SATELITTE- BASED CARBON STOCK ASSESSMENT IN MANGROVES SWAMPS AT CHORAO, GOA.

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DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled, "satellite- based carbon stock assessment in mangroves swamps at chorao, Goa." is based on the results of investigations carried out by me in the M.Sc. Environmental science at School of Earth Ocean and Atmospheric Sciences, Goa University under the Supervision of Dr. Sheryl O. Fernandes and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities / College will be not be responsible for the correctness of observations / experimental or other findings given the dissertation.

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COMPLETION CERTIFICATE

This is to certify that the dissertation report "satellite- based carbon stock assessment in mangroves swamps at Chorao, Goa." is a bonafide work carried out by **Ms Nikita Nagesh Mankikar** under my supervision in partial fulfilment of the requirements for the award of the degree of **M.Sc. Environmental science** in the Discipline Environmental Science at the School of Earth Ocean and Atmospheric Sciences, Goa University.

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PREFACE

This study aims to comprehensively assess vegetation dynamics, biomass distribution, and carbon stock variations within a specific study area, utilizing remote sensing data from Sentinel-2 imagery via Google Earth Engine. The investigation covers multiple aspects, including NDVI (Normalized Difference Vegetation Index) analysis, biomass estimation, and carbon stock assessment, spanning different temporal scales. In the month of January 2024, the NDVI values ranged from -0.08 to 0.65, indicating a wide spectrum of vegetation cover within the study area. Concurrently, total biomass was estimated to range from 0.37 to 101.78 tonnes per hectare, reflecting substantial variability in vegetation productivity and biomass accumulation across the landscape. Similarly, carbon stock measurements ranged from 0.17 to 48.44 tonnes per hectare, highlighting the spatial heterogeneity of carbon storage within the ecosystem. Moreover, a comparative analysis of NDVI values between the years 2001-2014 and 2024 revealed significant changes in vegetation cover over time. By examining these temporal trends, the study aims to elucidate the underlying drivers of vegetation dynamics, such as land use changes, climate variability, or anthropogenic impacts, and their implications for ecosystem health and resilience. Through this integrated approach, the study endeavours to provide valuable insights into the current status and trends of vegetation, biomass, and carbon stocks within the study area, contributing to informed decision-making processes for sustainable land management, conservation, and climate change mitigation strategies.

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ABBREVIATIONS USED

Abbreviation	Full-form
AGB	Above ground biomass
BGB	Below ground biomass
ESA	European Space Agency
GEE	Google earth engine
MSI	Multi- Spectral Instrument
NDVI	Normalized difference vegetation index
NIR	Near- infrared
NASA	National Aeronautics and Space Administration
SAR	Synthetic Aperture Radar
SWIR	Short Wave Infra-Red
TON/HA	Tonnes per hectare
USGS	United States Geological Survey
VIS	Visible red light
IPCC	Intergovernmental Panel on climate change

ABSTRACT

Mangrove forests are the most carbon-rich ecosystems on the planet. Protecting mangroves is crucial for reducing greenhouse gas emissions and promoting sustainable ecosystem growth. Lately Carbon stock estimation has gained attention of many countries, with the aim of mitigating the impacts of climate change and to reduce emissions. Carbon dioxide is the most concentrated greenhouse gas in the atmosphere and is one of the main culprits for global warming. Compared to tropical rainforests and terrestrial forests, mangrove forests have a threefold higher capacity to absorb Carbon dioxide. Furthermore, mangrove forests have the potential to generate revenue through a blue economy; so, a precise approach is required to examine the carbon store of mangroves. A quick, inexpensive, and reliable way to obtain information on carbon stock estimation is obtained to compute carbon in the mangrove forests based on satellite imaging and vegetation index with data from remote sensing. The purpose of this study was to determine the most accurate model for Sentinel-2 imagery-based Carbon stock estimation of mangroves at Dr. Salim Ali bird sanctuary Goa (Chorao). Google Earth Engine and Sentinel-2 imagery was used to calculate the NDVI, Total Biomass and for Carbon stock estimation. The NDVI for the month of January 2024 was between the range of -0.08 to 0.65. Total biomass to found to be between the range of 0.37 – 101.78 tonnes/hectare and carbon stock was estimated to be 0.17 - 48.44 tonnes/hectare. Also NDVI values for the year 2001-2014 and 2024 were compared to detect the change in the vegetation cover and a significant difference was noticed.

Keywords: Mangrove, carbon-stock, GIS, Biomass, NDVI.

CHAPTER 1. INTRODUCTION

1.1 General

Mangroves are found in the tropical and subtropical coastal intertidal zones. The mangrove community is composed of salt-tolerant plants that thrive in soft, marshy mud, typically trees and shrubs with broad, leathery, evergreen leaves. Roots from some trees' main stems and branches grow vertically down and provide additional support. Many others have roots that protrude into the air that can be entirely exposed at low tide. The roots are intended to absorb air for respiration because moist soil is poor in oxygen.

Certain Mangrove trees have seeds that grow while the fruits remain on the plant. Green seedlings of various lengths dangle from the parent plants until they reach the appropriate length for their species, at which point they fall vertically into the soft mud. They quickly establish a root system and become self-sustaining plants. The ability of certain mangroves to 'give birth' to living seedlings rather than dropping their fruits or seeds is known as vivipary. Mangroves use a variety of survival and reproduction strategies to produce a distinct type of vegetation that thrives on the border between two ecosystems.

Until the 1960s, mangroves were largely seen as "economically unproductive areas" and were therefore cleared to make room for new land uses. Nonetheless, their advantages to the ecology and economy have increasingly become apparent, and their importance is recognised. Mangroves are a type of halophytic plant that supports a range of other coastal and marine environments. They are also known as salt-tolerant forests. They provide a diverse range of environmental and economic products and services.

Mangroves cover around 75% of the world's tropical coastline, yet they account for less than 1% of the planet's area (Saenger, 2002).

Mangrove trees absorb Carbon dioxide from the atmosphere and utilise it to make oxygen (and carbon via photosynthesis. They integrate carbon into their leaves and branches. The tides routinely flood coastal woods, bringing carbon into them in the form of organic material from the carcasses of plants, animals, and other species. Depending on the climate, mangroves can store carbon in sediments for decades, centuries, or even millennia. This is due to the slow breakdown of organic material, which produces Carbon di oxide, in the saline and oxygen-poor substrate.

Scientists estimate that mangrove sediments contain 3-5 times as much carbon as tropical rain forest soils. The total quantity of carbon expected to be stored in coastal forests worldwide ranges between 4 and 20 billion tonnes. Depending on the environment, these carbon sinks grow faster in some woods and slower in others. Logging and other damage of mangrove forests releases carbon into the atmosphere as Carbon-di- oxide. The sediment can now be stirred up because the mangrove roots are no longer holding it in place. The organic material in the sediment decomposes as it is exposed to oxygen and bacteria.

Mangrove biomass is typically measured directly using well-established forest inventory techniques, which include the time-consuming collection of tree measurements (such as height, canopy/crown area, and diameter at breast height) within specific plots. These non-destructive tree measurements are then used in allometric equations to relate tree above ground biomass (Kauffman and Donato, 2012; Picard et al., 2012).

Using a typical multiplier of 0.45–0.50, biomass estimations for mangroves can then be translated to estimates of above-ground carbon (IPCC, 2014). Assuming that the surveyed plots' average values and tree density metrics are typical of the larger mangrove area, estimates of biomass and carbon per tree can be scaled up to area estimations. In addition to being time- and resource-consuming, collecting in-situ measurements from mangrove trees can be dangerous, especially in dense mangrove stands or isolated locations with restricted accessibility. There is also a chance of catching potentially fatal diseases spread by mosquitoes or coming into contact with predatory animals (like crocodiles). When conducting in situ surveys of mangroves, these obstacles may cause measurement errors and inadequate survey coverage. When actual measurements from mangroves are not feasible, safe, or economical, default carbon values might be applied to calculate carbon stocks at sites (IPCC, 2014). Nevertheless, this results in lower carbon market prices and adds a significant degree of uncertainty to the above-ground biomass and derived carbon estimations (Gibbs et al., 2007; Kauffman and Donato, 2012; Howard et al., 2014). On the other hand remote sensing methods or airborne imagery can be used to monitor vegetation dynamics over a large area with high accuracy and lower cost.it is possible to map vegetation cover distribution and change over time.

Understanding the carbon dynamics of mangrove ecosystems is essential for effective conservation and climate change mitigation strategies. This project aims to estimate the carbon sequestration capacity of mangrove forests in [location], utilizing a combination of field measurements, remote sensing data, and modeling techniques. By quantifying the amount of carbon stored in mangrove biomass and sediments, we can assess the contribution of these ecosystems to global carbon budgets and identify areas for targeted conservation efforts.

In this study Google earth engine (GEE) was used to generate the NDVI (Normalized difference vegetation index) values of the study area. The GEE is a cloud-based geospatial analysis platform that enables users to visualise and analyse satellite images of our planet. Scientists and non-profit use Earth Engine for remote sensing based research, predicting disease outbreaks, natural resource management, and more. Study was conducted using Sentinel-2, which provides high resolution multispectral imagery to map the vegetation accurately. Sentinel-2 is a satellite constellation developed by the European Space Agency (ESA) for Earth observation.

The Sentinel-2 mission is part of the European Union's Copernicus programme and is designed to provide high resolution optical images of the Earth's surface for a wide range of applications, including land use and land cover mapping, agriculture, forestry, and coastal monitoring. Sentinel 2 is equipped with a multispectral imaging instrument called the Multi- Spectral Instrument (MSI). which has 13 spectral bands in the visible, near infrared and short wave infrared regions of the electromagnetic spectrum. These band ranges from 443 nanometres to 2190 nanometres and has a spatial resolution of about 10 meters. The satellite have a revisit time of about 5 days at the equator, which means that they can acquire images of the same location on the Earths surface every 5 days.

Normalized difference vegetation index (NDVI) is a widely adopted parameter utilized in vegetation classification, and it is also applied in conjunction to Sentinel -2 data. NDVI is a commonly used remote sensing index to monitor vegetation. It measures the difference between the near- infrared (NIR) and visible red light (VIS) of a surface. Which is sensitive to the amount of chlorophyll present in the vegetation, NDVI can provide information on the spatial and temporal distribution of vegetation cover and its changes over time. Using NDVI and above ground biomass (AGB) and below ground biomass (BGB) carbon stock can be determined.

A number of Earth-observing satellite missions are jointly administered by NASA and the United States Geological Survey (USGS) as part of the Landsat programme. Eight of the nine missions that have been carried out so far have been operational. Landsat Next, the tenth mission, is currently in the planning stages with a late 2030 launch window. Images of the Earth's land surfaces have been continuously and reliably taken by Landsat satellites since the launch of Landsat 1 (previously known as ERTS-1) in 1972. Our knowledge of the Earth, its natural resources, and its dynamic processes has significantly increased because to the Landsat programme, which has amassed over five decades of observational experience and produced a data library of unparalleled quality and scope .In GEE, Landsat data can be accessed via the ee.ImageCollection interface. Based on the satellite sensor (Landsat 5, 7, 8) and degree of preprocessing. To choose the photos that best fit your analytic needs, you can filter Landsat image collections using parameters like date, location, cloud cover, and image quality.

After choosing the appropriate Landsat images, you can carry out a number of analyses, such as time-series analysis, change detection, picture compositing, and the computation of spectral indices (NDVI, NDRE etc.). GEE offers time-series charts, interactive maps, and exportable images as tools for visualising the analysis results.

1.1.1 Importance of Chorao mangroves:

Ecologically and socioeconomically, the Chorao mangroves in Goa are vital because they contribute significantly to carbon sequestration, biodiversity conservation, coastal protection, and livelihood support. This is a closer look at the significance of Goa's Chorao mangroves, with an emphasis on their contribution to the carbon stock. Mangroves are very effective at storing carbon in their biomass and sediments. They do this by using photosynthesis to absorb carbon dioxide from the atmosphere. By storing organic matter in their soils and flora, the Chorao mangroves aid in the sequestration of carbon, which helps to slow down global warming and cut down on greenhouse gas emissions.

1.1.2 carbon stock estimation:

Mangroves are very good at absorbing carbon dioxide from the atmosphere. We can gain a better understanding of mangroves' function in mitigating climate change by calculating their carbon stock. Policymakers and environmentalists developing measures to mitigate climate change will find this information useful. Mangrove carbon sequestration services may be made profitable through the use of mechanisms like carbon trading or payments for ecosystem services, which are made possible by the estimation of carbon stocks in mangroves. In the end, this can support the preservation and sustainable management of mangrove ecosystems by offering financial incentives for their preservation and restoration.

A deeper comprehension of mangrove ecological functions and societal value results from quantifying their carbon content. This value, which takes into consideration the numerous advantages offered by mangrove ecosystems beyond carbon sequestration, might assist decision-makers in prioritising conservation efforts and allocating resources efficiently. For the purpose of developing and implementing policies pertaining to biodiversity preservation, climate change mitigation, and sustainable development, accurate estimations of the reserves of carbon in mangroves are essential. Targets, plans, and initiatives aiming at local, national, and international mangrove habitat preservation and restoration can be informed by this information.

Estimates of carbon stocks are used as baseline data to track changes in mangrove ecosystems through time. We can measure trends in ecosystem health, evaluate the success of conservation and restoration initiatives, and track our progress towards climate targets and conservation. The assessment of carbon stocks in mangrove ecosystems is a crucial scientific endeavour that advances our comprehension of ecosystem dynamics, carbon cycling mechanisms, and the effects of environmental modifications on mangrove ecosystems. This information improves our capacity to foresee and control how mangroves would react to potential future climatic conditions and human activity.

1.2 Objectives

1. To compare NDVI values for the years 2001- 2014 – 2024 of the study area to detect changes in vegetation cover.

2. To estimate biomass of mangroves using the normalized difference vegetation index (NDVI).

3. To assess the mangrove carbon stock at Dr Salim Ali Bird Sanctuary.

1.3 STUDY AREA

Chorao is an estuary island in the backwaters of the Mandovi River, lying between coordinates 15°25'N and 15°30'N , 73°45' East and 73°59' East. It is the largest riverine island in Goa. Mangrove swamps dominate the western edge of the island of Chorao along the River Mandovi, creating a bird-watchers' paradise named after India's most famous ornithologist. This is Goa's only bird sanctuary, covering an area of 1.8 square kilometres. This island is home to a diverse range of both indigenous and migratory birds.. Apart from a rich variety of coastal birds, one may spot flying foxes, jackals and crocodiles. The area is made up of mangrove vegetation. Mangrove ecosystems are among the most productive known to humans. They provide shelter and hatching places for a variety of fish and insects that are at the bottom of the food chain. The Sanctuary is crisscrossed with water channels. As a result, if one wishes to travel by boat, one must do it during high tide. Canoes, on the other hand, have access to the waterways even at low tide.

The Sanctuary floral community consist of nine mangrove species and four associate mangrove species. The most common species was Avicennia marina, followed by Rhizophora mucronata, Sonneratia alba. The composition of mangrove species varied significantly at the intertidal zone. Rhizophora mucronata dominated the lower intertidal zone, followed by Avicennia marina and Bruguiera cylindrica in the middle zone, and Avicennia marina in the high tide zone. (CMPA Technical Report Series No. 09.)

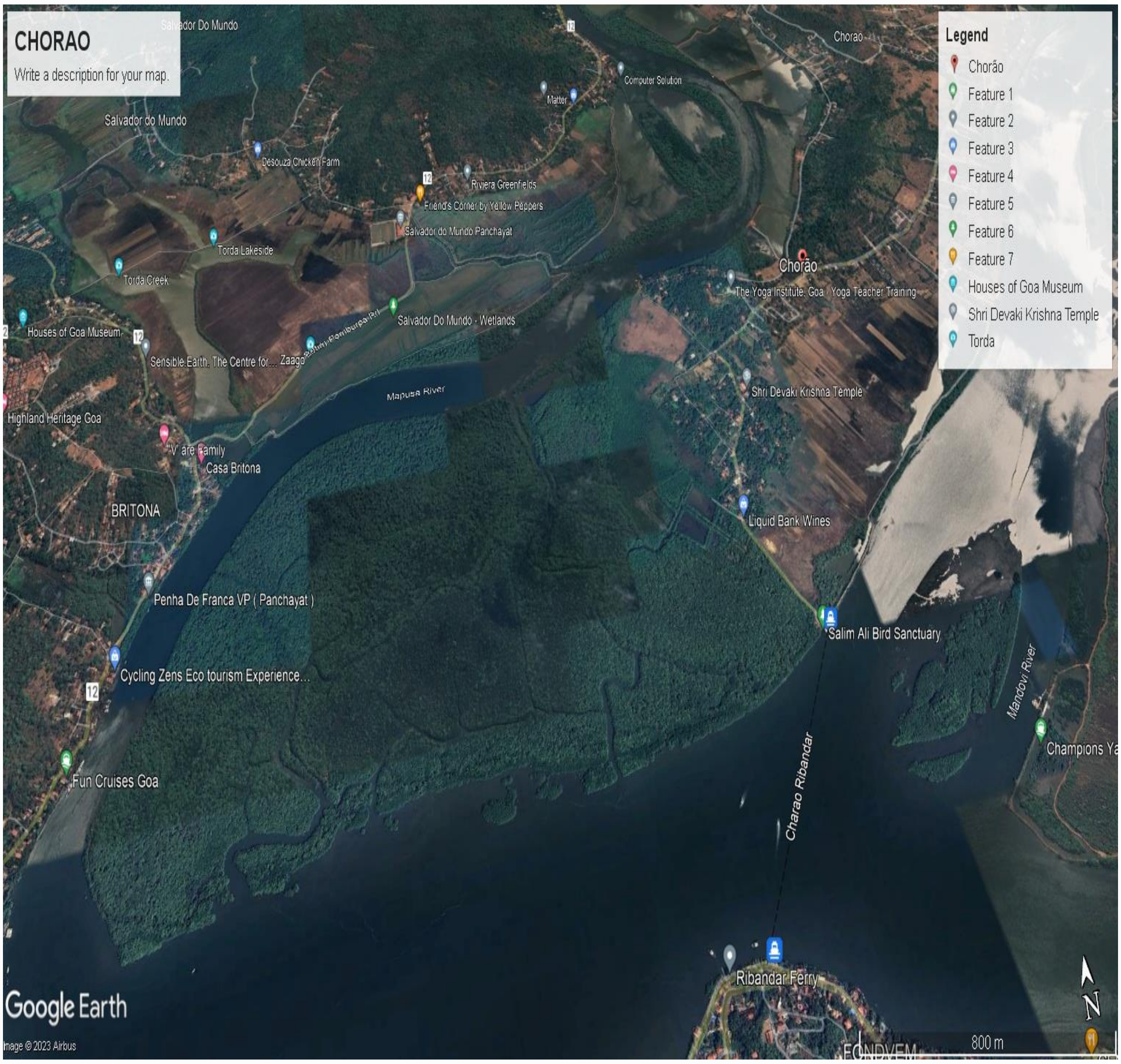

Fig. 1.1. Study area captured using Google Earth Pro.

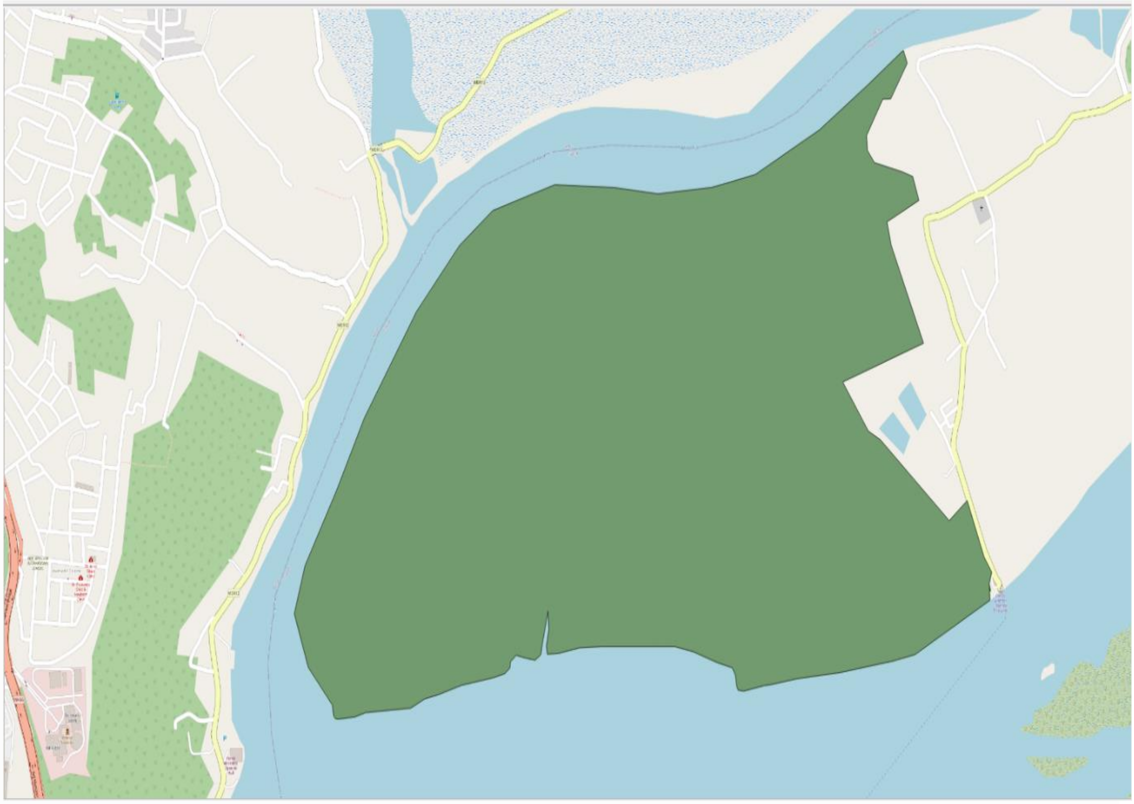

Fig. 1.2. shapefile used of the study area in GEE.

Table. 1.1. Details of mangrove species present in the study area.

SL NO	SCIENTIFIC NAME
1.	*Avicennia marina*
2.	*Avicennia alba*
3.	*Sonneratia alba*
4.	*Rhizophora mucronate*
5	*Rhizophora apiculata*
6	*Acanthus illicifolius*
7	*Aegiceras corniculatum*
8	*Kandelia candel*
9	*Bruguiera cylindrica*
10.	*Excoecaria agallocha*

11.	*Derris heterophylla*

(Source: Forest Department Govt. of Goa website)

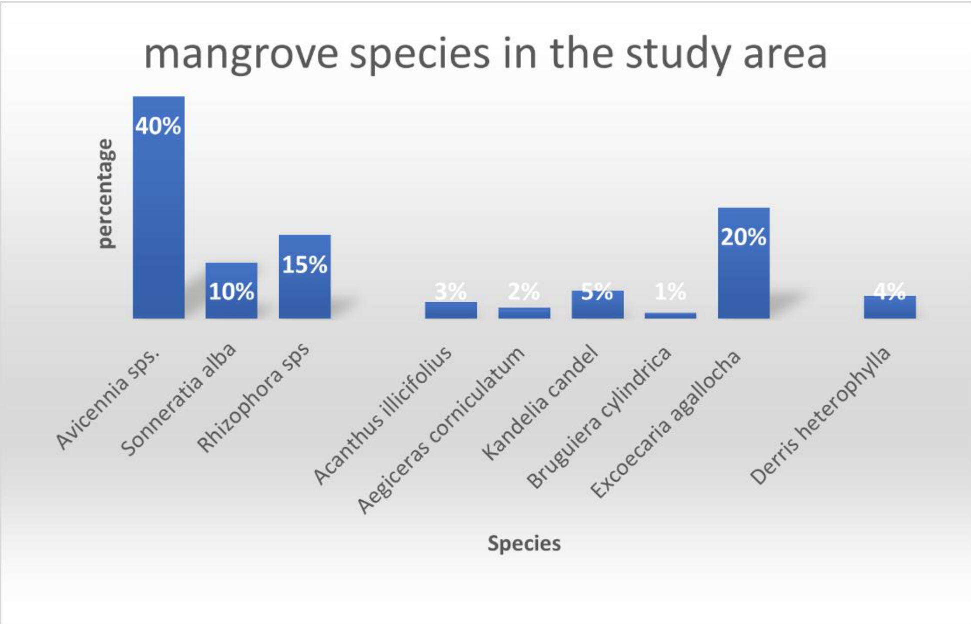

Fig. 1.3. graphical representation of percentage of mangrove species present in the study area.

a) *Avicennia marina*

b) Avicennia alba

c) *Sonneratia alba*

d) *Rhizophora mucronata*

e) *Rhizophora apiculata*

f) *Acanthus illicifolius*

g) *Kandelia candel*

h) Aegiceras corniculatum

i) Bruguiera cylindrica

j) Excoecaria agallocha

Fig. 1.4. Images of species found in Salim Ali Bird Sanctuary (. *Images sourced from website mikoko and forestry.pedia).*

1.4 Hypothesis

The spatial distribution and variability of mangrove carbon stocks within a specific geographic area can be accurately estimated using GIS-based techniques. GIS, combined with remote sensing technologies and geospatial analysis, can provide reliable estimates of mangrove carbon stocks across different habitats and environmental conditions. The study aims to test this hypothesis by applying GIS tools (Google Earth Engine) and methodologies to assess mangrove carbon stocks.

1.5 Scope

The study will concentrate on a specific geographic area containing mangrove ecosystems that has been chosen based on its ecological relevance, conservation status ,and ease of data collecting and analysis. Data collection will use remote sensing data from satellites such as Sentinel-2, Landsat, to collect important data on mangrove extent, plant cover, biomass, and carbon stock.

Geographic Information Systems (GIS) will be used to integrate and analyse spatial data layers, such as satellite images, vegetation indices (e.g., NDVI), land cover in order to quantify mangrove carbon reserves. The study may incorporate temporal analysis to investigate changes in mangrove carbon stocks overtime, examining trends, Variability

The spatial variability of mangrove carbon stocks in the research region will be studied, taking into account mangrove species composition, hydrological circumstances, soil characteristics, and disturbance regimes. study will bring insight into the regional distribution and quantity of mangrove carbon stocks, influencing management and conservation strategies for increasing carbon sequestration, improving ecosystem resilience, and mitigating climate change consequences. Findings will have implications for policy-making in biodiversity protection, sustainable land management, climate change mitigation, and carbon offsetting activities, allowing for more informed decisions at the local, national, and international levels. The study may involve collaboration across disciplines such as ecology, remote sensing, geography, forestry, and environmental science, bringing together expertise and methodologies from various fields to address complex research questions about mangrove carbon stock estimation with GIS.

CHAPTER 2: LITERATURE REVIEW

2.1. Protection of mangrove and their conservation:

Mangrove forests are incredibly productive ecosystems that provide as habitats for a variety of plant and animal species. Fish and other species looking for cover from predators are drawn to these woods because of their thick root systems.

Many fish species find that the underwater habitat is an ideal place for nursing. Many different species of fish, crabs, prawns, and molluscs can be found in mangrove forests. In these wetlands, migratory birds are frequently observed building nesting sites and foraging for food in the muddy soil beds. These areas are also home to a variety of turtle, monkey, and other species (Kumar Jitendra 2014).

The research conducted by Bindu et al. (2020) aims to assess carbon stocks in mangroves using remote sensing and GIS techniques. The study likely focuses on mangrove area or region of Kannur in Kerala, utilizing satellite imagery and GIS data to estimate various components of carbon stocks, including aboveground biomass, belowground biomass, and soil organic carbon. By integrating remote sensing data with ground-truth measurements and GIS analysis, the authors aim to provide a comprehensive understanding of carbon storage patterns within the mangrove ecosystem.

Estimation of Mangrove Carbon Stocks by Applying Remote Sensing and GIS Techniques Patil V et.al. This study was conducted in Mumbai, ground-based (GB) and remote sensing (RS) approaches for C stock estimation. RS based approach use Normalized differential vegetation index (NDVI), as the important parameters for C stock estimation. The paper, reports a statistically robust framework, which is a combination of the Remote Sensing and Ground Based approaches, and can be used for estimating the biomass and carbon stock of any ecosystem.

Similarly. A study by Tang W. et.al (2018) estimated biomass and carbon stock using geospatial analysis and high-performance parallel computing. Also R. Ramasubu et.al (2021). attempted to quantify the mangrove carbon sequestration rate using mutitemporal analysis, and the maps of carbon stocks in the mangrove forest at Pichavaram were developed for 2015, 2018 and 2020.

2.1.2 carbon stock estimation and its importance

Carbon is one of the many components of the environment. It is an important constituent of greenhouse gas that may cause a global climate change. Forest is acting as a carbon sink (an organism or chemical reaction that removes carbon) and potentially offsets the adverse effect of global climate change. The sum of carbon stored in the forest is called carbon stock. The function of the forest as a carbon sink is silently challenged by the widespread deforestation done for the sake of gaining more land, illegal logging, and shifting cultivation. Various efforts and research have been committed to finding a way of slowing down or stopping the adverse effect.

Remote sensing technology can be a cost-effective way of furnishing data on environmental variables in tropical regions. High- resolution satellite and climate data give spatial and temporal thickness in the data on crucial environmental variables. In an earlier study by Lenney, 1978 photos were used to calculate tree volume and its biomass. Also, he converted the biomass data to carbon data to know the quantum of carbon stored. With the current advancement of technology and the creation of Google Earth, researchers now have a cost-effective way to collect and analyze the data of environmental variables in tropical regions. In comparison with upstanding photography, the operation of high- resolution satellite and climate data can provide spatial and temporal thickness in the data on crucial environmental variables. This technology is useful for studies pertaining to estimating the damage after a natural disaster to comparing deforestation rates in an area with terrestrial operation. High- resolution satellite and climate data can be attained . One of them is also reused and anatomized using Google Earth Engine.

Mangroves play a crucial role in mitigating climate change through their capacity to sequester and store carbon. Here are several reasons highlighting the importance of accurate mangrove carbon stock estimation such as:

1. **Carbon sequestration**: Mangroves sequester and store significant amounts of carbon dioxide from the atmosphere. They are among the most carbon-rich ecosystems, storing carbon at rates much higher than terrestrial forests. Accurate estimation of mangrove carbon stocks helps quantify their contribution to global carbon sequestration.

2. **Climate Change mitigation**: As carbon-rich ecosystems, mangroves contribute to climate change mitigation by removing carbon dioxide from the atmosphere. Understanding the extent of carbon stored in mangroves aids in assessing their role in mitigating climate change and formulating effective climate change mitigation strategies.

3. **Policy and conservation**: Accurate estimation of mangrove carbon stocks provides essential information for policymakers, conservationists, and resource managers. It helps in the formulation and implementation of conservation policies, management plans, and restoration efforts aimed at preserving mangrove ecosystems and their carbon storage capacity.

4. **Economic valuation**: Mangroves provide various ecosystem services, including carbon sequestration, which have economic value. Estimating mangrove carbon stocks helps in economic valuation exercises, enabling decision-makers to appreciate the economic importance of mangrove ecosystems and make informed decisions regarding their conservation and sustainable use.

5. **Resilience and adaptation**: Mangroves serve as natural buffers against coastal hazards such as storm surges, erosion, and sea-level rise. Understanding the relationship between mangrove carbon stocks and ecosystem resilience helps in assessing the vulnerability of coastal communities to climate change and developing adaptation strategies that incorporate the conservation and restoration of mangrove ecosystems.

6. **Biodiversity Conservation**: Mangroves support diverse flora and fauna, and their conservation is vital for maintaining biodiversity. Accurate carbon stock estimation aids in assessing the impact of land-use changes, anthropogenic activities, and climate change on mangrove ecosystems and their associated biodiversity.

Remote sensing has significant importance in ecology and conservation research as it provides a non invasive way to study and monitor Earths ecosystem. The use of satellite imagery enables researchers to collect data on a large scale and for extended periods, providing valuable insights into the processing driving ecosystem dynamics and aiding in conservation and management decisions.

2.1.3 Monitoring changes in vegetation using remote sensing

Monitoring changes in vegetation using remote sensing involves utilizing satellites or aircraft-mounted sensors to gather data about the Earth's surface without physical contact. This method offers several advantages, including large-scale coverage, frequent revisits, and the ability to capture data in inaccessible or remote areas. Here's a general overview of how remote sensing can be used for monitoring changes in vegetation, Remote sensing platforms capture electromagnetic radiation reflected or emitted from the Earth's surface. Sensors can detect various wavelengths of light, including visible, near-infrared, and thermal infrared, which are particularly useful for vegetation monitoring.

Vegetation indices, such as the Normalized Difference Vegetation Index (NDVI) or Enhanced Vegetation Index (EVI), are calculated from remote sensing data to quantify vegetation health and density. These indices are derived from the reflectance of different wavelengths and provide information about vegetation Vigor, biomass, and greenness. Data can be acquired at regular intervals, allowing for temporal analysis to monitor changes over time. By comparing vegetation indices over multiple time periods, trends related to growth, seasonal variations, disturbances, and long-term changes can be identified. Change detection techniques are applied to remote sensing data to identify alterations in vegetation cover and structure. This involves comparing images acquired at different times and detecting areas where significant changes have occurred, such as deforestation, urbanization, wildfires, or agricultural activities.

Remote sensing data can be classified to distinguish different vegetation types or land cover classes. Supervised or unsupervised classification algorithms are used to partition the landscape into discrete categories, enabling the mapping of vegetation distribution and changes over time. Remote sensing data is often integrated with Geographic Information Systems (GIS) for spatial analysis and visualization. GIS platforms enable the integration of diverse datasets, facilitating comprehensive assessments of vegetation dynamics and their interactions with environmental factors.

2.1.4 NDVI (Normalized Difference Vegetation Index) to estimate vegetation presence.

The NDVI is a way to compare the amount of red light and near-infrared light reflected by the plants. By looking at the values, one can estimate how much vegetation is present in an area. In the case of sentinel-2 satellite, the infrared band is called band 8and red band is called band 4 . Healthy plants with with a lot of green leaves will absorb more red light and reflect more near-infrared light, resulting in a high NDVI value close to 1.

CHAPTER 3 : METHODOLOGY

3.1 The study incorporates field inventory data with the satellite images. Analysis involves four major steps namely,

(i) Image processing

(ii) Derivation of vegetation indices using satellite imagery .

(iii) Above ground biomass was calculated using NDVI.

(iv) Below ground biomass was calculated using above ground biomass values.

(v) Total carbon stock was calculated.

3.1.1 REMOTE SENSING ANALYSIS

The European Space Agency's (ESA) Sentinel satellites collect datasets that are included in GEE. Sentinel-1 Synthetic Aperture Radar (SAR) (2014–present), Sentinel-2 multispectral (2015–present), and Sentinel-3 are among the sentinel collection's members.

Sentinel-5P Tropospheric Monitoring (2018–present) and Ocean and Land Colour (2016–present) datasets. GEE users have made considerable use of Sentinel-1 and Sentinel-2 for various purposes. Compared to Landsat images, their 10 m spatial resolution allows for a higher level of object analysis. In image classification jobs, they can help streamline the process of training and validation procedures.

The Sentinel-2 is a multi-spectral imaging program, consisting for two Satellites : Sentinel-2A and Sentinel-2B, both equipped with multi Spectral Instrument (MSI) It can capture images every 5 days at the equator, with a radiometric resolution of 12 bits covering the visible (VIS), Near Infra-Red(NIR) and Short Wave Infra-Red (SWIR) spectra, with a total of 13 bands. The Copernicus Open Access Hub offers free access to the Sentinel-2 images.

Sentinel-2A optical data downloaded from Google Earth Engine (GEE), is included. Sentinel-2A data were acquired from the Multispectral Instrument (MSI) L2A product. The product has been pre-processed by ESA for radiometric calibration, atmospheric correction, etc, so the data reflect the reflectance information at the surface. A high-quality reflectance data that is suitable for a wide range of applications, including land cover mapping, vegetation monitoring, and natural resource management is produced.

In this study processed image in Google Earth Engine using Java script for NDVI processing was used. The NDVI processing is based on detection of both red and near-infrared(NIR) light, which allows for the estimation of chlorophyll content in vegetation by measuring the absorption and reflection of lights by the leaves. NDVI values obtained were further used in estimating the biomass and also the carbon stock.

3.1.2 NDVI analysis

The satellite image used in this study has a temporal resolution of 2-5 days and a spatial resolution of upto 10 meters in Band 4(Red) and 8(Near Infra-Red). The NDVI was computed for the month of January 2024. NDVI was calculated by comparing the reflectance values of the two bands.

NDVI was measured as: $NDVI = (NIR - VIS)/(NIR + VIS$ -----------Eq 1

The NDVI values for each image were determined using google earth engine, with Band 8 serving as the Near Infra-Red (NIR) and band 4 as the red band (VIS). Plants with heavy and dense green leaves absorb more VIS and reflect more NIR, leading to high NDVI values.

Table 3.1: NDVI classification based on laksono et.al. 2020

NDVI value	**Vegetation class**
-1.00 – 0.00	No vegetation class (ND)
0.01 – 0.30	Slight density (SD)
0.31 – 0.60	Moderate density (MD)
0.61 – 1.00	High density (HD)

NDVI values obtained were classified based on Laksono et.al 2020

3.1.3 Total Biomass estimation

Biomass is the sum total of all the components of a tree, below ground as well as above ground (Hogart,1999). Mangroves have a relative higher root mass(saenger,1982). So calculating Below ground biomass is equally important.

From the NDVI values of satellite data AGB can be calculated using the following equation by Myeong et al. (2006)

$$AGB = a * e(NDVI \ x \ b)$$ ----------Eq 2

a and b are the constants that is determined by Bindu et al. (2020) from a nonlinear regression equation.

Then BGB was calculated using formula by Wika Wulandari (2024)

$$BGB = 0.2x \ AGB$$ -------------Eq 3

3.1.4 Calculation of carbon stock

Cabon content is then obtained by multiplying the total biomass by a conversion factor 0.475

(47.5% of biomass, IPCC).

$$AGB + BGB = TOTAL\ BIOMASS \text{--------Eq 4}$$

$$TOTAL\ CARBON = TOTAL\ BIOMASS\ X\ 0.475 \text{ ---------Eq 5}$$

3.2 Study of NDVI values of 2001 , 2014 , 2024

Landsat satellite imagery for the study area from 2001, 2014, and 2024 was obtained from the United States Geological Survey's (USGS) Landsat archives. The obtained Landsat imagery was pre-processed to compensate for atmospheric influences, including radiometric calibration and atmospheric correction, using Google Earth Engine (GEE) tools to ensure data quality and consistency. NDVI was determined using the following formula: $NDVI = (NIR - red) / (NIR + red)$, where NIR stands for near-infrared reflectance and red for red reflectance.

In GEE, the Landsat images was masked to extract the near-infrared (NIR) and red bands by removing non-vegetated or cloudy pixels. Mathematical operations were used to calculate the NDVI pixel by pixel throughout the whole image stack for each year (2001, 2014, and 2024), resulting in NDVI raster images. NDVI images were visualised using a specific palette to depict the range of values.

A colour palette was chosen to represent low NDVI values (indicating non-vegetated areas) in one colour, moderate NDVI values (showing sparse vegetation) in another, and high NDVI values (representing dense vegetation) in a separate colour (e.g., dark green). The NDVI photos from 2001, 2014, and 2024 were compared visually and quantitatively to discover changes in vegetation cover overtime. Statistical studies, such as mean NDVI comparison and geographical distribution mapping, were used to identify areas of vegetation change and quantify changes in photosynthetic activity throughout the research region.

Accuracy metrics were used to assess the dependability and precision of NDVI-derived vegetation cover changes. Interpretation and The NDVI results were evaluated in conjunction with supplementary data, such as land cover maps, climatic data, and land management techniques, to gain insight into the drivers of vegetation dynamics and changes observed over the study period. Conclusions were drawn about vegetation cover trends, spatial patterns of NDVI changes, and their consequences for ecosystem health, biodiversity conservation, and land management techniques. Following this methodology, the study successfully uses Landsat imagery in GEE to calculate NDVI and analyse vegetation changes over time.

CHAPTER 4: ANALYSIS AND CONCLUSION

4.1. Results and Discussion

4.1.1. NDVI Analysis

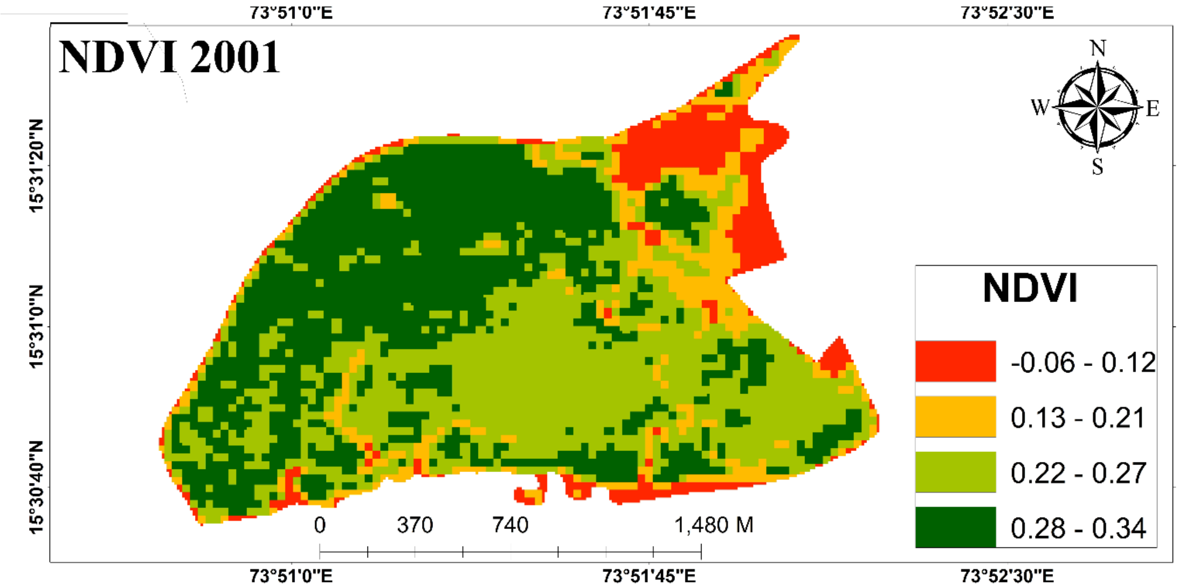

Fig. 4.1. Normalized difference vegetation index (NDVI) image generated from Landsat Using Google Earth Engine for the year 2001.

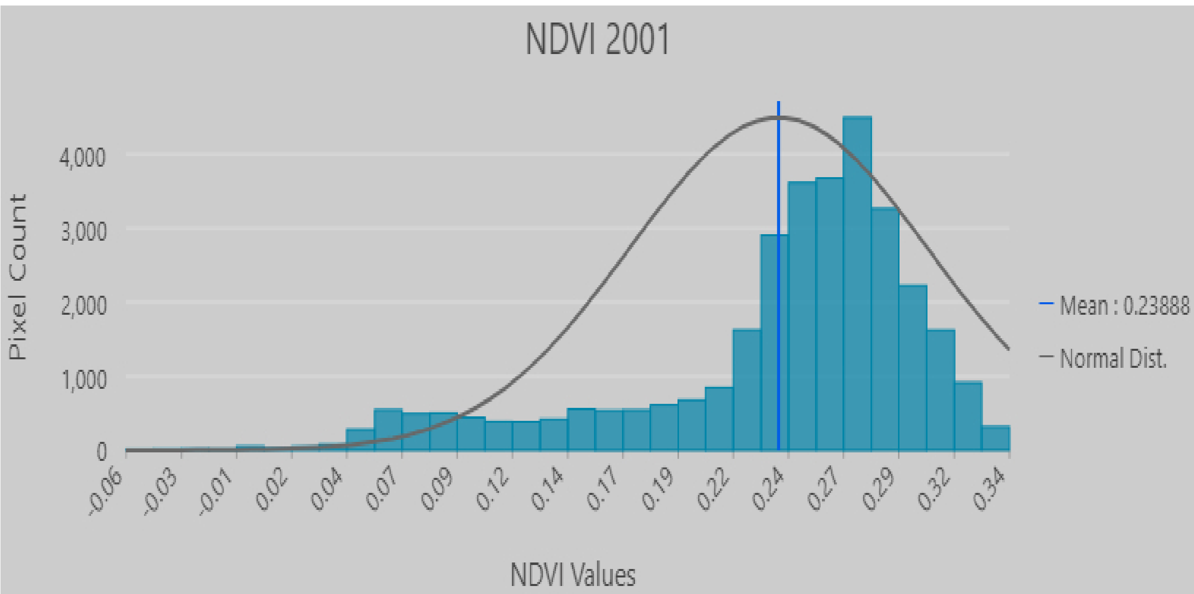

Fig. 4.2. Summary graph of NDVI values for year 2001

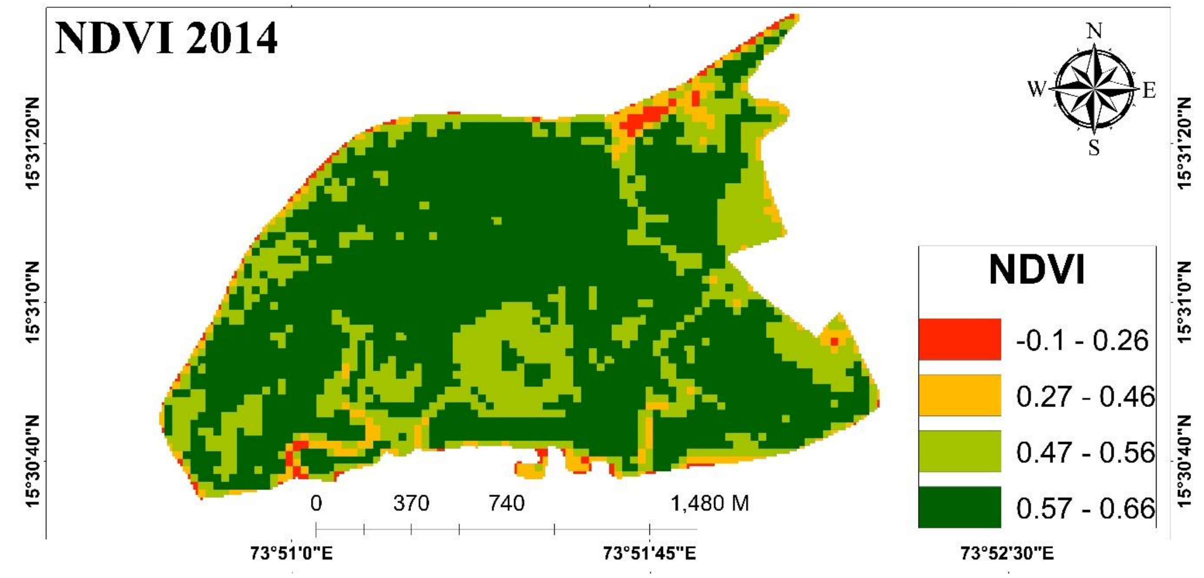

Fig. 4.3.Normalized difference vegetation index (NDVI) image generated from Landsat Using Google Earth Engine for the year 2014.

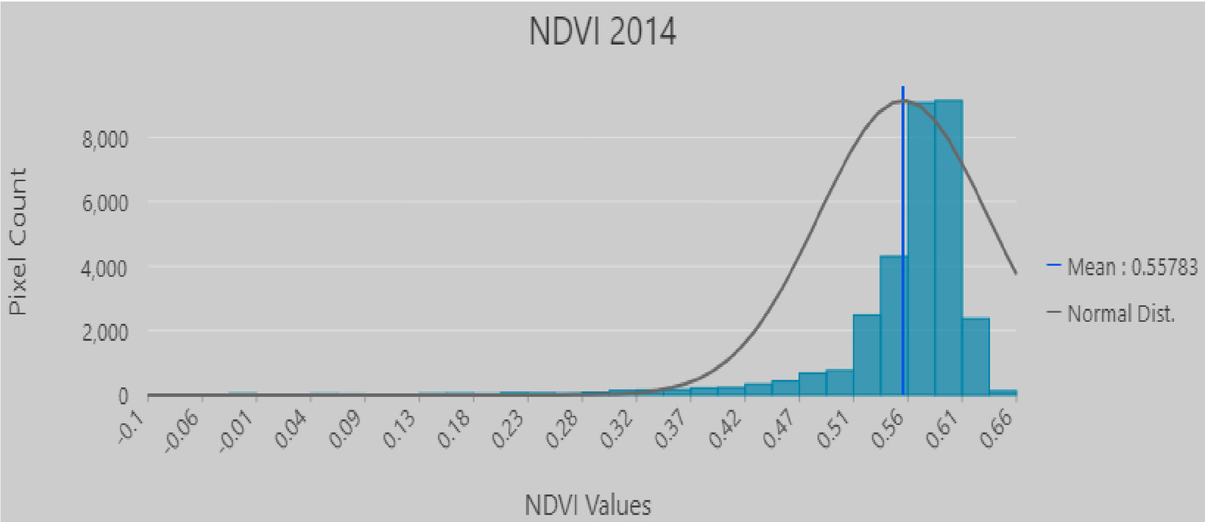

Fig. 4.4. Summary graph of NDVI values for year 2014

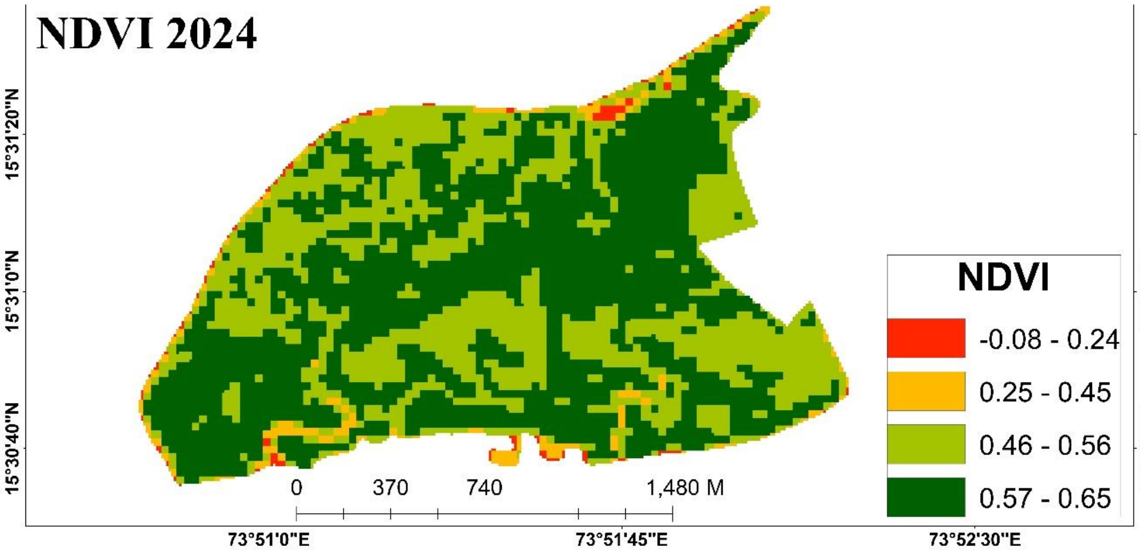

Fig. 4.5. Normalized difference vegetation index (NDVI) image generated from Landsat Using Google Earth Engine for the year 2024.

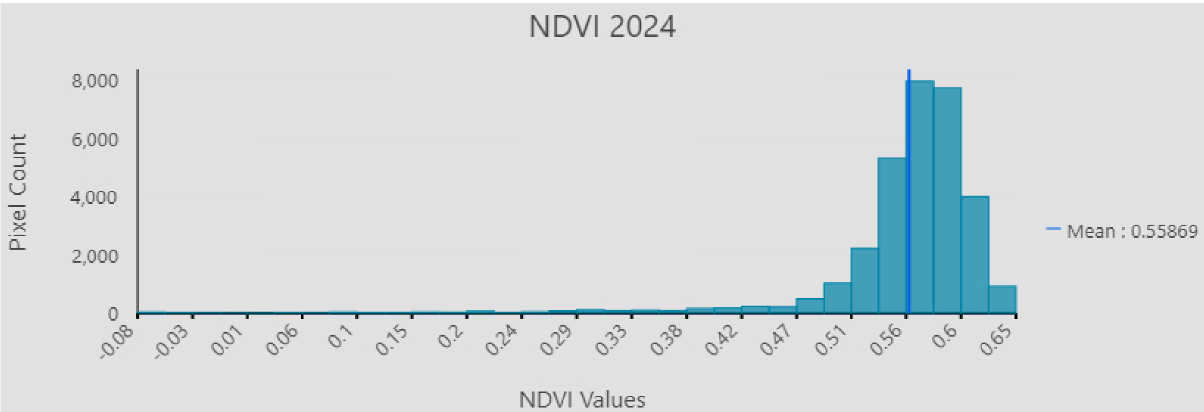

Fig. 4.6. Summary graph of NDVI values for year 2024

4.1. Spatial Analysis of NDVI for year 2001, 2014 , 2024

The NDVI values observed in 2001, with the highest recorded at 0.34 and the lowest at -0.06, indicating the vegetation status and land cover characteristics during that period. A NDVI value of 0.34 suggests moderate to healthy vegetation cover. This could imply areas with decent vegetation density, such as grasslands, moderately dense forests, or agricultural fields with healthy crops. While not as high as some values seen in more lush areas, a NDVI of 0.34 still indicates relatively good vegetation health and productivity. Conversely, a NDVI value of -0.06 indicates areas with very little or no vegetation cover. These areas might include barren land, urban areas, water bodies, or regions affected by severe environmental stressors such as drought or human-induced degradation.

For the year 2014, the highest observed NDVI value of 0.66 suggests dense and healthy vegetation cover in the area. This could indicate areas with abundant green vegetation, such as forests, healthy crops, or dense grasslands. High NDVI values often correlate with vigorous photosynthetic activity and robust vegetation growth. On the other hand, the lowest NDVI value recorded at -0.1 indicated areas with little to no vegetation cover. Negative NDVI values typically occur in non-vegetated or sparsely vegetated areas such as deserts, bare soil, urban areas, or water bodies. These areas absorb more energy in the visible spectrum and reflect less in the near-infrared spectrum, resulting in negative NDVI values. Interpreting these extremes in NDVI values requires considering various factors such as land cover types, seasonal variations, and environmental conditions. Overall, NDVI data provides valuable insights into the spatial distribution and health of vegetation.

For the year 2024, the NDVI value of 0.65 suggests areas with dense and healthy vegetation cover. This could indicate regions with lush green vegetation, such as dense forests, healthy agricultural fields, or vibrant grasslands. High NDVI values often correspond to areas experiencing active photosynthesis and robust vegetation growth .These areas may play a crucial role in ecosystem services, biodiversity conservation, and carbon sequestration. A NDVI value of -0.08 suggests areas with little to no vegetation cover. Such low NDVI values are typically associated with non-vegetated or sparsely vegetated surfaces, including deserts, urban areas, water bodies, or barren land. Negative NDVI values often indicate surfaces that absorb more energy in the visible spectrum and reflect less in the near-infrared spectrum, such as bare soil, impervious surfaces, or areas devoid of vegetation.

Interpreting these NDVI values requires considering various factors such as land cover types, seasonal variations, and environmental conditions present during the observation period. NDVI data provides valuable insights into vegetation dynamics, land use changes, and ecosystem health, supporting applications in agriculture, forestry, land management, and environmental monitoring.

It can be interpreted that the health of mangroves at Dr. Salim Ali Bird Sanctuary (Chorao) showed a good improvement from of 2001- 2014. But from the year 2014 – 2024 decrease in the green cover was observed. This calls for urgent measures to conserve and restore the sanctuary.

4.2 Biomass analysis

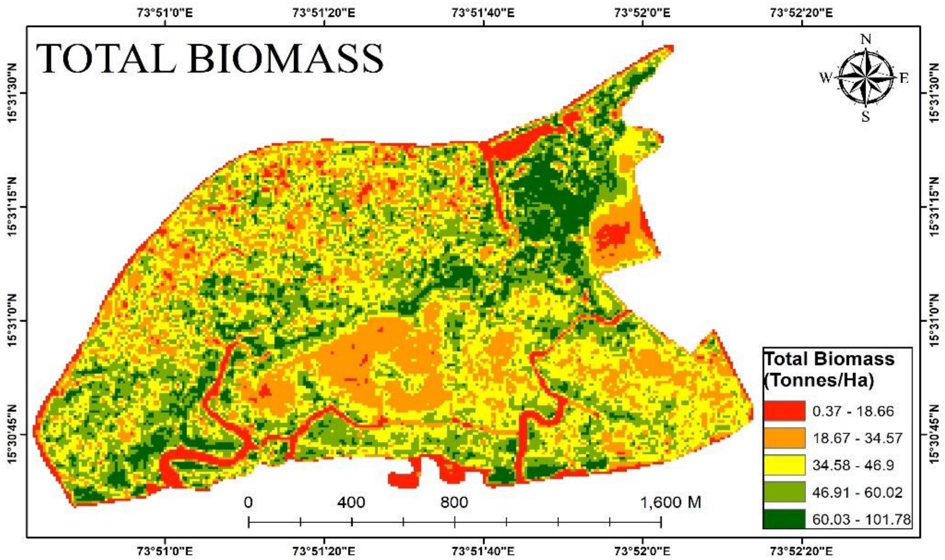

Fig. 4.7. Biomass mapping of the study area generated from Sentinel -2 using Google Earth Engine.

The range of biomass observed in the study area, spanned from 0.37 to 101.78 tons per hectare, provides crucial insights, especially in the context of mangrove ecosystems. Lowest Biomass (0.37 ton/ha) as can be seen in the fig. 4.7. . The lower end of the biomass range suggests areas with relatively sparse or young mangrove vegetation. A biomass value of 0.37 ton/ha may indicate recently established mangrove plants, areas with low mangrove density, or regions affected by environmental stressors such as salinity variations, sedimentation changes, or human disturbances. Understanding the factors contributing to low biomass levels is essential for mangrove conservation and restoration efforts, as healthy mangrove ecosystems provide invaluable ecological services such as coastal protection, carbon sequestration, and habitat provision. Highest Biomass (101.78 ton/ha) as can be seen in fig. 4.7. . upper end of the biomass range indicates areas with dense and mature mangrove vegetation. A biomass value of 101.78 ton/ha suggests thriving mangrove forests with high canopy cover, extensive root systems, and optimal environmental .conditions. These areas are likely to be ecologically significant, serving as important habitats for numerous species, contributing to coastal resilience against erosion and storm surges, and playing a vital role in mitigating climate change through carbon sequestration.

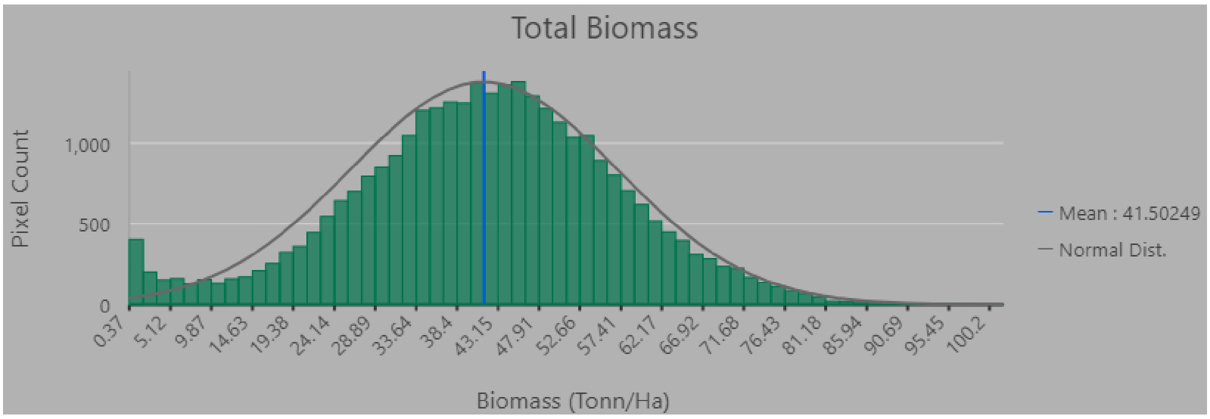

Fig. 4.8. Histogram to show distribution of biomass.

4.3. Carbon stock analysis

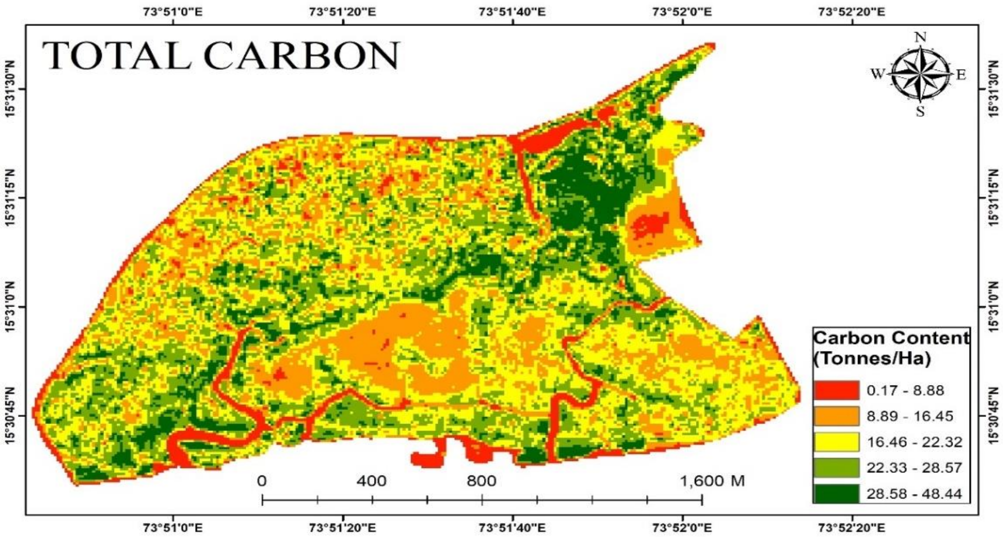

Fig. 4.9. :Total carbon mapping generated from Sentinel-2 using Google Earth Engine.

The total carbon mapping generated from Sentinel-2 using Google Earth Engine, with values ranging from 0.17 to 48.44 tons per hectare, provides valuable insights into carbon storage and distribution within the study area. Lowest Carbon (0.17 ton/ha) as can be seen in the fig. 4.9. The lower end of the carbon range suggests areas with relatively low carbon storage. A carbon value of 0.17 ton/ha may indicate regions with sparse vegetation cover, degraded ecosystems, or areas subjected to land use changes that have resulted in reduced carbon sequestration capacity.

Understanding the factors contributing to low carbon storage levels is essential for identifying areas requiring restoration or conservation efforts to enhance ecosystem resilience and carbon sequestration potential.

Highest Carbon (48.44 ton/ha) as can be seen in the fig. 4.9. The upper end of the carbon range indicates areas with substantial carbon storage. A carbon value of 48.44 ton/ha suggests regions with dense vegetation cover, such as mature forests, mangrove swamps, or peatlands, which are known for their high carbon sequestration capacity. These areas play a crucial role in mitigating climate change by sequestering large amounts of atmospheric carbon dioxide through photosynthesis and storing it in biomass and soil organic matter.

Understanding the factors contributing to high carbon storage levels is essential for prioritizing conservation efforts and sustainable land management practices to maintain or enhance carbon sinks and mitigate climate change impacts. Overall, the total carbon mapping provides valuable information for assessing the carbon stocks and dynamics within the study area. By identifying areas with high carbon storage potential and understanding the factors influencing carbon accumulation, stakeholders can develop informed strategies for carbon management, land use planning, and climate change mitigation initiatives.

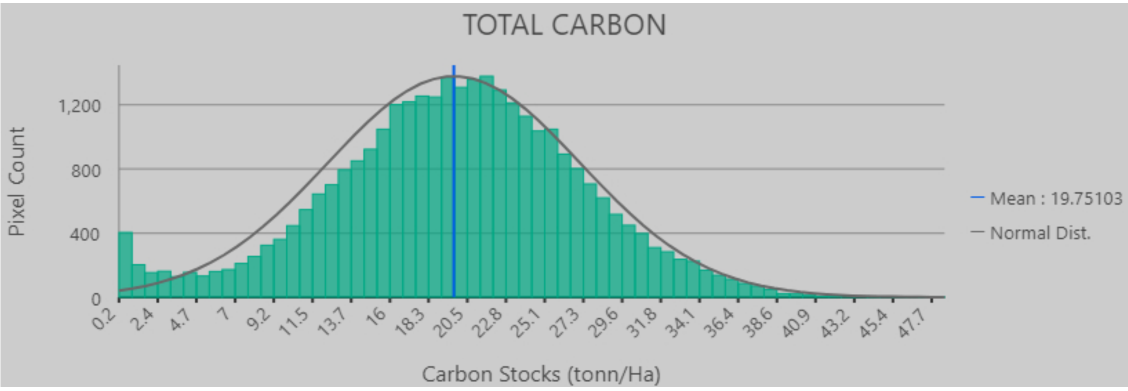

Fig. 4.10. Histogram showing carbon stock at different pixel count.

4.4 Summary

The findings of this study provide comprehensive insights into vegetation dynamics, biomass distribution, and carbon stock variations within the study area, as assessed through remote sensing analysis using Sentinel-2 imagery via Google Earth Engine.

In January 2024, NDVI values ranged from -0.08 to 0.65, indicating diverse vegetation cover across the landscape. Concurrently, total biomass exhibited a wide range, from 0.37 to 101.78 tonnes per hectare, reflecting variability in vegetation productivity and biomass accumulation. Carbon stock estimates also showed spatial heterogeneity, ranging from 0.17 to 48.44 tonnes per hectare.

Furthermore, comparative analysis of NDVI values between the years 2001-2014 and 2024 revealed significant changes in vegetation cover over time. These changes suggest potential shifts in ecosystem dynamics, likely influenced by factors such as land use changes, climate variability, or human-induced disturbances. The observed variations in NDVI, biomass, and carbon stock underscore the importance of ongoing monitoring and assessment of ecosystem health and resilience. Understanding the drivers of vegetation dynamics and carbon storage fluctuations is critical for informed decision-making in land management, conservation, and climate change mitigation efforts. Overall, this study provides valuable information for policymakers, land managers, and conservation practitioners to develop targeted strategies for sustainable land use planning, biodiversity conservation, and carbon sequestration initiatives, thereby fostering the resilience and long-term health of the studied ecosystem.

For the Carbon stock estimation Salim Ali Bird Sanctuary Chorao was selected as there are no studies carried out in Goa, and no data is available for the same. Dr. Salim Ali Bird Sanctuary is a protected site and has the best mangrove forest cover.

4.5. conclusion

mangrove forests include their role as a filter for pollutants, their ability to lessen the intensity of coastal waves, and their ability to lessen the effects of catastrophic events like coastal storms. Plant root systems are supported by sediment that is trapped by blue carbon systems. Over time, this sediment buildup may allow coastal habitats to adapt to increasing sea levels.

Mangrove forests and coastal wetlands will grow in importance as a source of carbon credits. This is because, compared to mature tropical forests, mangrove forests and coastal wetlands may absorb carbon at a rate that is up to ten times higher. In aquatic forests and wetlands, carbon is sequestered and stored in the benthos, where it is retained for over 10 times longer than in tropical forests.

The organisation who holds carbon credits is allowed to emit greenhouse gases, or carbon dioxide. One credit is equal to one tonne of carbon dioxide that will be released, or, for other gases, the mass equivalent of carbon dioxide. Organisations own as many credits as they would like to buy in order to make up their emissions. These carbon credits can bring dollars to the country as these credits sell in the international market for 5-12$ each.

The range of biomass observed in the study area, spanned from 0.37 to 101.78 tons per hectare, and The total carbon mapping generated values ranging from 0.17 to 48.44 tons per hectare. Furthermore, comparative analysis of NDVI values between the years 2001-2014 and 2024 revealed significant changes in vegetation cover over time.

An accurate information on carbon stocks of mangrove forest provides financial justification for protection, management and rehabilitation of this critical ecosystem. A more detailed study in this line can be helpful to more economical and improved environmental management.

REFERENCES

- .Bindu, G., Rajan, P., Jishnu, E. S., & Joseph, K. A. (2020). Carbon stock assessment of mangroves using remote sensing and geographic information system. *The Egyptian Journal of Remote Sensing and Space Science*, *23*(1), 1-9.
- Myeong, S., Nowak, D. J., & Duggin, M. J. (2006). A temporal analysis of urban forest carbon storage using remote sensing. *Remote Sensing of Environment*, *101*(2), 277-282.
- Ruan, L., Yan, M., Zhang, L., Fan, X., & Yang, H. (2022). Spatial-temporal NDVI pattern of global mangroves: A growing trend during 2000–2018. *Science of The Total Environment*, *844*, 157075.
- Locatelli, T., Binet, T., Kairo, J. G., King, L., Madden, S., Patenaude, G., ... & Huxham, M. (2014). Turning the tide: how blue carbon and payments for ecosystem services (PES) might help save mangrove forests. *Ambio*, *43*, 981-995.
- Sitoe, A. A., Comissario Mandlate, L. J., & Guedes, B. S. (2014). Biomass and carbon stocks of Sofala Bay mangrove forests. *Forests*, *5*(8), 1967-1981.
- Hogarth, P. J. (1999). *The biology of mangroves* (pp. ix+-228).
- Malik, A. D., Nasrudin, A., & Withaningsih, S. (2023, July). Vegetation Stands Biomass and Carbon Stock Estimation using NDVI-Landsat 8 Imagery in Mixed Garden of Rancakalong, Sumedang, Indonesia. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1211, No. 1, p. 012015). IOP Publishing.

- Soares, M. L. G., & Schaeffer-Novelli, Y. (2005). Above-ground biomass of mangrove species. I. Analysis of models. *Estuarine, Coastal and Shelf Science*, *65*(1-2), 1-18.
- Castillo, J. A. A., Apan, A. A., Maraseni, T. N., & Salmo III, S. G. (2017). Estimation and mapping of above-ground biomass of mangrove forests and their replacement land uses in the Philippines using Sentinel imagery. *ISPRS Journal of Photogrammetry and Remote Sensing*, *134*, 70-85.
- Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature geoscience*, *4*(5), 293-297.
- Patil, V., Singh, A., Naik, N., & Unnikrishnan, S. (2015). Estimation of mangrove carbon stocks by applying remote sensing and GIS techniques. *Wetlands*, *35*, 695-707.
- Ghosh, S. M., Behera, M. D., Jagadish, B., Das, A. K., & Mishra, D. R. (2021). A novel approach for estimation of aboveground biomass of a carbon-rich mangrove site in India. *Journal of Environmental Management*, *292*, 112816.
- Baloloy, A. B., Blanco, A. C., Candido, C. G., Argamosa, R. J. L., Dumalag, J. B. L. C., Dimapilis, L. L. C., & Paringit, E. C. (2018). Estimation of mangrove forest aboveground biomass using multispectral bands, vegetation indices and biophysical variables derived from optical satellite imageries: Rapideye,
- Muhsoni, F. F., Sambah, A. B., Mahmudi, M., & Wiadnya, D. G. R. (2018). Estimation of mangrove carbon stock with hybrid method using image Sentinel-2. *GEOMATE Journal*, *15*(49), 185-192.

- Gaikwad, S. D., Kumar, E. K., & Gude, S. (2018). Spatial Patterns of Soil Organic Carbon Stock in Different Land Use System in Salcete Taluka of Goa. In *Multidisciplinery International Conference on Green Earth: A Pararomic view ISBN* (pp. 978-81).
- Giri, C. (2021). Recent advancement in mangrove forests mapping and monitoring of the world using earth observation satellite data. *Remote Sensing*, *13*(4), 563.
- Harishma, K. M., Sandeep, S., & Sreekumar, V. B. (2020). Biomass and carbon stocks in mangrove ecosystems of Kerala, southwest coast of India. *Ecological Processes*, *9*(1), 1-9.
- Jones, A. R., Raja Segaran, R., Clarke, K. D., Waycott, M., Goh, W. S., & Gillanders, B. M. (2020). Estimating mangrove tree biomass and carbon content: a comparison of forest inventory techniques and drone imagery.
- Komiyama, A., Ong, J. E., & Poungparn, S. (2008). Allometry, biomass, and productivity of mangrove forests: A review. *Aquatic botany*, *89*(2), 128-137.
- Mahasani, I. G. A. I., Osawa, T., Adnyana, I. W. S., & Suardana, A. A. M. A. P. (2021, December). Carbon stock estimation and mapping of mangrove forest using ALOS-2 PALSAR-2 in Benoa Bay Bali, Indonesia. In *IOP Conference Series: Earth and Environmental Science* (Vol. 944, No. 1, p. 012044). IOP Publishing.
- Sahu, S. C., Kumar, M., & Ravindranath, N. H. (2016). Carbon stocks in natural and planted mangrove forests of Mahanadi Mangrove Wetland, East Coast of India. *Current Science*, 2253-2260.
- Tieng, T., Sharma, S., Mackenzie, R. A., Venkattappa, M., Sasaki, N. K., & Collin, A. (2019, April). Mapping mangrove forest cover using Landsat-8

imagery, Sentinel-2, very high resolution images and Google Earth Engine Algorithm for entire Cambodia. In *IOP Conference Series: Earth and Environmental Science* (Vol. 266, No. 1, p. 012010). IOP Publishing.