Analysis of Total Mangrove Carbon Stock Degradation in Kendari Bay

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Abstract. Mangrove ecosystems are one of the blue carbon ecosystems in the coastal region. Mangroves can assimilate high carbon and can save carbon in the long term. Settlements and various centres of community activities have developed on the coast of Kendari Bay, which drastically decreased mangrove vegetation. Research on blue carbon placed in mangrove forests is vital to be carried out to determine changes in regional conditions in the coastal region. Spatial modelling is used to estimate the degradation of blue carbon stocks. A remote sensing data is required for producing spatial and temporal maps. InVEST (Integrated Assessment of Ecosystem Services and Sacrifices) can be used for mapping and modelling total carbon stock changes based on land cover changing in Kendari Bay. Carbon stocks can be calculated through spatial and temporal mapping in InVEST with past, present and future scenarios. Spatial and temporal maps form InVEST can be considered in determining policies related to mangrove management and making more appropriate decisions in managing Kendari Bay area.

1. Introduction

Mangroves belong to the group of blue carbon ecosystems along with salt marshes and seagrass beds. Blue carbon ecosystem is an ecosystem that can store carbon for an extended period up to decades [1]. Mangroves can assimilate high carbon absorption rate [2]. Based on these capabilities, mangrove forests have a role to prevent global warming [17].

Kendari Bay is an area that supports community economic activities and has high socio-economic value for the community, business people, and the government [3]. The region has developed settlements and various community activity centres, such as ports, shops, and tourist attractions. Mangrove forests in this area are not only functioning as a barrier to abrasion and sedimentation but also used as tourist destinations because of the beauty of the panorama [4].

Mangrove forests in Kendari Bay in 1960 had an area of around 542.58 hectares. However, with the conversion of land by the community, the mangrove forest area decreased to the remaining 69.85 Ha in 1995 [16]. Mangrove forest areas located on the coast are vulnerable to land conversion. The development of Kendari City, which is mostly located on the edge of Kendari Bay, will affect the existence of mangrove forests. Development of urban areas that do not pay attention to the regional ecosystems makes mangrove areas vulnerable to be converted into other use areas. Degradation of
mangrove forests results in changes in the coastal ecosystem [12]. Mangrove areas reduction will reduce the ability of mangrove forests to absorb carbon from the atmosphere [1].

Calculation of carbon stock stored in mangrove forests is important for knowing the total area that able to absorb CO$_2$ from the air. This data can be used for sustainable management of the region related to the effort in reducing CO$_2$ concentrations in the atmosphere, as well as the region's function in climate change mitigation [5].

Changes in coastal areas that occur due to land conversion and infrastructure development will have an impact on the function of mangrove ecosystems as a provider of coastal blue carbon stocks. The dynamics of the mangrove ecosystem in Kendari Bay will result in changes in coastal blue carbon stocks. The value of mangrove ecosystems changes caused by the area development can not be known, even though this information is needed in integrated coastal area management. The dynamics of the mangrove ecosystem have only reviewed descriptively. Spatial mapping and modelling have not been carried out on the mangrove carbon stocks as a provider of blue carbon on the coast. To overcome this, we need a method of calculation which can describe the conditions of the past, current, and estimating future mangrove carbon stocks based on various desired scenarios. Remote sensing for mangrove ecosystems can be used to obtain information about changes in area and density, especially due to the dynamics of spatial use in coastal areas [16]. The advantage of remote sensing is that it can streamline research time with relatively cheaper costs [3].

This research is expected to produce a model that can be used to predict the total carbon stocks of degraded mangroves in the Kendari Bay coastal area at a certain time due to changes in land use and cover.

2. Literature review

2.1. Coastal area of Kendari Bay
Kendari Bay is semi-enclosed estuary water located in the centre of Kendari City [11]. Kendari Bay with an area of around 29.5 km$^2$ is part of a very strategic and unique Kendari area. In the north of Kendari Bay lies the Nipa-Nipa mountain range, which is a protected forest. In the southern part of Kendari Bay lies the Nanga-Nanga mountain, which also a protected forest. These three aspects, namely the Kendari Bay coast, the Kendari City area, Nipa-Nipa and Nanga-Nanga protected forests, are a unified and interconnected ecosystem [16].

Kendari Bay is the estuary of 13 rivers in the city of Kendari and surrounding areas, causing a decrease in the quality of the environment. Some of these problems include silting due to sedimentation, decreased water quality, and reduced mangrove ecosystems caused by infrastructure development [6].

2.2. Development plan of Kendari Bay
In the Regional Regulation Number 1 of 1984-2004 regarding the City Master Plan of Kendari City, the area on the west and south of Kendari Bay affected by tides is determined as a green belt. This determination is an effort to maintain land usage harmonization. But, many land-use changes because of the construction of road infrastructure in the green belt area from 1990 to 2017. The effect of new road construction is the increasing number of settlements on the sides of new roads. Violations that mentioned in Regional Regulation Number 1 of 1984-2004 regarding the City Master Plan are likely to occur again in the Kendari City Regional Regulation Number 1 of 2012 regarding the Kendari City Spatial Plan. Based on Kendari City Regional Regulation Number 1 of 2012, road network development in Kendari City aims to direct the development of settlements. In the future, there will be a concentration of settlements on the sides of the new circular road along the mangrove forest area where the mangrove forest is designed as a water catchment area and urban forest [16].
2.3. Blue carbon mangrove

Mangrove forests have another function which is to reduce CO$_2$ gas in the atmosphere through photosynthesis so that they can store more carbon. It is estimated that mangrove forests can absorb CO$_2$ from the atmosphere by 25.5 million tons/year globally so that it is very potential to reduce global warming [7]. Changes in land use due to mangrove forest degradation both for ponds and for tourism can be a major factor in producing greenhouse gases [18]. This is inseparable from the phenomenon of increasing human populations living in coastal areas [19].

Mangrove forests are one of the forests that have the highest carbon storage in the tropics. The amount of carbon stock is determined by the biomass in the tree. Biomass is closely related to photosynthesis. Biomass will increase when plants absorb CO$_2$ and convert it into organic compounds through photosynthesis. The results will be used by plants to grow horizontally and vertically. The amount of biomass is determined by diameter, plant height, wood density, and soil fertility [8]. Carbon stores in mangrove forests are higher than in other forests, where the most abundant carbon deposits are in mangrove sediments. Dead leaves and branches of mangrove trees are decomposed by microorganisms and become one source of organic material in mangrove sediments [9].

Mangrove forest carbon stores are higher than other forests. Mangrove forests deposit of 1,023 Mg C H$^{-1}$, terrestrial tropical forests deposit around 300 Mg C H$^{-1}$, and temperate forests deposit around 350 Mg C H$^{-1}$. High productivity and rate of carbon sequestration in mangrove ecosystems produce high carbon deposits, especially below the surface. The high carbon stock in mangroves makes it globally important [2]. Sources of carbon in mangrove vegetation are in four parts, that is above ground (leaves, twigs, branches and branches of mangrove vegetation), litter (the dead carbon and standing dead carbon), and soil/sediment [13].

Based on the Ikonos satellite imagery data of Kendari City recorded in 2003, the coast of Kendari Bay is dominated by ponds and mangroves, where the area of mangrove forests is 182 Ha. However, in the period of 6 years (2003-2009), there has been a change in land use from mangroves and ponds to trade areas and new business centres so that the area was reduced from 56.57 Ha to 125.43 Ha [3]. Mangrove forests in Kendari Bay only have four types of plants, namely *Rhizophora* sp., *Soneratia alba*, *Bruguiera* sp., and *Avicennia* sp. with rare densities [10]. The density of mangroves in the coastal area of Kendari Bay is relatively thin at 20 to 100 meters, and even in certain locations have completely disappeared as a result of conversion into a pond. High mangrove density was found in locations that are crossed by rivers around the mouth of the Wanggu River, Kambu and Kadia [3].

3. Methods

This research is a type of quantitative descriptive research that focuses on spatial and temporal modelling. The analysis was done using 1980, 2000, and 2019 medium resolution satellite data, global carbon data, and using spatial modelling software for an area with input into the development plan or without development. The results expected from the modelling are the description of spatial and temporal maps of land-use change which quantitatively show the dynamics of mangrove carbon stocks.
Spatial modelling was done to determine the condition of mangrove carbon stocks at present and in the future due to the development of coastal areas. This research uses Integrated Valuation of Ecosystem Services And Tradeoffs (InVEST) modelling. InVEST could predict the amount of carbon that is stored and absorbed in coastal areas over a certain period due to changes in land cover. The results from InVEST can be used to compare current and future planning of carbon stocks and carbon sequestration [13].

InVEST coastal blue carbon models the carbon cycle through a simplified carbon cycle approach by calculating carbon storage in three main storage sites, namely biomass, sediment, and carbon in standing/littered dead mangroves. Carbon accumulation in coastal habitats mainly occurs in sediments [14]. This model requires the availability of maps of coastal ecosystems that store carbon, such as mangroves and seagrasses. The annual rate of carbon accumulation is stored in biomass and sediment. If local information is not available, it can utilize a global database of carbon stocks stored and the level of accumulation derived from the peer-reviewed literature included in this InVEST model set.

InVEST can be used in the decision-making process. It started by identifying various development plans to be implemented, collecting data, then running the software to produce spatial and temporal maps according to the desired plan so that stakeholders can make policies based on information from the modelling. In general, the InVEST model is used to evaluate the effect of human activities and climate change, human concern and needs on the environment [15].

4. Result and discussion
This research is still running at the running model stage. This study will produce: 1. Carbon Stock Rasters (Units: Megatonnes CO$_2$ e per Hectare), 2. Carbon Accumulation Rasters (Units: Megatonnes CO$_2$ e per Hectare), 3. Carbon Emissions Rasters (Units: Megatonnes CO$_2$ e per Hectare).

5. Conclusions
The conclusion obtained in this study is the mapping of the current condition of coastal blue carbon stocks and future conditions based on regional development plans through spatial modelling.
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