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ASSESSING FOREST COVER CHANGE DETECTION AND CARBON STOCK IN EAST JAVA USING GIS

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ABSTRACT: This study uses GIS to assess the extent of deforestation, forest degradation, and carbon stock in East Java, Indonesia. The dataset for this study required preprocessing and proper GIS analysis tools to track and quantify land cover changes, specifically deforestation and forest degradation from 1990 to 2022. The results show that East Java has experienced significant deforestation and forest degradation, with a total deforested area of approximately 180,000 hectares and a degraded forest area of around 270,000 hectares. Among the subregions, Malang had the highest deforestation rate, with a total area of 42,605 hectares, while Banyuwangi had the highest forest degradation, with around 64,782 hectares affected. Primary mangrove forest in East Java has decreased from approximately 15,000 hectares in 1990 to around 9,000 hectares in 2022. Furthermore, the study estimated the carbon stock changes over the study period. The total carbon stock in 1990 was around 196 million tonnes, but by 2022 it had decreased to approximately 156 million tonnes. The difference in carbon stock between 1990 and 2022 is approximately 40 million tonnes of carbon. Analyzing carbon stock with remote sensing and GIS will give faster results than the manual approach. These findings highlight the urgent need for effective forest management and conservation measures in East Java to mitigate further environmental degradation and carbon emissions. Integrating GIS-based forest monitoring techniques provides a valuable tool for assessing land cover changes and their impact on carbon stock, enabling informed decision-making for sustainable land use planning and conservation strategies.

Keywords: Carbon Stock, Land Cover Change, Deforestation, East Java, Forest Degradation, Environmental GIS, Remote Sensing, Sustainable Land Use, Conservation Strategies

1. INTRODUCTION

Forests are crucial in the global carbon cycle by absorbing carbon dioxide (CO^2) and helping to reduce climate change [1]. Land use/land cover changes are major factors driving global environmental change, especially in forests [2-3]. Eventually, deforestation resulting from development leads to changes in land cover, reducing carbon stock. Monitoring changes in land cover using a Geographic Information System (GIS) is essential. In recent years, GIS technology has emerged as a powerful tool for analyzing and visualizing spatial data related to land cover and carbon dynamics [4]. The dataset for GIS required some preprocessing and equitable tools for analysis of the extent of deforestation, forest degradation, and carbon stock in East Java, Indonesia. This study workflow contains land cover data from the government from 1990 to 2022, then preprocessing to select the data according to our area of interest (AOI) and calculate each area of land cover classes yearly. Intersect tools are good for changing the land cover between one year and another and categorizing deforestation and forest degradation.

According to previous studies, East Java has been experiencing significant land cover changes, including deforestation and forest degradation. These activities have not only resulted in the loss of valuable forest ecosystems but also led to the release of large amounts of greenhouse gases, contributing to global climate change. Therefore, the transition from one land-cover category to another can impact water and carbon cycles [5,6]. The objectives of this study are twofold: (1) to track and quantify land cover changes, specifically deforestation and forest degradation, in East Java using satellite imagery and GIS analysis, and (2) to estimate the changes in carbon stock over the study period.

By integrating GIS-based forest monitoring techniques, this research will provide valuable insights into the extent of environmental degradation in East Java and inform decision-making for sustainable land use planning and conservation strategies. This study will focus on the years 1990 to 2022, allowing for a comprehensive analysis of land cover changes over a significant period. High-resolution satellite imagery will accurately identify and map deforested and degraded areas. GIS analysis solves the carbon stock monitoring faster than the manual approach. The GIS analysis will also help to identify hotspots of land cover change and prioritize areas for conservation efforts and reforestation. The findings from this study will serve as a crucial tool for monitoring and evaluating the effectiveness of future land use policies and conservation strategies in East Java, ultimately aiming to improve ecosystem resilience and enhance carbon sequestration potential in the region. The findings of this study will contribute to the existing knowledge on land cover change and carbon stock in East Java, providing valuable information for policymakers. By quickly understanding the extent of deforestation, forest degradation, and carbon stock, appropriate measures can be taken to further study with wider areas, such as environmental study, forestry, and city planning.

The objectives of this study are twofold: (1) To track and quantify land cover changes, specifically deforestation and forest degradation in East Java using satellite imagery and GIS analysis. (2) To estimate the changes in carbon stock over the study period.

The rest of this paper is organized as follows: the methods and discussion in Section 3. The results for annual carbon stock in Section 4. Finally, in Section 5, the conclusions are summarized.

2. RESEARCH SIGNIFICANCE

This research is important because it can quickly determine total carbon stock values over a large area compared to direct surveys, as demonstrated by Afentina et al. [8], who manually sampled ground carbon stock in Katingan Hulu, Central Kalimantan on 2022. Obtaining data faster is crucial due to Indonesia's vast size. This study aims to investigate land cover change and carbon stock in East Java, Indonesia, by employing a GIS-based forest monitoring approach. This study aims to assess deforestation, forest degradation, and carbon stock in East Java, Indonesia, from 1990 to 2022. This research will improve our comprehension of the environmental impacts of land use alterations in the area and direct sustainable land use planning and conservation measures. This research is crucial for policymakers, environmentalists, and land managers as it will provide vital insights into the level of environmental degradation and help reduce deforestation while promoting sustainable land management methods.

3. METHODOLOGY

The methodology used to estimate the above ground biomass stock and carbon stock conversion values in East Java involved preprocessing the land cover dataset, classifying the land cover into different categories, estimating the biomass stock for each category, and converting the biomass stock into carbon stock values using conversion factors. The changes in land cover over time were analyzed to assess degradation and deforestation with ArcGIS Pro intersect tools. This methodology provides valuable information on the region's carbon dynamics and potential climate change mitigation strategies.

3.1 Annual Land Cover Dataset

The land cover dataset was obtained from the Ministry of Environment and Forestry from multiple resources such as Landsat, SPOT, additional maps related to forest activity, and field surveys [9]. The Ministry of Forestry uses visual interpretation and digitation on land scenes from The National Institute of Aeronautics and Space Indonesia, as shown in Fig 1. Land cover refers to the physical and biological features that cover the Earth's surface, including natural and human-made elements [10,11]. It provides a detailed description of the different types of land surfaces and the vegetation or artificial structures that exist on them. Land cover is an essential component of studying and understanding the Earth's ecosystems, environmental changes, and the impact of human activities on the landscape. Land cover classification typically categorizes land into various classes based on distinct characteristics, such as vegetation type, land use, terrain, water bodies, and artificial structures [12].

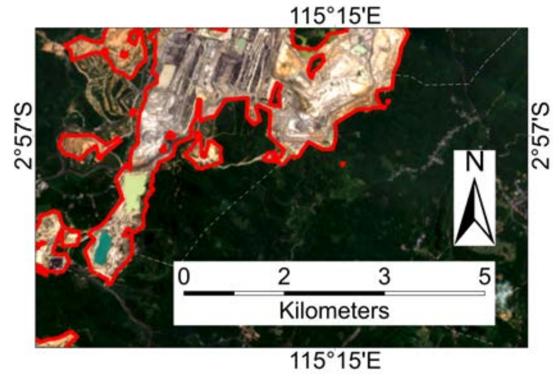

Fig.1 Coal Mining Area on Tapin Regency, South Kalimantan, Indonesia (Inside Red Line) visual interpretation with RGB composite for land cover analysis.

Some common land cover classes include forests, grasslands, wetlands, croplands, urban areas, barren land, water bodies (rivers, lakes, oceans), and snow or ice-covered areas. Land cover information plays a vital role in various fields and applications. Here are a few examples:

a. Environmental Monitoring: Land cover data is used to track deforestation, ecological changes, urban growth, wetland health, and climate change impacts on diverse land types.

b. Land cover classification aids biodiversity conservation by identifying habitats for animal and plant species, enabling restoration planning and safeguarding endangered ecosystems.
c. Land cover data aids in urban planning, infrastructure management, and zoning decisions. It reveals land usage, population density, and built-up areas.
d. In agriculture and forestry, land cover data is essential for analyzing productivity, managing forests, maximizing land use, and identifying suitable sites for crops or tree species.
e. Disaster Management: Land cover knowledge aids in anticipating and preventing natural disasters including floods, wildfires, and landslides. It helps identify susceptible locations and create reaction plans.

and designing appropriate response strategies. Various methods of obtaining land cover data include satellite imagery analysis, aerial photography, remote sensing techniques, ground surveys, and geographic information systems (GIS) technology [13].

3.2 Carbon Stock

Carbon stock based on land cover refers to estimating and quantifying the amount of carbon dioxide ($\mathbf{CO^2}\boldsymbol{ag}$) stored or emitted by different types of land cover [14], specifically in the context of deforestation and forest degradation in Indonesia.

Table 1 Carbon Stock Rates of East Java

Land Cover Classes	Carbon Sequestration (TC/Ha)
Airport	0
Shrub	30
Swamp Grove	30
Primary Dryland Forest	112.377
Secondary Dryland Forest	84.788
Primary Mangrove Forest	170
Secondary Mangrove Forest	120
Plantation Forest	50
Settlement	5
Plantation	63
Mining Area	0
Dryland Agriculture	10
Mix Dryland Agriculture	30
Grassland	4.5
Agriculture	35
Pond	0
Bare Land	2.5

The National Forest Reference Emission Level (FREL) is a benchmark established by the Indonesian government to assess and monitor changes in carbon stocks in forests. It provides a reference point against which future emissions from deforestation and forest degradation can be measured. The FREL considers factors such as land cover, forest type, and carbon density to estimate the amount of carbon stored in Indonesia's forests [15]. The total Above Ground Biomas (AGB) for each plot (per hectare) was then quantified by summing AGB estimates for all trees on the plots in dry weight (expressed in tonnes (t)).

$$\mathbf{MP} = \sum_{1}^{n} \frac{M_t}{A_p} \quad (1)$$

where MP = AGB of plot expressed as (t ha-1), MT = AGB of measured tree (t), AP = plot area (ha), n = number of trees per plot. The total AGB per hectare for each forest type in the main island was derived by averaging the AGB of the total plots. where Mj = mean AGB(t ha-1) of forest type j, MPi = AGB of plot, n= plot number [15].

$$M_j = \sum_{1}^{n} \frac{M_{pi}}{n} \quad (2)$$

A detail of the carbon stock rate based on land cover from those equation results on each forest type, especially in East Java, can be seen in Table 1. The carbon stock values in metric tonnes of carbon per hectare per year associated with different land cover types are provided in Table 1 as follows:

a. Airport: Paved surfaces and structures often dominate this land cover category, resulting in minimal carbon stock contribution. The carbon stock value is 0.
b. Shrub: Vegetation biomass in shrub land can increase carbon stock. Carbon stock value of 30 metric tons per hectare per year.
c. Swamp groves, with dense vegetation in wetland settings, have a carbon store value of 30 metric tons per hectare per year.
d. The Primary Dryland Forest land cover category refers to mature, undisturbed forests in dryland environments. Carbon stock value: 112.377 metric tons per acre per year.
e. Secondary Dryland Forest: Forests experiencing disturbance or regeneration.84.788 metric tons per hectare per year.
f. The primary mangrove forest is a productive ecosystem found in coastal locations. The annual carbon stock is 170 metric tons per hectare.

g. Secondary Mangrove Forest contains 120 metric tons of carbon per hectare per year, similar to secondary dryland forests.
h. Plantation Forest: Commercially cultivated tree species add 50 metric tons of carbon per hectare annually.
i. Urban or settlement regions have less vegetation, resulting in decreased carbon stock potential. Five metric tons of carbon per hectare per year is the carbon stock value.
j. Plantation: This land cover type includes cultivated plantations, not necessarily woods, with a carbon stock value of 63 metric tons per hectare per year.
k. Mining regions are often disrupted and lack flora, resulting in low carbon stocks. Thus, the carbon stock value is 0. l.
l. Dryland Agriculture: This land cover type refers to agricultural areas in dry climates. Carbon stock is 10 metric tons per hectare per year.
m. Mix Dryland Agriculture: This term describes a variety of agricultural activities in arid locations. The carbon stock is slightly higher at 30 metric tons per hectare per year.
n. Grasslands: Low carbon stock value of 4.5 metric tons per hectare per year.
o. Agriculture: This land cover class includes croplands and pasturelands. Carbon stock is 35 metric tons per hectare per year.
p. Pond: Water bodies with little vegetation contribute little to carbon stock. The carbon stock value is 0.
q. Bare Land: Areas without vegetation. Vegetation has limitless carbon stock potential, resulting in a low 2.5 metric tons of carbon per hectare per year.

These carbon stock values estimate each land cover type's annual carbon storage potential [16]. It is important to note that these values can vary depending on various factors such as geographical location, climate, land management practices, and specific vegetation types present within each land cover category.

3.3 Degradation and Deforestation Analysis

Degradation refers to the deterioration or loss of the quality and productivity of natural resources such as land, forests, and water bodies. It can occur due to various factors, including unsustainable land use practices, overexploitation of resources, pollution, and climate change. On the other hand, deforestation specifically refers to the permanent loss of forest cover and the conversion of forested areas into other land use types, such as agriculture, urban areas, or infrastructure development. Based on Fig 2 and Fig 3 show which classes are forest and non-forest.

(a) Dryland Forest (b) Mangrove Forest

Fig.2 Forest classes

(a) Shrub (b) Agriculture
(c) Plantation (d) Airport
(e) Settlement (f) Pond

Fig.3 Non-forest classes

4. RESULTS AND DISCUSSION

4.1 Degradation and Deforestation on East Java

East Java is one of Indonesia's most populous provinces, located on the eastern part of Java Island. It covers an area of approximately 47,800 square kilometers and includes a diverse range of cosystems. East Java has total 30 Regencies and Cities including a diverse range of administrative regions. Degradation and deforestation from 1990 to 2022 analysis based on land cover in East Java derived from Landsat and survey by Ministry of Environment and Forestry can be seen on Fig 4. Table 2 shows the detail result of degradation and deforestation from every each city or regency based on Fig 4. Malang at 42605.70 Ha and Jember at 26219.19 Ha have the most deforestation.

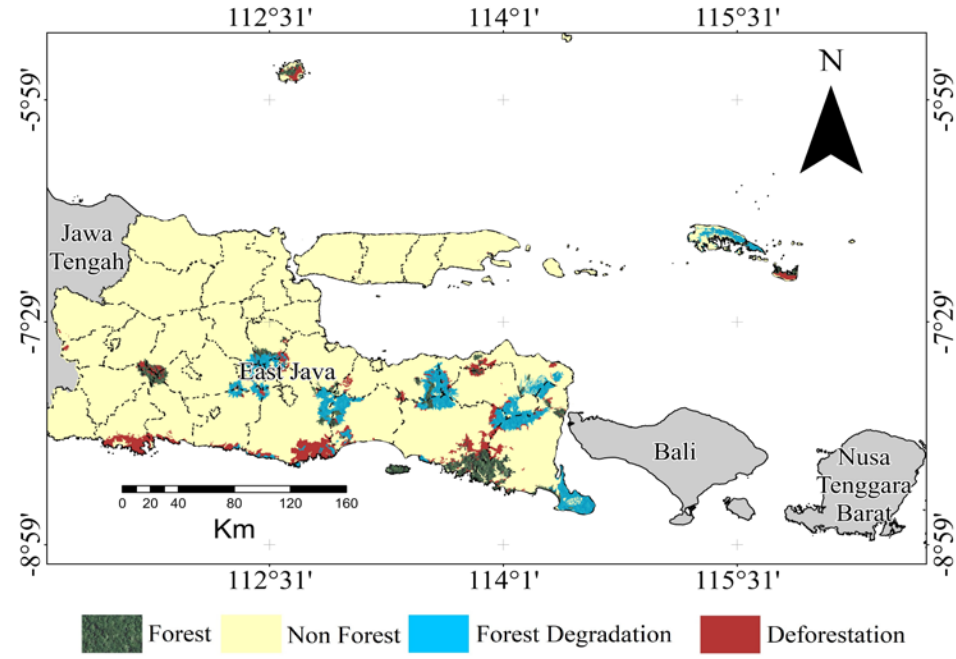

Fig. 4 Degradation and Deforestation on East Java from 1990 to 2022 This Map Shows Forest Cover, Non-Forest Areas, Forest Degradation, And Deforestation Over the Study Period

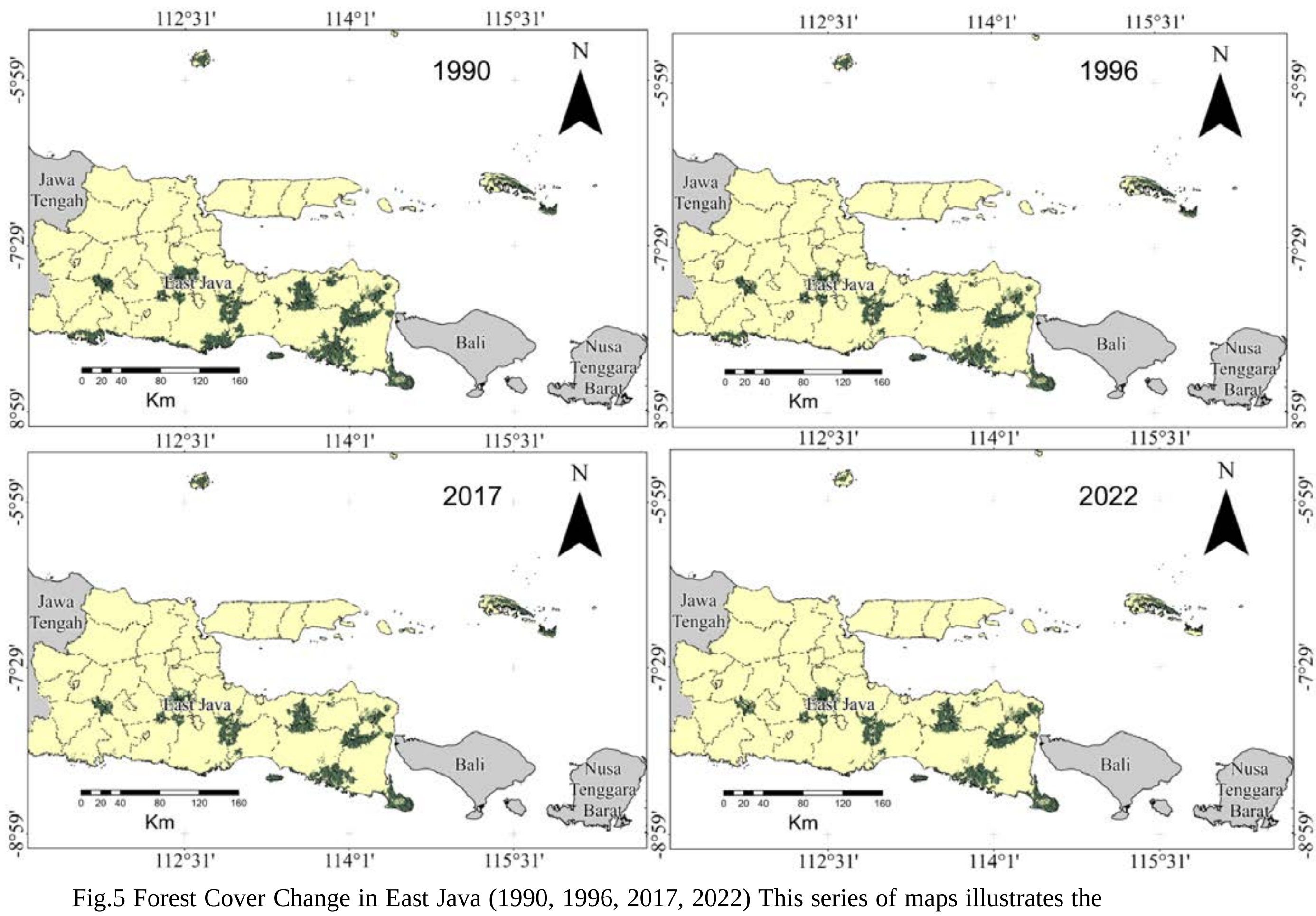

Fig.5 Forest Cover Change in East Java (1990, 1996, 2017, 2022) This series of maps illustrates the progressive changes in forest cover over the years

With 65957.99 Ha and 38184.20 Ha, Banyuwangi and Malang have the most degradation.

Table 2 Degradation and Deforestation from 1990 to 2022 on East Java

City	Degradation (Ha)	Deforestation (Ha)
Banyuwangi	65957.99	14587.63
Blitar	8863.38	6323.32
Bondowoso	19783.54	5980.77
Jember	27592.00	26219.19
Jombang	4551.63	311.03
Kediri	3537.05	1693.32
Kota Batu	5985.20	701.46
Lumajang	22186.79	6818.92
Malang	38184.20	42605.70
Mojokerto	7312.06	1865.17
Pacitan	2.00	0.63
Pasuruan	2241.20	3986.82
Probolinggo	19945.78	17.98
Situbondo	22545.61	10154.16
Sumenep	20376.37	5636.73
Trenggalek	9.39	23139.87
Banyuwangi	65957.99	14587.63
Bangkalan	-	388.49
Gresik	-	5310.56
Surabaya	-	1.63
Lamongan	-	36.24
Madiun	-	1895.07
Magetan	-	1111.19
Nganjuk	-	2591.14
Ngawi	-	397.26
Pamekasan	-	81.21
Ponorogo	-	1106.74
Sampang	-	257.86
Sidoarjo	-	142.93
Tulungagung	-	6261.43

The conversion of 30000 Ha of dryland forest to mixed dryland agriculture is Malang's biggest deforestation driver. Jember has deforested 12000 acres of dryland forests into bushes. Dryland forest change, which covers 65000 ha in Banyuwangi and 38000 ha in Malang, is the biggest degradation driver. Fig 5 depicts the changes in land cover in East Java, Indonesia, over the years 1990, 1996, 2017, and 2022, using color coding to differentiate between forested (green) and non-forested (yellow) areas. The maps reveal a clear trend of deforestation and forest degradation across these years. In 1990, substantial forest cover is visible throughout the region. However, by 1996, significant reductions in forested areas are evident, indicating early stages of deforestation and land conversion. This trend continues more aggressively in 2017, with a marked decrease in green areas and a corresponding increase in yellow areas, reflecting extensive land use changes for agriculture or urban development. By 2022, the forest cover has diminished further, highlighting severe deforestation and degradation over the decades. Most of the forest in southwest east Java, like Trenggalek, is gone. Data in Fig 6 were obtained by collecting dryland forest class and mangrove forest class annually from 1990 to 2022 for degradation and deforestation analysis. According to the data presented in Fig 6, the annual change in primary dryland forest in East Java showed a significant decrease in 2010, indicating a period of intense degradation. The results show a high increase in secondary dryland forests but also a massive loss in primary dryland forests. However, since 2015, there has been an increasing trend in the area of primary dryland forest, with a total increase of approximately 32,000 hectares compared to 1990.

The total area was around 353,000 hectares, indicating some efforts towards reforestation and restoration of primary dryland forests in East Java. In contrast, the data for secondary dryland forests showed an extreme increase in 2010, indicating a period of degradation and disturbance of these forests. The annual change in the primary mangrove forest also can be seen in Fig 6. The area of primary mangrove forest in East Java has decreased from approximately 15,000 hectares in 1990 to around 9,000 hectares in 2022. This indicates a significant loss of primary mangrove forests over the years. In contrast, the trend for secondary mangrove forests has been different. From 1990 to 2009, there was a decreasing trend, suggesting a loss or degradation of secondary mangrove forests. However, after 2009, there has been an increasing trend in secondary mangrove forests, reaching a total area of around 16,000 hectares in 2022 [9]. The increasing trend in secondary mangrove forests indicates some potential for reforestation efforts.

According to Fig 7, the total carbon stock of East Java in 1990 was approximately 196 million tonnes of carbon. However, there has been a decreasing trend in carbon stock from 1990 to 2022. This indicates a loss or degradation of forested areas, which are important carbon sinks. Between 1990 and 2010, there was a gradual decrease in carbon stock, attributed to deforestation and forest degradation, which reduced the region's ability to sequester carbon. The conversion of forested areas

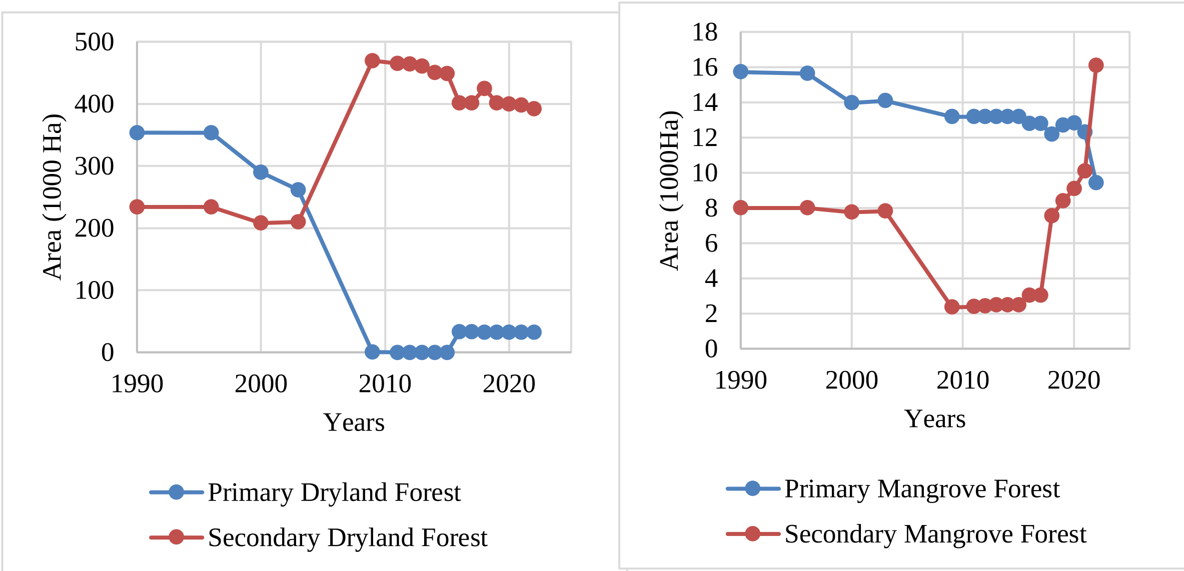

Fig.6 Annual East Java Dryland Forest Change (left) and East Java Mangrove Forest Change (right) This graph shows the significant decrease in primary forest area and the corresponding increase in secondary forest area over the study period.

to agricultural land, urban development, and other land uses contributes to this reduction. The period from 2010 to 2022 shows a more pronounced decline in carbon stock, dropping to approximately 156 million tonnes by 2022, highlighting an accelerated rate of deforestation and forest degradation in recent years [15].

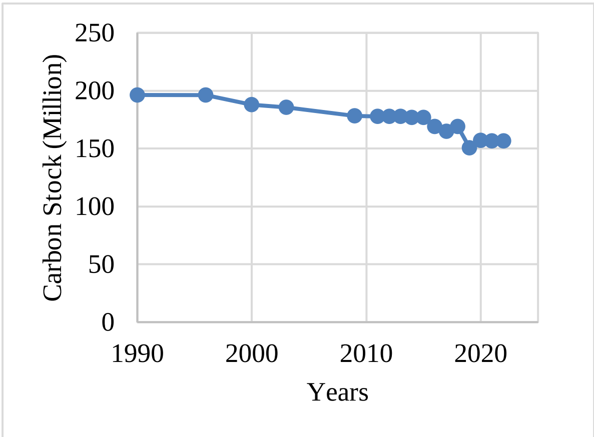

Fig.7 Annual East Java Carbon Stock in Million This graph illustrates the decline in carbon stock over the study period, indicating the impact of deforestation and forest degradation on carbon

5. CONCLUSIONS

In conclusion, this study demonstrates the significant extent of deforestation, forest degradation, and carbon stock changes in East Java, Indonesia, from 1990 to 2022. The integration of GIS-based forest monitoring techniques, including satellite imagery and GIS analysis, allowed for the precise tracking and quantification of land cover changes. The findings reveal that East Java has undergone substantial deforestation, with approximately 180,000 hectares of forest lost and around 270,000 hectares degraded. Malang had the highest deforestation rate due to agricultural expansion and urban development, while Banyuwangi experienced significant forest degradation from illegal logging and plantation agriculture.

Primary dryland forests decreased dramatically from 400,000 hectares in 1990 to near zero by 2010, with a modest recovery of around 32,000 hectares by 2022, indicating reforestation efforts. Secondary dryland forests increased significantly, peaking at 400,000 hectares by 2010, showing natural regeneration and reforestation. Primary mangrove forests declined from 16,000 hectares in 1990 to 9,000 hectares by 2022, but secondary mangrove forests increased to 16,000 hectares by 2022, suggesting successful restoration.

The total carbon stock in East Java decreased from 196 million tonnes in 1990 to 156 million tonnes by 2022, highlighting the impact of deforestation on carbon sequestration. The pronounced decline between 2010 and 2022 underscores the need for effective forest management to mitigate environmental degradation and carbon emissions. GIS-based monitoring proved valuable for land cover analysis and management, offering critical insights for policymakers and conservationists.

Future research should focus on long-term monitoring of forest recovery and the effectiveness of reforestation strategies. Integrating socio-economic data with environmental monitoring can provide a comprehensive understanding of deforestation drivers and effective conservation measures. Further studies should investigate the socio-economic impacts of deforestation on local communities and explore sustainable land use practices balancing economic development with environmental conservation. Overall, this study highlights the critical state of forests in East Java, the importance of continued conservation efforts, and the valuable role of GIS in environmental monitoring and decision-making.

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