered habitats in the world's tropical regions. The removal or decline of mangroves is suggested by the presence of mangrove vegetation in one image and its absence in the same region in images taken in the following year. The land has dried out as a result of changes in the hydrology and salt encrustation in the area, as excessive salinity can induce mangrove plant death (Chen and Ye 2014). It was discovered that between 1993 and 2003, the study area's mangrove loss due to deforestation and natural decline was 358 ha (or 35.8 ha yr-1).

4.2.1 Tropical cyclone

Tropical cyclones can affect the coastal area, especially the eastern shore. The coastal districts of Andhra Pradesh—Krishna, Nellore, Guntur, East Godavari, and Srikakulam—are extremely susceptible to cyclones. Nearly 80% of the cyclones produced in the Indian Ocean affect the east coast of India, making it more vulnerable to cyclones than the west. According to Unnikrishnan et al. (2011), there will be much more cyclones along the East Coast between 2071 and 2100 than there were between 1961 and 1990 because of increasing wind speeds.

In both 1990 and 1977, the Krishna mangroves took the brunt of two powerful cyclonic storms. Even though the exact number of mangroves destroyed by these cyclonic storms has not been thoroughly recorded, the storm surges produced a great deal of sand casting, which made the environment unsuitable for the growth and survival of many mangrove species. Additionally, it has led to the siltation of numerous drainage systems that supplied fresh and tidal water, which has deteriorated the mangroves. Because of its extremely low land elevation, the Nizampatnam region is highly vulnerable to storm surges.

4.2.2 Mangrove degradation for aquaculture

Encroachment for aquaculture is one of the major causes of mangrove destruction in recent decades in many countries (Thu and Populus 2007; Stuart 2013; Karstens and Lukas 2014). Satellite image analysis substantiated by field observations revealed that mangrove vegetation was extensively damaged for aquaculture encroachments and there was an increasing trend in the aquaculture in the study area. As compared to first decade (1993-2003), there was a decrease in the aquaculture, because most of the ponds are not active. Study of Kubo S and co-workers in 2017 reveals that there was a loss of mangroves in Krishna delta during 1977-2013 for aquaculture, at an average rate of 36.4ha yr^{-1}. The rate of destruction was higher during the 1990–2000 at 68ha yr^{-1} in the Krishna delta.

Plate 4.1: Aquaculture area showing in FCC (False color composite) Sentinel image (Blue green patches) and Active aquaculture pond in Nizampatanam, Bapatla

4.3 MANGROVE RESTORATION

Programmes for reforesting mangroves must take into account the selection of species that are appropriate or the specific environmental conditions, such as topography and soil quality (Miyagi et al. 2014). Mangrove restoration began in Indonesia in the early 1960s (Soemodihardjo et al., 1996), and up to 1992, an area of around 38,923 ha of mangroves was recovered. In the K–G delta region, a number of agencies started working on mangrove restoration initiatives. The Andhra Pradesh Forest Department began mangrove afforestation in 1991. Non-governmental organisations (NGOs) like the Coastal Environmental Rehabilitation Programme (CERP) from 2004 to 2008 and the M. S. Swaminathan Research Foundation (MSSRF) from 1997 to 2007 also took part in the mangrove reforestation efforts in the area. There were two kinds of canal network attempts. At first, the MSSRF and the Forest Department dug branch canals at a 30° angle to the main feeder canal, a technique known as "fish-bone" canals. Nevertheless, CERP adopted a completely new approach known as the "snake" method of canal network, as illustrated in plate 4.2. Mangrove species, specifically *Avicennia* *marina, Avicennia officinalis,* and *Excoecaria agallocha*, were chosen for planting in the degraded areas based on the soil's salinity (Ramasubramanian and Ravishankar 2004). The mangrove vegetation in the area has been successfully restored using both approaches. Using species of *Avicennia marina*, *Avicennia officinalis, Rhizophora mucranata, and Rhizophora apiculata*, CERP began afforestation across 264 hectares in the Krishna delta. However, the predicted increase in mangrove extent derived from the analysis of satellite images was significantly more than the total area covered by mangrove replanting. The mangroves have expanded beyond their original planting site and into nearby locations. Mangrove propagules disperse by means of water to broaderregions where they anchor favourable ground (Van der Stocken et al. 2015).

Plate 4.2: Mangrove restoration through a network of canals using fish-bone method during the years 2003 and 2022

Plate 4.3: Planted mangrove in Nizampatnam and Natural mangrove in Kothapalem

4.3.1 Net increase of mangrove area

In spite of cumulative loss of mangrove vegetation due to several causes, there has been a net increase in mangrove cover in the region, obviously as a result of afforestation measures by allowing flow of brackish water into the degraded areas through artificial canal networks between the time period 1991-2008 Various studies reveal that analysis of time series satellite images revealed that the mangrove cover in the Krishna delta decreased from 17,966ha in 1977 to 16,110ha by 1990 as a direct result of the mangrove degradation. In Bapatla landscape, during 1993–2003, however, the net loss was only 35.8 ha from 4207 ha in 1993 to 3849.16 ha in 2003. That means the restoration programs led to a total addition and thereby covering up for most of the mangrove loss. Later, during 2003–2013, the net increase of mangrove cover was 1849 ha from 3849.16 ha in 2003 to 5698.4 ha by 2013. Then according to the study increasing in the mangrove cover up to 2022 on the whole, the net gain of mangrove extent was 2,918 ha in the Bapatla landscape during 1993–2022.

4.4 MANGROVE BIOMASS

4.4.1 Floristic composition

A total of ten species of mangroves viz., *Avicennia officials, Avicennia marina, Rhizophora mucronata, Excoecaria agallocha, Acanthus ilicifolius, Ceriops decandra, Xylocarpus granatum, Aegiceras corniculatum, Lumnitzera racemose* and *Sonneratia apetala* were recorded from the different sites of Bapatla landscape.

Poguru: It is a tiny wetland near Bapatla, just about 4 km from Suryalanka beach. Mangroves are patchy to dense found either side of the Perali drain. *Avicennia marina* is the dominant species in this region. Some areas are dominated by *Rhizophora mucronata.* Only found natural mangroves and it extended up to the Suryalanka Beach.

Kothapalem: This area has the densest mangroves in the Bapatla land scape. In Kothapalem R.F, thick vegetation of *Avicennia marina*, *Excoecaria agallocha, Avicennia officinalis, Rhizophora mucronata* are seen. Other species like *Ceriops* *decandra, Xylocarpus granatum, Aegiceras corniculatum* also found in this reserve forest area. Among these species, *A. officinalis* was the predominant species in terms of number as well as in terms of coverage of area. *Rhizophora mucronata* is very dense in some region.

Nizampatnam: Mangroves in Nizampatnam areas are mostly planted. *Avicennia marina* is the common species in Nizampatnam. This area has maximum number of inhabitants and dominated by Aquaculture ponds. *Rhizophora mucronata* found only in one site. Mangrove tress are small as compared to other sites. *Lumnitzera racemose, Aegiceras corniculatum and Excoecaria agallocha* are also common in this site.

Table.4.2 Mangrove species in Bapatla area ranked by their Importance Value Index (IVI).

Species	Relative Frequency	Relative density	Relative domine nce	IVI
Avicennia officinalis	20.0	24.3	20.2	64.5
Avicennia marina	17.8	28.6	10.4	56.8
Excoecaria agallocha	13.3	14.6	8.1	36
Rhizophora mucronata	13.3	10.7	5.6	29.6
Ceriops decandra	4.4	2.4	7.9	14.8
Xylocarpus granatum	6.7	3.9	7.9	18.4
Bruguiera gymnorrhiza	4.4	4.9	8.7	18
Aegiceras corniculatum	8.9	4.9	5.7	19.4
Avicennia alba	2.2	0.5	4.5	7.2
Bruguiera cylindrica	2.2	0.5	8.1	10.8
Lumnitzera racemosa	4.4	1.9	7.9	14.3

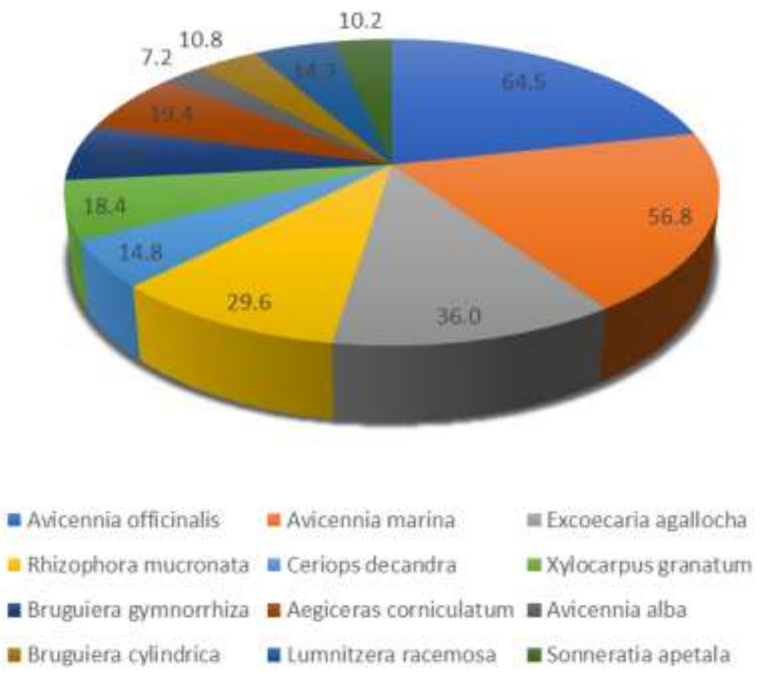


Fig. 4.7: Mangrove species found in Bapatla landscape based on Importance value index

In Bapatla areas, *Avicennia officinalis* was the dominant species with the highest value of Important Value Index (IVI) =64.5. The *Avicennia officinalis* has ranked the first out of eleven in sampling plot. The second highest IVI was that of *Avicennia marina*, with a value of 56.8. The third was *Excoecaria agallocha* (36), and followed by *Rhizophora mucronata* (29.6), *Aegiceras corniculatum*(19.4).

Table 4.3. Value of mangrove species diversity according to diversity indices

Station	Simpson index(D)	Shannon-Weiner index (H’)
Poguru	0.75	1.3
Kothapalem 1	0.76	1.3
Kothapalem 2	0.77	1.5
Kothapalem 3	0.78	1.2
Kothapalem 4	0.9	2.1
Nizampatnam 1	0.76	1.4
Nizampatnam 2	0.76	1.3
Nizampatnam 3	0.85	1.3
Nizampatnam 4	0.6	0.9

The value of mangrove species diversity in planted mangrove area is less diverse with Shannon-Weiner (H’) ranging between 0.9-1.4 as compared to natural mangrove area which has a higher value with Shannon-Weiner (H’) =2.1. *Avicennia officinalis* is the most important and dominant species with the highest Important Value Index (IVI) value of 64.5 in the study area. Simpson’s Diversity Index (1-D) for the two kind of mangroves, 0. 9(Kothapalem4) and 0.6 (Nizampatnam 4) (Table 4.3). The diversity index represents the chances of the next species being observed is differing from the previous one; therefore, a value of 0 means that the community is uniform or homogeneous and a value approaching 1 means that the community is highly diverse (Krebs 1989). The Simpson’s Diversity Index found was fairly high in the natural mangrove areas as compared to the planted mangrove areas.

Table 4.4. Mangrove species of Bapatla landscape (overall mean with standard error)

Sl No.	Species name	Local name	Height (m)	DBH (cm)	Mean wood density (g cm^{-3})	AGB	BGB
1	*Avicennia officinalis*	Nalla mada	8.83±5.4	10.18± 3.57	0.65	59±56.0 8	26.90±2 2.71
2	*Avicennia marina*	Tella mada	4±3.02	7.32±2 .88	0.64	26.95±2 8.86	13.12±1 2.51
3	*Excoecaria agallocha*	Tilla	3.5±1.29	6.44±1 .88	0.43	12.08±6 .63	6.5±3.3 5
4	*Rhizophora mucronata*	Ponna	4±2.73	5.34±1 .95	0.85	15.67±1 2.17	7.74±5 8
5	*Ceriops decandra*	Togara	3.5±0.70	6.37±2 .25	0.73	19.35±1 5.24	9.9±7.1 9
6	*Xylocarpus granatum*	Senuga	5	6.36±1 .6	0.67	28.95±1 3.74	14.37±6 .18
7	*Bruguiera gymnorrhiza*	Kandri ga	3.5±2.12	6.68±0 .45	0.76	20.65±3 .59	10.65±1 .67
8	*Aegiceras corniculatum*	Guggil am	1.83±0.29	5.41±2 .60	0.6	12.3±13 .15	6.46±6. 38
9	*Lumnitzera racemosa*	Thand uga	1.5	6.36	0.83	19.7	10.25
10	*Sonneratia apetala*	Kaling a	4	5.09	0.53	7.27	4.17

4.4.2 Biomass and C-stock

Understanding the role of biomass in this process is essential since mangroves are a special type of coastal ecosystem that are extremely good at storing and sequestering carbon. Mangroves contain large volumes of biomass, including both above- and below ground plant parts, which store a lot of carbon. AGB is an important parameter to estimate forest carbon storage, and its current information is needed to study the importance of forest distribution for total biomass (Wijaya et al., 2010). AGB was estimated for one year using different data and approaches, namely field observation data (Brown and Lugo 1984, 1992), remote sensing (RS) data (Steininger 2000; Foody 2003; Thenkabail et al. 2004), and GIS data. (Brown and Gaston). 1995). Among the various methods, field observation is known as the best and most accurate method, although it is expensive and time-consuming (Lu 2006). Table 4.3 shows the above ground biomass (AGB), below ground biomass (BGB) and the total biomass of Carbon in Tonnes per Hecter. The highest total biomass of 97.46 t C ha^{-1} (AGB C of 67 t C ha^{-1}) and below ground biomass in C of 30.4 t ha^{-1}) was recorded in Kothapalem station 4 and *Avicennia officinalis* being the dominant species of this area. This area has the densest mangroves in the Kothapalem RF in this study. While the lowest C stock in biomass of 16.44 t C ha^{-1} was recorded in Nizampatnam Station 3. Here dominant species are *Avicennia marina* and *Avicennia officinalis*. The mean carbon stock (in biomass) of mangroves in Bapatla was found to be 39.8 ± 25.6 t C/ha (Table 4.3), and there were considerable variations in the biomass between different species (range 11-85.9 t C/ha; SD = 78.79 t/ha). Comparing the biomass of the mangrove species in different regions of Bapatla, Kothapalem was found to have the maximum biomass with mean 59±25.1 t C /ha. The lowest biomass was observed in Poguru (21 t C /ha). All stations in Nizampatnam region have planted mangroves only. Field observation reveal that, height and DBH was lower than natural mangrove regions. So, the result shows that there was a low biomass in these regions.

Carbon stock in biomass is more in natural mangroves as compared to the planted mangroves. Nizampatnam area has less carbon stock. Result shows that Poguru and Kothapalem has high biomass and carbon stock. Mean carbon stock in biomass compares with various countries in South East Asia such as Indonesia, Bangladesh, Sri Lanka and Japan show in the table. The result shows that some part of Indonesian region is comparable with the carbon stock in AGB like Cilacap (18.7 C t ha^{-1}), (Murdiyarso et al., 2015) and Bali (12.4 t C ha^{-1}), (Putra et al., 2019). However, other regions of Indonesia has high AGB values compare to the study area. In the case of carbon stock in BGB, study from Murdiyarso in 2015 shows that Kubu Raya region in Indonesia has a value of 14.3 t C ha^{1} and also reveals that Cilacap (Indonesia) region as a low BGB (2.5 t C ha^{-1}) as compared to the study area. According to Kairo et al. (2008) and Fatoyinbo et al. (2008), the main factors influencing the accumulation of biomass include species, tree age, climate, management approach, accessibility to a water channel, and nutrient-rich silt that supplements mangrove productivity. The ratio of AGB to BGB was found to range from 1.8 to 2.2 with an average of 2, which was comparable to studies carried out globally (Komiyama et al. 2008) and the mangroves in Mahanadi Delta, India, which have an average of 2.3 (Sahu et al. 2016). Mangroves' reduced AGB to BGB ratio suggests that there is a significant biomass allocation in their underground root system, which may be necessary for them to stand firmly in muddy conditions (Harishma et al., 2018)

4.4.3 Relationship of AGB with diversity indices

The relationship of AGB with diversity indices shown that there was a strong correlation with AGB and Simpson index. Positive significant ($p < 0.05$) correlation ($r = 0.95$) in the natural mangrove areas. While there was no significance in the planted mangrove area. In the case of Shannon diversity index, there was strong correlation with AGB with significant level less than 5 % and $r = 0.94$. According to Caspersen and Pacala there is a positive relationship between diversity and productivity.

Table 4.5. Biomass and Carbon stock in different sampling station

	Station	AGB C in kg/100 m2	BGB C in kg/100 m2	AGB C in t/ha	BGB C in t/ha	Total biomass Cin t/ha
Natural	Poguru	143.5	75.2	14.3	7.5	21.87
	Kothapalem stn1	324.3	148.6	32.4	14.9	47.29
	Kothapalem stn 2	339.5	164.3	33.9	16.4	50.37
	Kothapalem stn3	295.3	150.8	29.5	15.1	44.62
	Kothapalem stn4	670.2	304.4	67	30.4	97.46
Planted	Nizampatnam stn 1	117.1	64.4	11.7	6.4	18.15
	Nizampatnam stn 2	285.9	141.7	28.6	14.2	42.77
	Nizampatnamstn 3	108.6	55.8	10.9	5.6	16.44
	Nizampatnamstn 4	127.3	66.7	12.7	6.7	19.4
	Mean biomassC			**26.7 ±17.8**	**13 ±7.8**	**39.8±25.6**

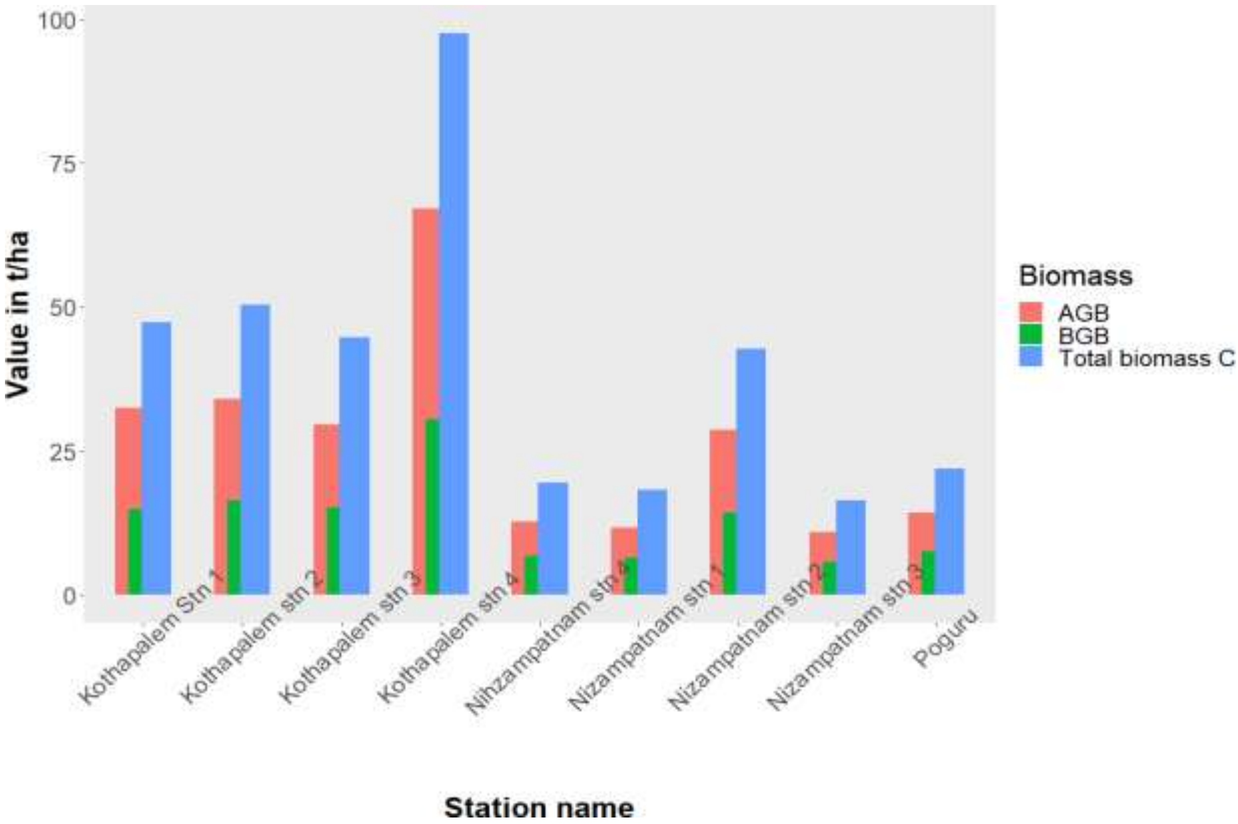


Fig.4.8: Graphical representation of Biomass and carbon stock

4.5. MANGROVE SEDIMENT

4.3.1 Sediment Carbon stock in the Bapatla mangroves

Even more carbon is stored in mangrove soils and sediments than in above-ground biomass. These ecosystems' anaerobic conditions and organic-rich mud inhibit the breakdown of organic materials, causing carbon to accumulate over time.

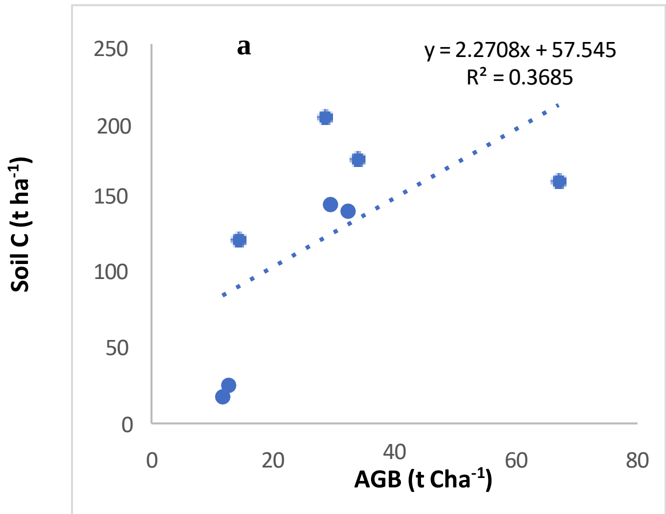
Long-term carbon sinks are thought to exist as a result of the carbon storage in the soil and sediments. This carbon can be trapped for centuries in undisturbed mangrove ecosystems.

Table 4.6. Sediment Carbon stock in different station

Sl. No	**Station**	**Mean (OC %)**	**±SD**	**Forest type**	**OC (gm/kg)**	**Bulk density (gm ml^{-1})**	**Carbon Stock in 1 msoil (ton/hector)**
1	Poguru	1.19	1.20	Natural	11.88	1.02	121.13
2	Kothapalem 1	1.37	1.07		13.70	1.02	139.69
3	Kothapalem 2	1.71	0.49		17.07	1.02	174.13
4	Kothapalem 4	1.57	0.46		15.66	1.02	159.74
5	Kothapalem 3	1.41	0.48		14.12	1.02	144.04
6	Nizampatnam 1	0.19	0.13	Planted	1.85	0.94	17.40
7	Nizampatnam 2	2.15	0.55		21.46	0.94	201.72
8	Nizampatnam 4	0.27	0.14		2.66	0.94	25.03
	Mean						**122.86±67.2**

Table 4.6 summarizes the sediment bulk density and the organic carbon pool in the 1m depth of the mangrove sediment in different study stations. The mean percentage organic carbon obtained in the present study was 1.23 (range of 0.19% to 2.15%). The total soil organic carbon ranged from 17.4 to 201.72 t C ha^{-1}. Nizampatnam station 1 has less carbon stock as compared to other station. Stations which have planted mangroves shows less sediment carbon stock except one station (Nizampatnam station

2). This station shows high sediment carbon stock (201.72 t C ha-1) as compared to other natural mangrove stations. Fig.4.11 and Fig.4.12 shows the graphical representation of organic carbon (%) with corresponding depth. The average sediment organic carbon (122.86±67.2 t C ha^{-1}) obtained for Bapatla mangroves. Findings of this study were also substantially higher compared to the sediment C-stock values obtained at 1 m depth in Okinawa, Japan (57.3 t C ha^{-1}; Khan et al., 2007), Kerala mangroves (81.3 t C ha^{-1}) and Mahanadi Mangrove Wetland, India (57.6 t C ha^{-1}; Sahu et al., 2016). However, the values were much lower than the value obtained from various regions of Indonesia (Murdiyarso et al., 2009). In comparison to the lower layers, the top 30 cm of the soil had a higher carbon concentration. But in this study some different trends are occurred. In Kothapalem station 2 shows that there was a decrease in the organic carbon content up to 30 cm depth. Soils collected from 1meters depth from Kothapalem station 2 (Fig.4.11 c) shows that (near to the sea) low organic matter content (less than 1%) up to 30 cm, probably due to frequent tidal flushing which rapidly exports mangrove litter. However, in case of Poguru (Fig.4.11 a), up to 30 cm there was an increase in the OC and then decreases. But when we considering the planted mangroves sites, only one station (Fig.4.12: b) there was high carbon stock (201.72 t ha^{-1}) as compare to other sites. Because this area has a huge mangrove loss (plate 4.4).



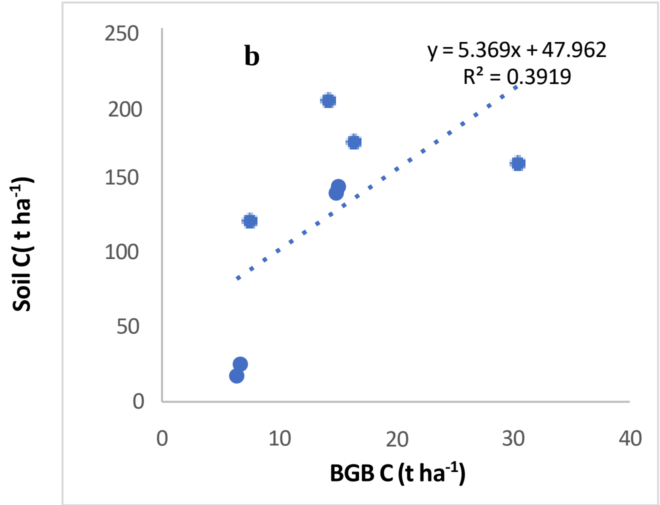


Fig 4.9: (a, b) Linear regression analysis between soil organic carbon and mangrove AGB and BGB

R square value of 0.36 suggests that about 36% of the variability in above ground biomass can be explained by change in organic carbon content. It shows in Fig 4.10.a. In the case of Below ground biomass R square value is 0.39. Here 39% of variability in below ground biomass can be explained by change in organic carbon content (fig.4.10 b).

Plate 4.4: Disturbed mangroves in Nizampatnam station 2

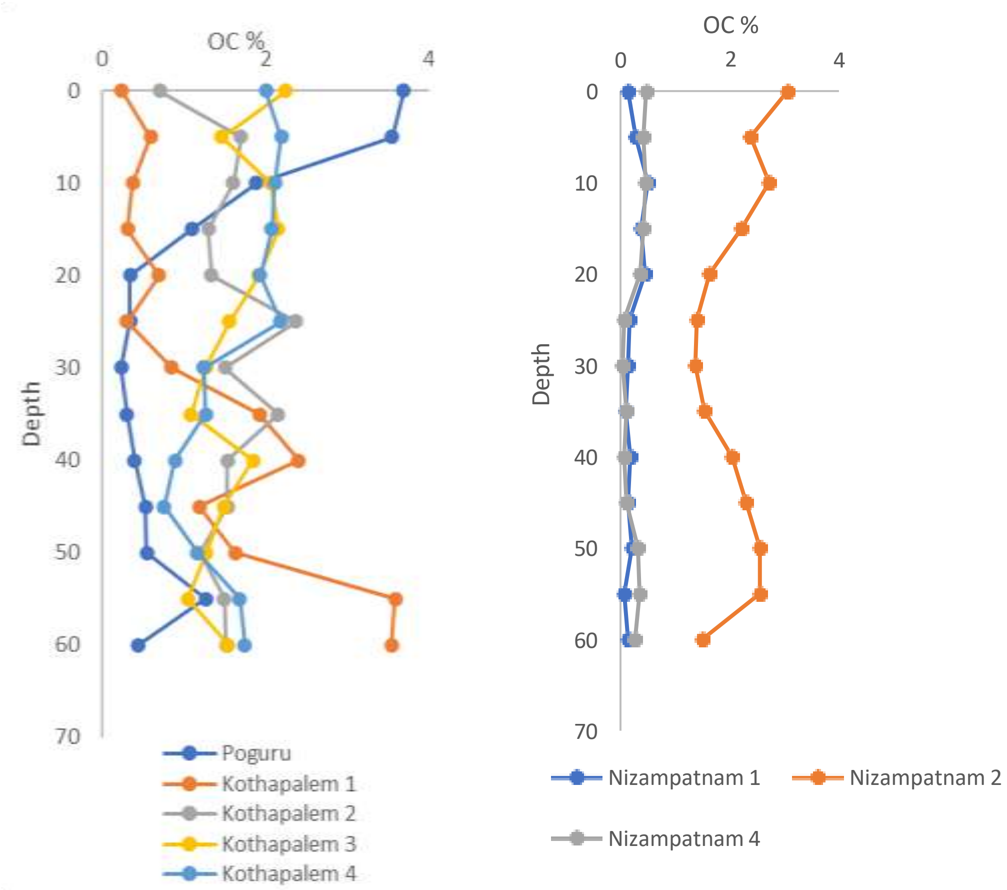
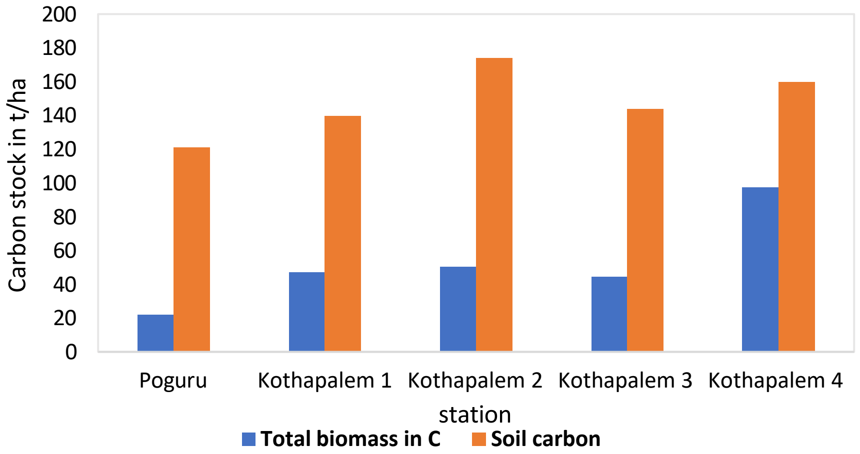


Fig.4.10: Organic carbon (%) with depth in natural and planted mangrove sampling stations



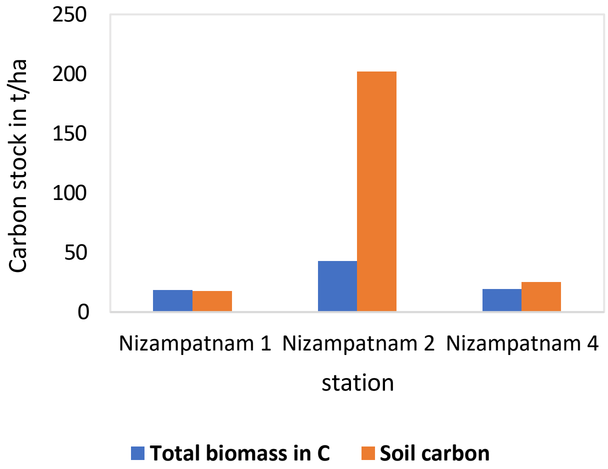


Fig.4.12 Carbon stock in natural and planted mangroves in the study area

Table 4.7 Carbon stock in the South East Asian countries

Country	**Location**	**AGBC$_{org}$ ha^{-1}**	**BGBC$_{org}$ ha^{-1}**	**SC$_{org}$ ha^{-1}**	**Total C$_{org}$ stock ha^{-1}**	**Reference**
Indonesia	West Papua	86.1	33.5	967.4	1087	Sasmito et al.,2020
	Bintuni	246.6	33.1	1032	1311.7	Taberima et al., 2014
	Timika	243.0	35.8	964.9	1243.7	Taberima et al., 2014
	Sembilang	311.8	27.9	979.5	1319.1	Murdiyarso etal.,2015
	Cilacap	18.7	2.5	571.6	592.8	Murdiyarso et al.,2015
	Kubu Raya	159.0	14.3	620.9	794.2	Murdiyarso et al.,2015
	Bali	12.4	-	678.3	690.7	Putra et al., 2019
India	Kerala	80.2	36.9	81.3	198.4	Harishma et al.,2020
	Sundarbans	-	-	-	360.1	Rahman et al.,2015
	Bhitarkanika	-	-	-	187.0	Bhomia et al., 2016
Bangladesh	Ganges delta	107.4	53.6	386.0	547.0	Donato et al.,2011
Sri Lanka	Kala Oya	171.7	33.0	376.3	581.0	Perera et al.,2017
	Batticaloa Lagoon	131.6	27.0	347.8	506.4	Perera et al.,2018
Japan	Okinawa	35.1	26.9	57.3	119.3	Khan et al.,2007
India	Bapatla, AndhraPradesh	26.7	13	122.8	162.5	Present study

4.6 InVEST MODELLING

4.6.1 Analysis of InVEST Blue Carbon Model results

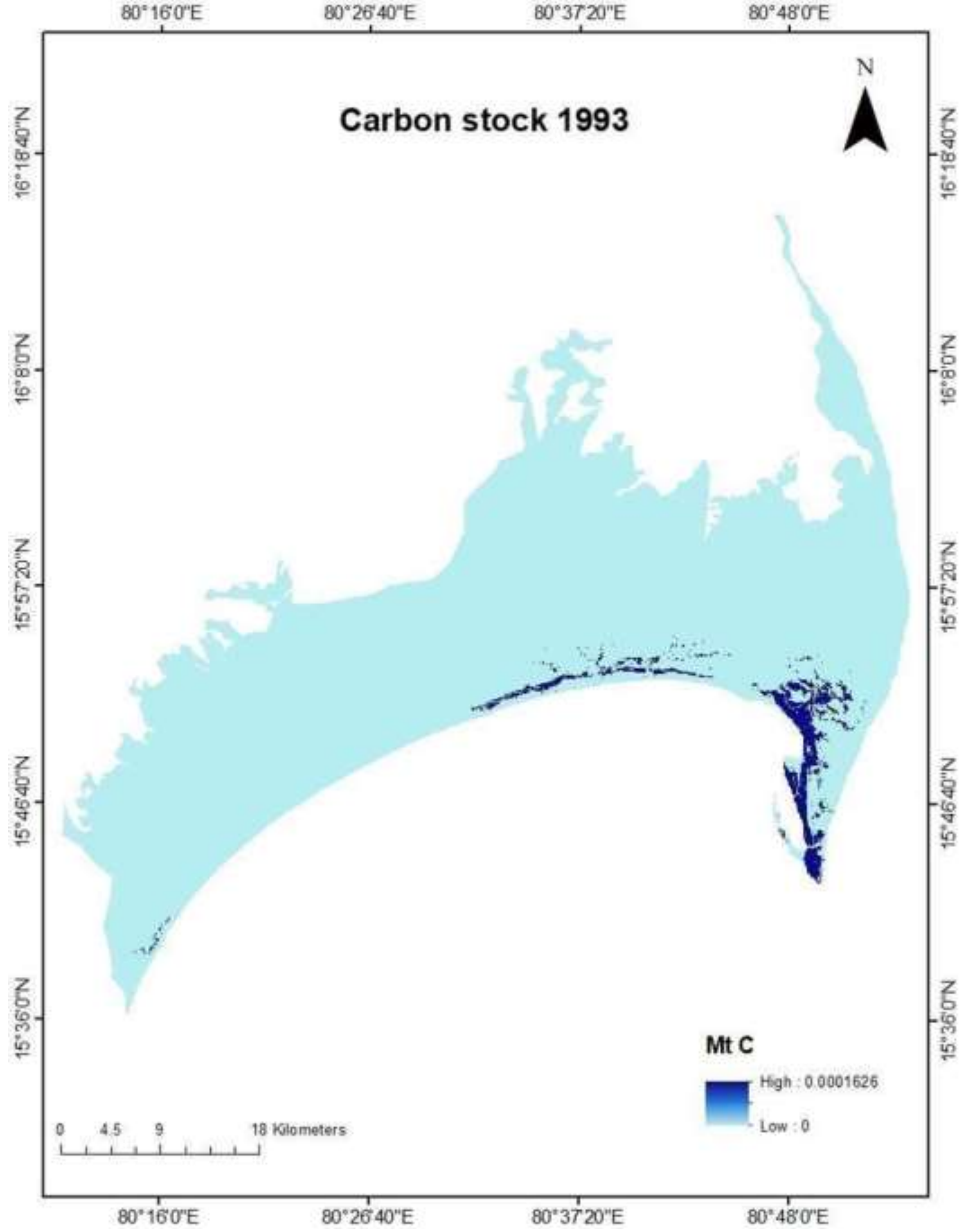


Fig.4.13: Map of carbon stock in 1993 for the study area

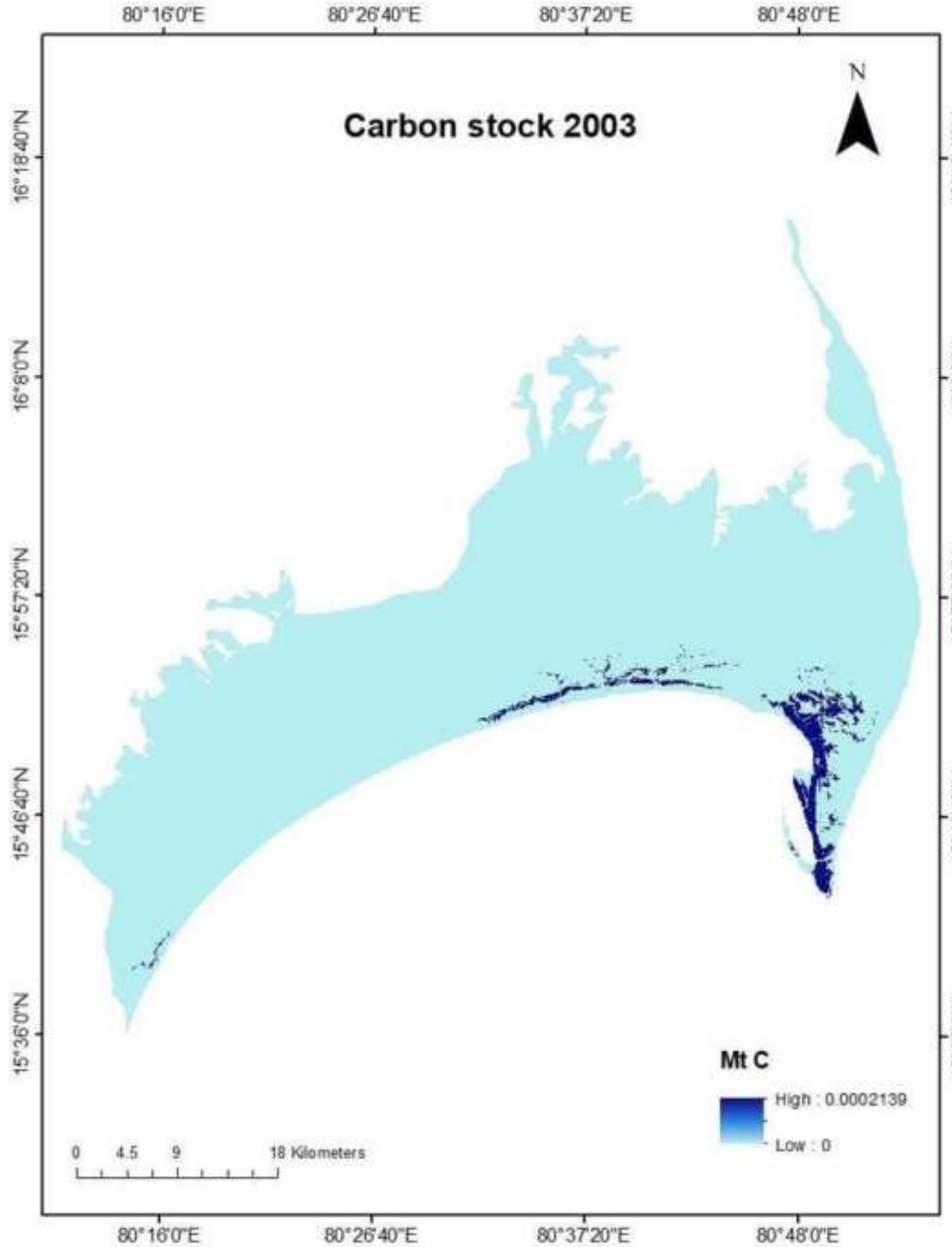


Fig.4.14: Map of carbon stock in 2003 for the study area

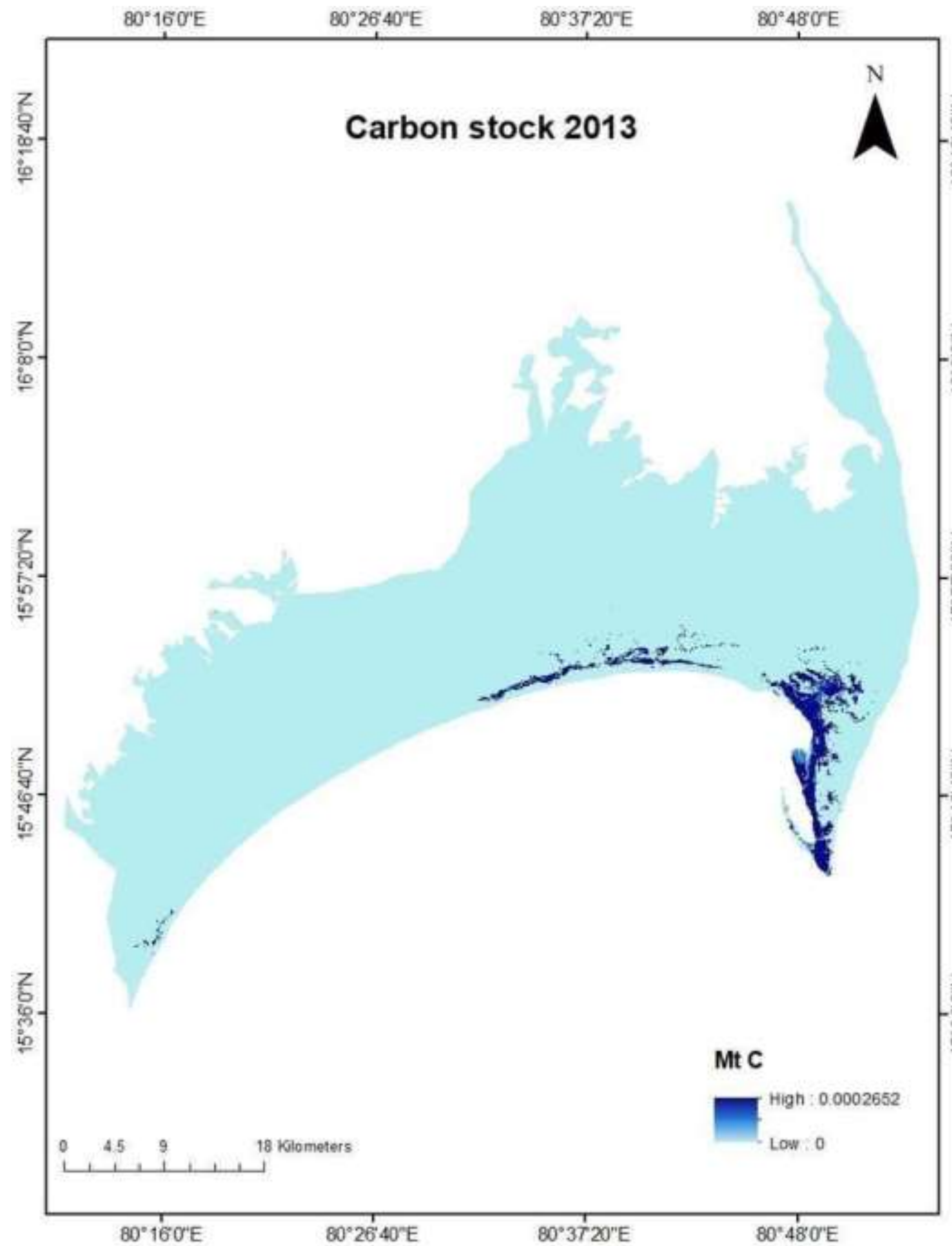


Fig.4.15: Map of carbon stock in 2013 for the study area

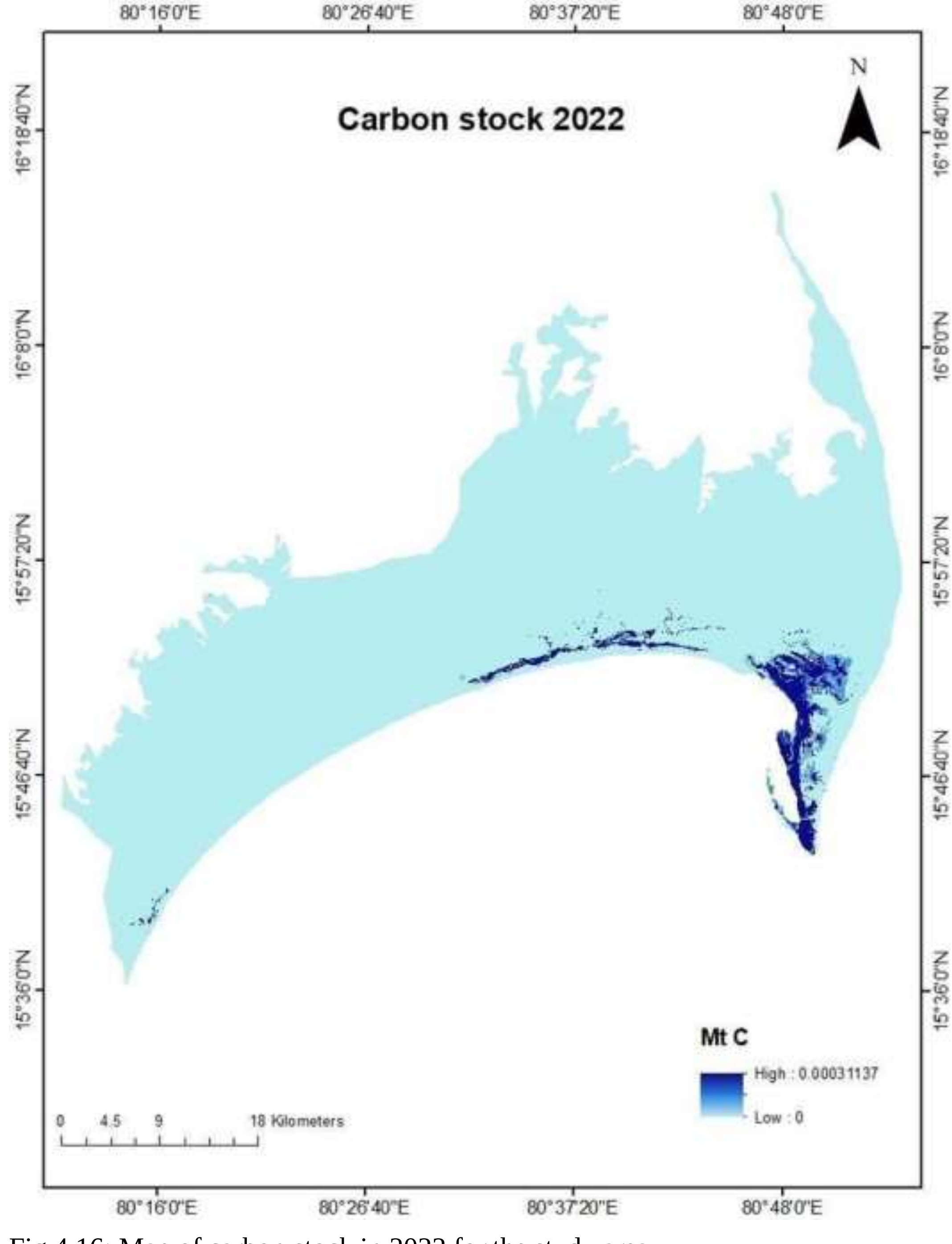


Fig.4.16: Map of carbon stock in 2022 for the study area

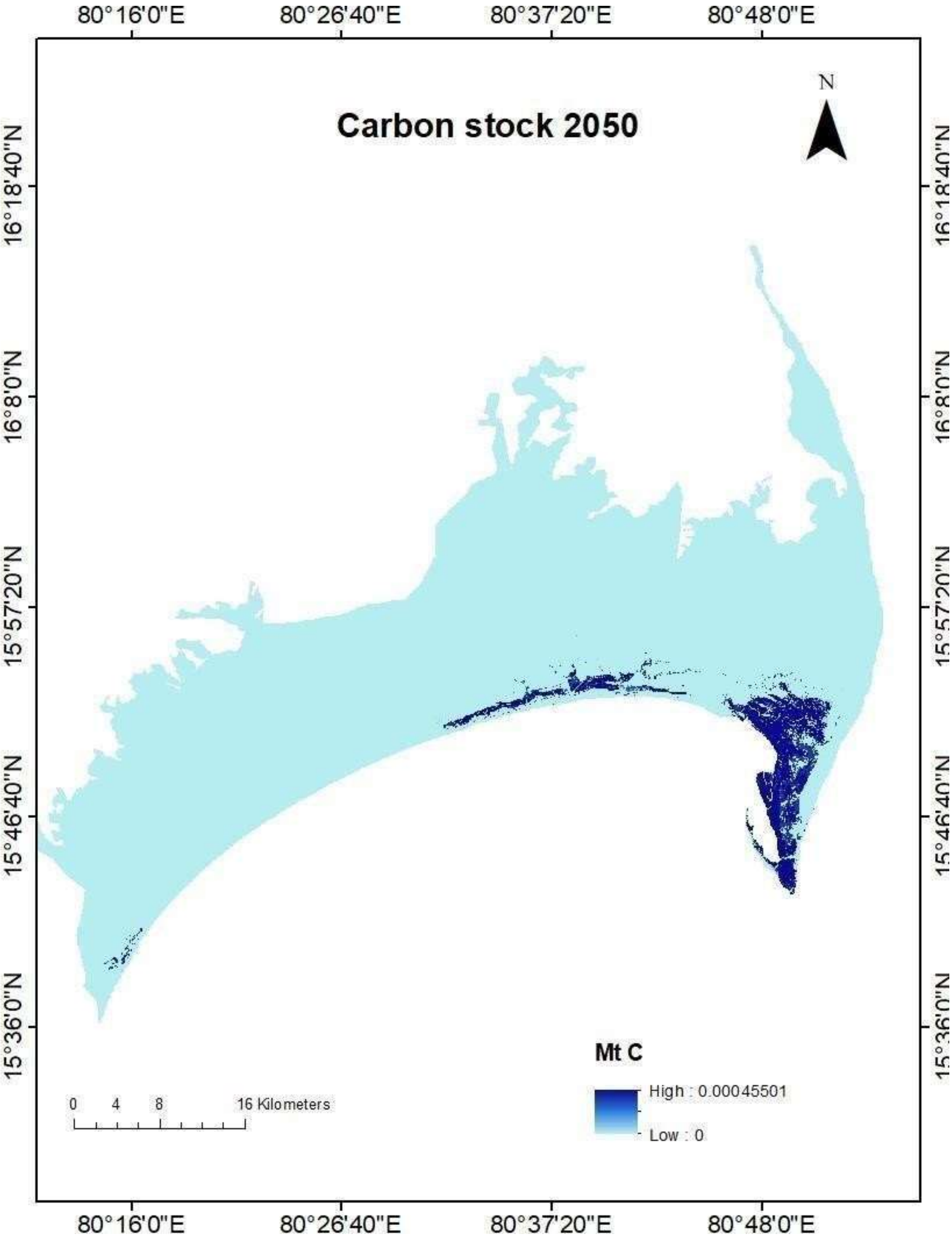


Fig.4.17: Map of carbon stock in 2050 for the study area

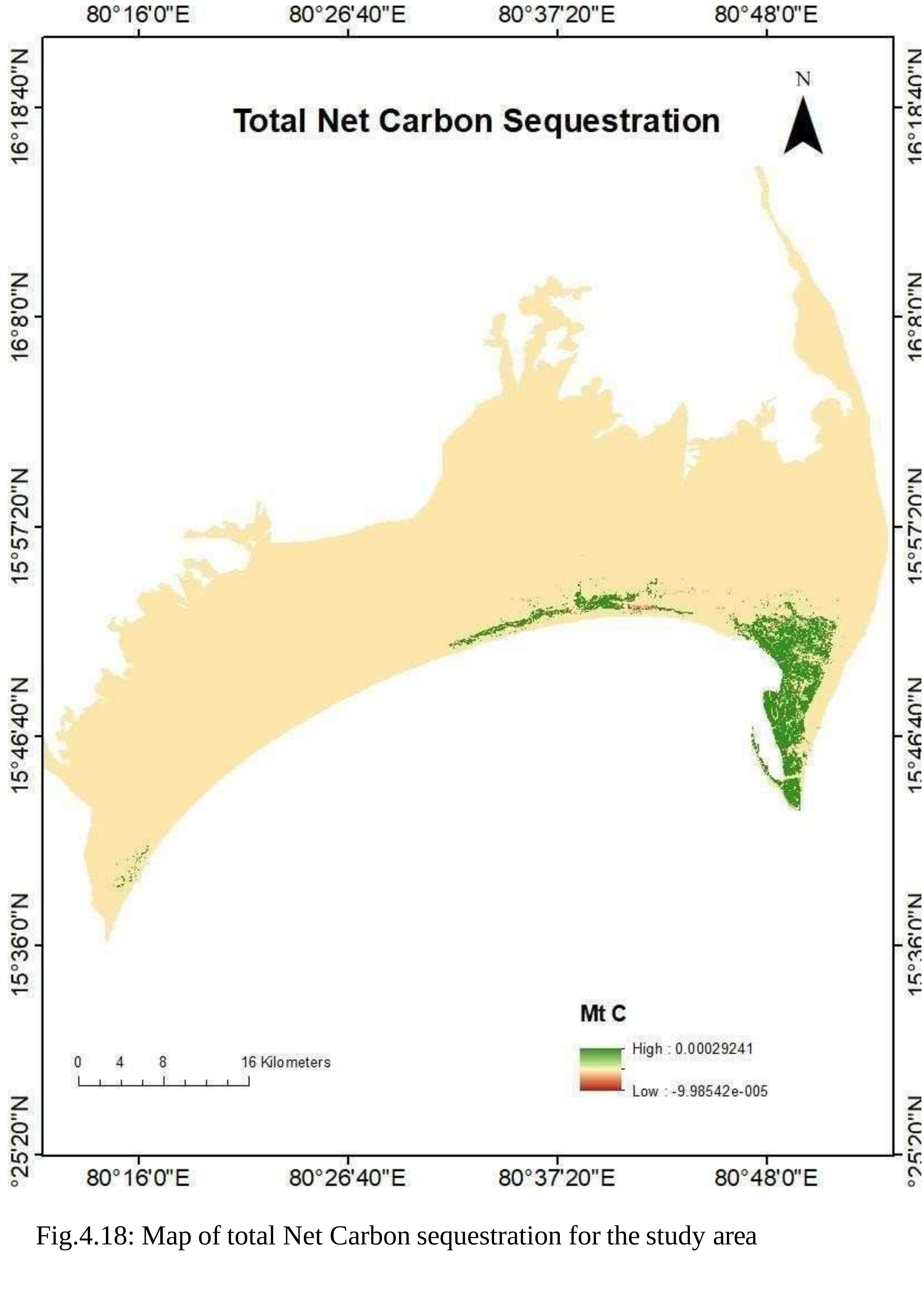


Fig.4.18: Map of total Net Carbon sequestration for the study area

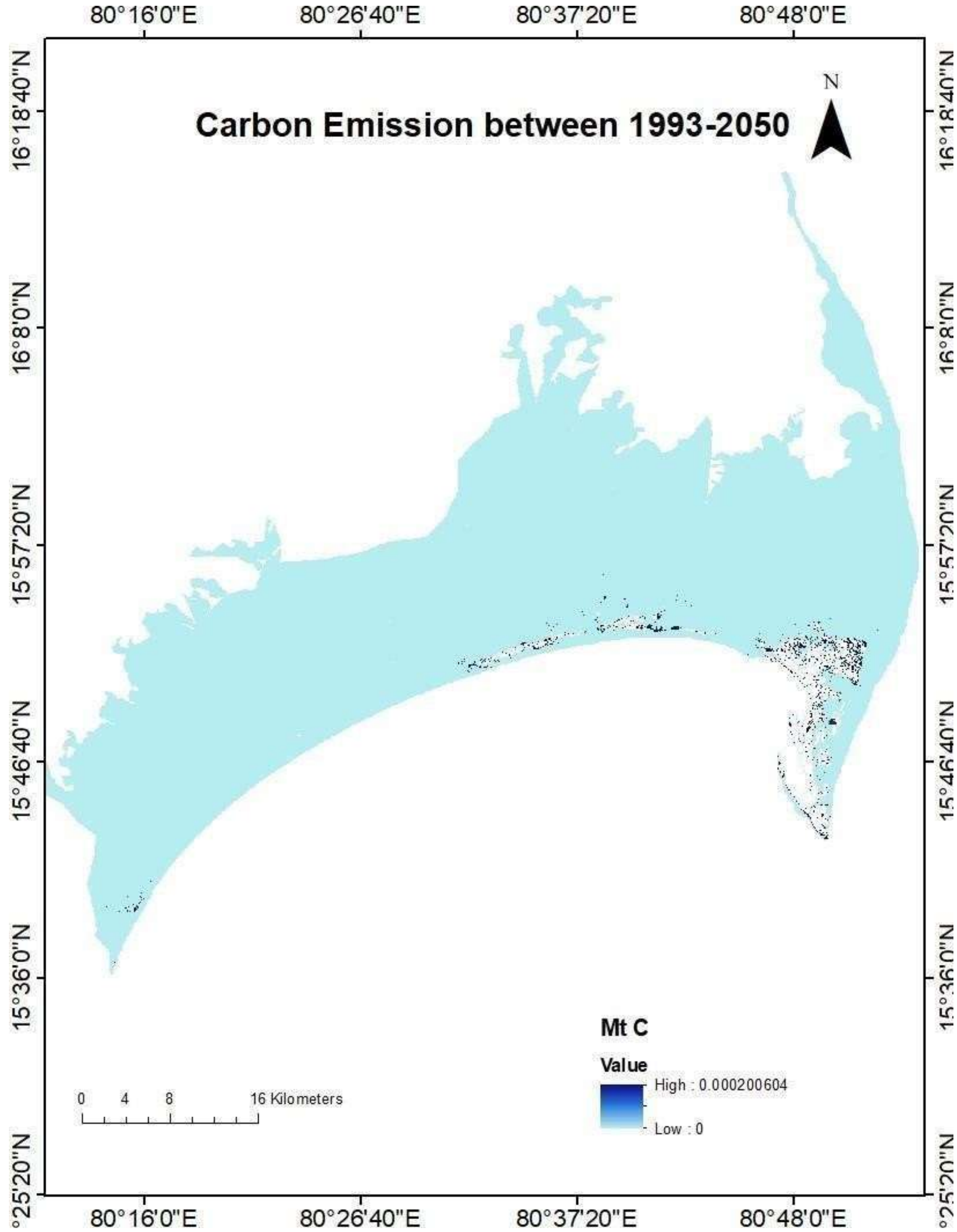


Fig.4.19: Map of emission between 1993 and 2050 for the study area

4.6.2 Bapatla Blue Carbon results

InVEST model is a powerful tool for assessing the carbon stock and other ecosystem services in the Bapatla Landscape, helping decision -makers make informed choice about land management and conservation strategies that can contribute to climate change mitigation and sustainable resource use. InVEST model results provide values for carbon stock across The Bapatla landscape at the baseline year of 1993 (Fig.4.14) to Transition year 2022 (Fig.4.17). Blue carbon stock refers to the amount of carbon stored in mangrove within biomass, soil, and litter carbon. Darker blue representing greater carbon storage per grid cell and lighter blue less carbon storage. The total carbon stocks varied significantly throughout the mangroves of the study area, there is an increasing trend in carbon stock from 1993 to 2050 (Fig.4.21)

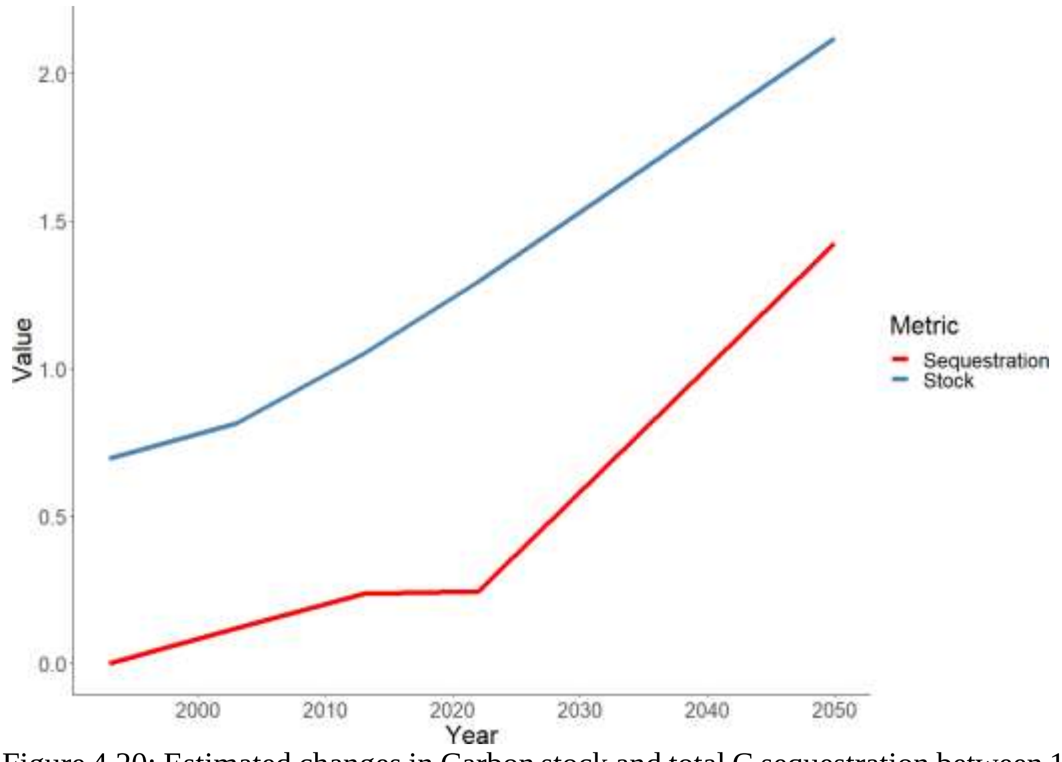


Figure 4.20: Estimated changes in Carbon stock and total C sequestration between 1993 and 2050

The trend shows that in the baseline year (1993) the carbon stock was measured as 0.69 Mt C (Megatons of Carbon) on an area of 4207 hectares. By 2003, this amount had increased to 0.81 Mt C, with a decrease in area of 3849.1 ha. During 2013, carbon stock again increases to 1.04 Mt C for the area 5698 ha and this trend repeated for the year 2022 also. There was an increase in the Carbon stock (1.29 Mt C) and mangrove area (6767.98 ha) in 2022. In this case, existing mangroves, if conserved, could potentially accumulate approximately 2.12 Mt C by 2050. Total carbon sequestration is estimated at 1.425 Mt C between the years 1993 and 2050, with net carbon gains of 0.119 Mt C, 0.236 Mt C, 0.244 Mt and 0.827 Mt C respectively for the years 2003, 2013, 2022 and 2050. Result shows that Emission between 1993 and 2050 estimated as 0.91 Mt C. Sharma et al. (2020) observed that nearly 60% of ecosystem carbon is lost due to mangrove degradation. The availability of fled-level data specific to the study area is not straightforward. The lack of data standardization on carbon. Kacem et al. (2022) revealed that coastal blue carbon sequestration in Moroccan lagoon was 1.47 Mt C for 1979-2020. For this study, blue carbon habitat occupies in an area of 5259 ha. One of the studies conducted in Bhitarkanika mangroves, Odisa, based on the InVEST Coastal blue carbon model, the standing BC stored in biomass, litter, and sediments of mangrove ecosystems in the study area is estimated to be 4.55 Tg C as of 2020 for an area of 194 km^2. (R. Kadaverugu et al., 2022). Most of the studies shows that there was a net decrease in mangrove cover. But in the case of Bapatla Landscape there was an increase in the mangrove cover. The model result also depicts that carbon stock and sequestration increases from 1993 to 2022. Analysing the output of InVEST model result, it clear that there was a gradual increase in the mangrove cover from 1993-2022. It also reflects in the C stock and sequestration results.

4.7 ECONOMIC VALUATION OF CARBON STOCK

Table 4.6 shows an estimate of CBCS revenue between 1993 and 2050, which is equivalent to $1,710,000 ($300,000 per year) at a 5% discount, $5,985,000 ($1,050,000 per year, $80,000 at a discount)) 1,550,000 USD per year) with a discount rate of 2.5%. CBC's estimated financial loss ranged from -$2,280,000 ($40,000 per year) to - $1,178,000 ($206,666.67 per year) at the SCC price. As compare the revenue from land uses that will harm mangroves to the social cost of carbon. For instance, turning mangroves into aquaculture ponds will bring in money, but the expense of repairing climate-related damage will outweigh the profit (Pendleton et al., 2012). In addition, the removal of mangroves will cause soil disturbance, which will release carbon dioxide, which contains more than 40% of the carbon already stored in the atmosphere (Lovelock et al., 2017). To account for the harm to the climate caused by the removal of mangroves, the cost of these carbon emissions must be added to the lack of opportunities to sequester carbon. The third and final part of this study shows the economic value of blue carbon sequestration and storage in the Bapatla landscape of Andhra Pradesh. Blue carbon habitats have been included in Nationally Determined Contributions (NDCs) for climate change mitigation because of their important role in carbon storage and sequestration rates (Herr et al. 2017; Lovelock and Reef 2020).

Indian government intends to create the Indian Carbon Market (ICM), wherein a national framework will be put in place with the goal of pricing greenhouse gas (GHG) emissions through the trade of Carbon Credit Certificates, thereby decarbonizing the Indian economy.

Indian parliament authorized the establishment of a domestic carbon credit trading scheme that is consistent with India’s climate goals. In comparison to less tangible ecosystem services (such as aesthetic, spiritual, and biological control), the monetary valuation of mangrove forest ecosystem services is significant because it places a value on nature. As a result, the valuation's findings are more concrete and simpler to understand. This makes it easier to spread the word about the need of managing forest ecosystems sustainably. The value can also serve as a reference point for individuals making private or governmental decisions related to climate change. The policy changes connected to the India's increased climate ambition for 2030 and 2050 will contribute to the successful implementation of carbon pricing across the economy.

Table 4.8. Present value (USD) of CBCS service in Bapatla for 57 years (1993-2050) at SCC prices

Carbon Cost **SCC prices/tCO$_2$ eq**	CBCS service loss in Mega tones of C (1993-2050) (Total loss is -0.19 Mt Cat a rate of -6.55 Mt C/y)		CBCS service gain in Mega tones of C (1993-2050) (Total gain 1.425 Mt C ata rate of 25 Mt C/y)	
	Economic value of total loss by (US$)	**Economic value of annual loss by (US$/y)**	**Economic value of total gain by (US$)**	**Economic value of annual gain by (US$/y)**
5%: US$12	-2280000	40000	17100000	300000
3%: US$42	-7980000	140000	59850000	1050000
2.5%: US$62	-11780000	206666.67	88350000	1550000

CHAPTER 5

SUMMARY

Numerous ecosystem services that mangrove ecosystems offer are crucial for managing coastal settings. Anthropogenic stressors such as urbanisation, agricultural expansion, and aquaculture farms close to mangrove habitats have a direct impact on these ecosystems. India has some of the region's most biologically varied mangrove regions. Anthropogenic and climatic drivers are becoming more prevalent, endangering their existence. India's east coast is particularly vulnerable to a rise in extreme weather events, including cyclone frequency and intensity as well as sea level rise.

Despite their critical importance in managing coastal ecosystems, the ecological services provided by the Krishna mangroves remain largely unquantified. Based on field data collection and satellite imageries of these mangrove species, it was found that the mangrove patches are replaced with agricultural fields and aquaculture farms, which pose a direct threat to mangrove habitats. In addition, very few studies integrate scenario-based analysis into the assessment of mangrove ecosystem services. Scenario- based analysis is an effective assessment tool for predicting long-term changes in socio-environmental systems resulting from many uncertain factors.

This study investigates the blue carbon value of Bapatla mangroves in Andhra Pradesh based on LULC analysis. This demonstrates the economic importance of the coastal blue carbon services and the opportunity for countries to benefit from climate change financing and strengthen their efforts to manage coastal ecosystems. The main results of this study are: (1) Monitoring of LULC changes over three decades (29 years) showing an increase in mangrove cover across the landscape since 1993, (2) Assessment of carbon supply of planted and natural mangroves. the high carbon stock of natural mangroves in the study area compared to planted areas, (3) despite LULC changes, 0.69 Mt C of carbon is still naturally removed from the natural growth of coastal habitats, carbon sequestration reached 1.29 Mt C in 2022 (4).) InVEST model predicts that in existing mangrove forests, to accumulate approximately 2.12 Mt C by 2050 (5) if maintained, the monetary value of CBCS provided by coastal ecosystems is estimated to be US$ 1,050,000 in benefits with a 3% discount. rate as per SCC. InVEST Coastal

Blue carbon model results are solution to the policymakers, administrator and environmentalist for adopting a suitable land use management over this eco-sensitive region.

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MODELLING AND PREDICTION OF IMPACT OF CLIMATE CHANGE ON "BLUE CARBON " ECOSYSTEM SERVICE PROVIDED BY TROPICAL MANGROVES, EAST COAST OF INDIA

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ABSTRACT

Mangrove deforestation by land use conversions is the greatest threat to the conservation of coastal ecosystem. Here, the aim of this study is to predict the changes in mangrove regulatory services in Bapatla district Andhra Pradesh. Also estimate the carbon stock of planted and natural mangroves in the study area. Core of this study is Modelling and evaluation of spatial-temporal changes in blue carbon stocks and net sequestration potential in mangrove forests in Bapatla Landscape Andhra Pradesh, from 1993 to 2050. InVEST Coastal Blue Carbon model, which quantifies the potential carbon sequesteredin the study area based on changes in the land use and land cover. Also estimate the economic value of coastal blue carbon in Bapatla mangroves by analysing the changes in carbon storage that have taken place over 57 years. Field studies reveals that carbonstock in soil and biomass were high in natural mangroves as compared to planted mangroves. There is an increased trend in carbon stocks and net sequestration of mangroves. Over all net carbon sequestration was approximately 1.42 Mt C over a period from 1993 to 2050. The future projection by InVEST model reveals that there was a net increase on the carbon sequestration (0.83 Mt C from 2022) as a business-as-usual scenario. The monetary value of CBCS was subject to gains of between US$ 300000 and 1550000 per year, and losses of between US$ 40000 and 206666 per year, according to recent estimates by social cost of carbon (SCC). In spite of loss of mangrove vegetation over Krishna delta due to coastal erosion, deforestation, decline and aquaculture encroachments, several mangrove- restoration projects taken up during 1991–2008 led to an overall increase in its area. This study only considers about the regulatory services provided by mangroves. This finding can support the development of public policies for mangrove conservationand restoration actions to mitigate climate impact.

Key words : Coastal blue carbon, Land use/Land cover, Mangrove, InVEST model