Carbon Stocks Mapping of Mangrove Forest in North Buton Indonesia using Combination of Landsat and ALOS PALSAR Images in the Perspective of Climate Change Mitigation

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Abstract. Mapping of carbon stocks, distribution and its changes become one of the important strategies in climate change mitigation. This study aims to map the carbon stocks of mangrove forests and analyze the changes using a combination of Landsat and ALOS PALSAR images in North Buton, South East Sulawesi Province, Indonesia. Carbon stocks in mangrove forests are known stores several times more than forests in the mainland. Mangrove forest at coast of North Buton is one of the largest area of mangrove forest in south east Sulawesi. The research conducted using backscatter coefficient of HH and HV polarization from ALOS PALSAR and Normalized Difference Vegetation Index (NDVI) from Landsat. The results showed that Landsat image provided information about the distribution, density and change of the carbon stocks during year 2001-2017 while ALOS PALSAR provided the volume of carbon stocks in this region.

1. Introduction
The existence of mangrove in coastal area plays important role for a healthy coastline and able to become a resource for the environment and humans who live around the area. Mangrove forests have various advantages over other mainland natural forests in terms of carbon stocks, environmental functions and disaster mitigation as well as climate change. Mangrove forests are able to store carbon five times more than forests on land [1]. In terms of environmental functions, mangrove forests become spawning areas for several fish species and several other marine species. Regarding to disaster mitigation, mangrove forests can become a kind of strong barrier to ocean currents including tsunamis.

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Thus, mangrove forests need to be conserved for the future. However, population today increase and settlement expansion have threatened the existence of mangrove forests.

Mangrove forest and its carbon stocks need to be mapped and monitored periodically to ensure the sustainability of mangrove existence. Mapping of carbon stocks is carried out in various ways with various methods and approaches and with various instruments. One effective way to map and monitor carbon stocks is using remote sensing.

Landsat and also other optical sensor such as SPOT, Ikonos, World-View etc. have been used in biomass or carbon stock estimation since a few decades ago. Landsat has a high spectral resolution for the analysis of biomass and land. However, the optical remote sensing encountered obstacles due to hydrometeorology conditions such as cloud cover, rain, fog and smoke. Thus, today, remote sensing radar namely Synthetic Aperture Radar (SAR) becomes an alternative for mapping land use and land cover. SAR sensor can penetrate rain, clouds, fog and can be operated day and night.

Today, there are several radar satellites can be used to monitor and map carbon stocks, such as ALOS PALSAR and Sentinel-1. Dual polarization ALOS PALSAR (Advanced Land Observing Satellite-Phased Array type L-band Synthetic Aperture Radar) and Sentinel-1 images are available in abundance and distributed free of charge. The easy of obtaining cloud-free image data for carbon stocks mapping purposes in the context of disaster mitigation and climate change needs to be welcomed. The abundance of Landsat image data in the online system especially from https://earthexplorer.usgs.gov/ is very beneficial for biomass mapping today. We also can obtain ALOS PALSAR data (L-band) freely from https://www.asf.alaska.edu/sar-data/palsar/, as well as Sentinel-1 SAR data (C-band) from https://scihub.copernicus.eu/.

It has been hypothesized that the integration of SAR at different frequency or with optical data can improve biomass prediction [2]. Thus, the combination of optical and SAR images to obtain high accuracy biomass or carbon stocks become a good effort in disaster and climate change mitigation. This research aims to analyze combination of optical and radar images to map mangrove carbon stocks in North Buton, South East Sulawesi Province, Indonesia.

![Figure 1. The study location in North Buton, Indonesia.](image)

2. Methods

2.1. Location

This research conducted in mangrove forest in North Buton, Indonesia about 150 kilometers at south east of Kendari, the capital city of South East Sulawesi Province. The mangrove cover is about 13,000
hectare stretches from north to south of North Buton as displayed in Figure 1. The landscape surrounded by mountains in the north and relatively flat in south. The land cover dominated by forest, settlement and agriculture. Mangrove forest covers in some small islands near Ereke (the capital city of North Buton).

2.2. Data
We used optical and SAR image (Table 1) to show the beneficial of these images in mapping carbon stocks.

| Platform     | Acquisition Date | File Name                                      |
|--------------|------------------|-----------------------------------------------|
| Landsat ETM  | 2001             | EPP112R063_7F20010506                         |
| Landsat 8    | 2018             | LC08_L1TP_112063_20180614_20180614_01_RT.tar |
| ALOS PALSAR  | 18 July 2009     | ALPSRP185477090-L1.1                         |
| ALOS PALSAR  | 21 July 2010     | ALPSRP239157090-L1.1                         |

2.3. Procedure
Carbon stocks analysis can be conducted through several methods. In this research, we conducted backscatter coefficient analysis for ALOS PALSAR data and NDVI (Normalized Difference Vegetation Index) analysis for Landsat. Shimada et al [3] developed backscatter concept using equation (1).

\[ \sigma^g [dB] = 10 \times \log_{10}(DN^2) + CF \]  

(1)

Where DN=Digital Number of radar image and CF=Calibration Factor for ALOS PALSAR data,

While for NDVI, we used general equation (2) from [4]:

\[ NDVI = \frac{IR - R}{IR + R} \]  

(2)

Where NDVI = Normalized Difference Vegetation Index, IR= infrared band, and R = red band.

2.4. Validation
For validation, 20 sampling plots with 25 x 25 square meters grid have been measured in the field during July 2018 as displayed previous in Figure 1. We identified four species of mangrove in the field namely Sonneratia alba, Rizophora apiculata, Bruguiera gymnorrhiza, and Xylocarpus granatum. We used allometric equation for mangrove vegetation from [1] which integrate Diameter at Breast Height (DBH) and vegetation height using equation (3).

\[ B = 0.0825 \times (D^2H)^{0.89956} \times \rho \]  

(3)

where B = biomass (kg), D = DBH (cm), H = height (m) and \( \rho \) = vegetation density (gr cm\(^{-3}\)).

3. Result and Discussion
Mangrove in North Buton is one of the largest mangrove forest in South East Sulawesi. It consists about 13,000 hectares extend from north to south in Kulisu Utara, Kulisu Barat, Kulisusu and Bonegunu Sub Districts. Mangrove ecosystems play an important role in supporting the local communities. Mangroves provide food security and livelihoods through its natural resources, such as
mangrove crabs, and fish-spawning habitats. Related to disaster mitigation, mangrove forests also act as storm buffers for coastal communities who may otherwise lose their homes during storm surges. Unfortunately, mangroves in Indonesia are being lost at an estimated rate of 1-2% each year to agriculture and aquaculture [5].

Figure 2. Mangrove forest in North Buton coastal area surrounded by traditional settlement of Bajo, nipa, coconut tree and fishpond (Photo by Jamhir Safani and team)

Figure 2 shows mangrove forest and the existence of Bajo settlement surround the forest. Bajo (or Bajau) is traditional tribe who lives in coastal area. Their life is depending on coastal resources. However, for many years they are expanding settlement and fishpond in mangrove area. These activities release carbon in the atmosphere.

Figure 3. NDVI of mangrove density and distribution in North Buton based on Landsat image: (A) Year of 2001 and (B) Year of 2018

NDVI has been used to analyze carbon stocks in forest and mangrove [6][7]. Middle and high resolution satellite can be used for NDVI analysis. Besides forest density and biomass, we also obtain distribution of vegetation cover in a certain area. In line with this, SAR data become an alternative for biomass mapping. SAR data are acquired in X, C, L and P bands. Each of these bands has its own characteristics in relating to forest stand parameters [8]. The ability of radar images for mapping mangroves cover is very dependent on radar channel and also its polarization. Previous studies have shown that the use of bands with longer wavelengths, for example L Band, will be better in identifying mangroves [9]. While the polarization used is known to polarize HV or VH has the ability that is also better at mapping mangroves due to lower saturation values.
NDVI value normally is between -1 (for non-vegetated area) to +1 (fully-vegetated) [4]. Figure 3 shows NDVI map of mangrove density using Landsat in year 2001 and 2018. The NDVI value between -0.58 to +0.67 in 2001 and become -0.19 to +0.84 in 2018. This informs us that the forest density is increase. However, the area of mangrove forest reduces in the last seventeen years from 12,918 hectare in 2001 become 11,521 hectare in 2018 or 10.8% lost. It may change into fishpond, settlement or agriculture.

Figure 4. ALOS PALSAR image of mangrove forest in north Buton in multi looking mode: (A) HH Polarization, (B) HV Polarization, and (C) RGB composite (R=HH, G=HV, B=HH/HV) (note: north direction is opposite)

Figure 4 shows ALOS PALSAR image of mangrove forest based on HH and HV polarization and the color RGB composite. The darkness part of image indicates mangrove forest. It can be separated from other land cover such as water and non-mangrove cover.

Figure 5. Relation between carbon stocks from sample plot and backscatter coefficient

The backscattering of the L band is more related to the trunk and main branches and less sensitive to the environmental conditions so it is valuable in the biomass estimation [9][10], especially mangrove forest [11]. Using a combination of C and L band has shown better results than using of one band [12]. Figure 5 shows relation between carbon stocks from 20 sample plot and backscatter coefficient of ALOS PALSAR. The maximum carbon stocks among 20 sample plots is 48 ton/ha. We conducted survey only in the coastal line due to difficult accessibility for getting data the older mangrove in the middle part of mangrove cover. We obtained $R^2=0.4744$ for HH polarization and $R^2=0.7492$ using HV polarization. This result confirmed some previous researches that HV polarization of SAR image has a good result in mapping biomass.

4. Conclusion
Optical image such as Landsat has advantage to map density and distribution of carbon stocks through NDVI method. We found that the density of mangrove in the study site is increase, but the area of mangrove cover is reduced. In the other hand, SAR image can provide volume of biomass or carbon
stocks using backscatter coefficient analysis. We found that using ALOS PALSAR image, HV polarization has a good relation with carbon stocks than HH. The combination both methods can provide a good accuracy of carbon stocks map, distribution and density. The spatial information of carbon stocks can be used to support local and national program related to mitigation of climate change and disaster mitigation as well for example REDD+.

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