ALGORITHMS DEVELOPMENT OF THE FIELD MANGROVE CHLOROPHYLL-A BIOMASS, CARBON BASED ON SENTINEL-2A DATA AT CAWAN ISLAND, SUMATERA, INDONESIA

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DOI: 10.21163/GT_2022.172.11

ABSTRACT:

The study develop of algorithms for the tropical mangrove chlorophyll-a, biomass and carbon based on the field data measurements at Cawan Island Sumatera Indonesia and Sentinel-2A satellite data. Samples of mangrove leaf were used for chlorophylla-a measurements using spectrometry method. Field sampling data using purposive sampling method. Data of mangrove tree diameter at breast height (DBH) was processed using allometric equation to estimate the mangrove biomass and carbon content. Algorithms were developed after performing a series of polynomial regressions of field and Sentinel-2A satellite data and then select the highest correlation coefficient. The dominant mangrove is *Rhizophora apiculata*. The field mangrove leaf chlorophyll-a content ranged from 14.03-15.77 $mg.ml^{-3}$, while the estimated chlorophyll-a from algorithm is in the range of 13.714-16 $mg.ml^{-3}$. Calculated field mangrove biomass is in the range of 66.31-85.05 $tons.ha^{-1}$, while the value from algorithms is in the range of 51-90 $tons.ha^{-1}$. The highest biomass and carbon storage is in the trunks. This study produces the algorithm of mangrove leaf chlorophylll-a = $0.0002((B_4 + B_2)/2)^2 – 0.057((B_4 + B_2)/2) + 16.79$, with RMSE of 0.072 $mg.m^{-3}$. Algorithm for mangrove biomass = $24.69(B_4/Band_2)^2 - 47.41(B_4/B_2) + 36.06$, with RMSE of 0.337 tons/0.2ha and algorithm for mangrove carbon = $10.071(B_4/B_2)^2 – 23.159(B_4/B_2) + 44.233$; with RMSE of 0.235 tonsC/0.2ha. The new insight in this study is that the algorithm developments can be applied for mangrove chlorophyll-a content, biomass and carbon content estimation using any optical satellite data based on its relevant spectral range. This algorithm development is an open approach method based on highest correlation coefficient on regression equation of the field and the satellite spectral value. The algorithms resulted from this study can be applied over wide and in any area in the tropics.

Key-words: *Mangrove, Chlorophyll-a, Biomass, Carbon, Sentinel-2A, Algorithm*

1. INTRODUCTION

Mangrove is defined as an association of halophytic trees along brackish tropical and subtropical tidal coastlines (Donato et al., 2012). Their physical functions include reducing coastal erosion and sediment trap (Chapman, 1975). The chemical ecological function is to transform CO_2 into organic carbon as greenhouse effect reduction and thus global warming mitigation and adaptation (Hartoko et al. 2010, Lasibani and Eni, 2010). Atmospheric CO_2 generated by burning of fossil oil, coal and vegetation had increased cumulatively (Ramlan, 2008). According to Donato et al., (2011) and Ellison et al., (2015), mangrove ecosystem can reduce atmospheric CO_2, as mangrove biomasses account for 10% of the storage of total atmospheric CO_2 but only 0.7% by the global forest. Atmospheric CO_2 transformed into the trunk, branch and leaves of the mangrove biomass (Alongi, 2012). The organic carbon yield form the atmospheric CO_2 is reported to have organic carbon and CO_2 by ratio of 1 : 3.7 (Chapman, 2018). This can be mainly attributed to the mangrove ecosystem along the tropical coast of Indonesia (Murdiyanto, 2003). Mangrove ecosystem also function as carbon cycles and dissolve organic carbon exporter to other coastal ecosystem of coral reef and seagrass beds (Hartoko, 1989; Afifa et.al.,2020; Ershad et.al.,2020). Indragiri Hilir regency, Riau province in Sumatera is home to one Indonesian’s largest area of mangrove forest.

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In 2003, mangrove coverage in this area is 117.717 ha (Office of Environment. Indragiri Hilir, 2009), which had decreased to 65.534 ha by 2013 (Office of Forestry. Riau Province, 2013). According to Prianto et.al (2006) the decrease in mangrove coverage was due to coastal area developments and land-use changes in coastal areas. The traditional use of mangrove *R.apiculata* as the dominant species at Cawan Island is for household cooking wood (Lubis.et.al, 2018).

Previous studies had focus on the ecological conditions of mangrove, monitoring mangrove area cover with the use of low-resolution satellite imagery, so that the need to use of high-resolution satellite imagery to monitor mangrove area cover is inevitable. There have been some attempts for a more detail study using high resolution satellite imagery for the analysis of normalized difference vegetation index (NDVI) of mangrove leaf, but unfortunately no information's on the species of the mangrove. The information of each mangrove biomass based on each species is important, since each species of mangrove have their own growth characters and different chlorophyll-a, biomass and carbon content. The previous study has developed mangrove algorithms but not differentiated the mangrove biomass and mangrove carbon and without chlorophyll-a (Wicaksono et al, 2016). The use of radar data (Li et.al., 2007), which is fundamentally detect more on the wide of mangrove area based on the electromagnetic reflectance, not the optical satellite data is arguable for biomass estimation. Since mangrove biomass and carbon content is believed as the ecological function of the chlorophyll-a content.

This study develops of spatial algorithms for mangrove biomass and carbon based on step-by-step mangrove biomass and carbon with approach through the chlorophyll-a content. This using the optical data of Sentinel-2A data which is relevant to the reflectance or the spectral value of the mangrove leaf chlorophyll-a data, especially using Band-3 and Band-4. The result of the study with respect to mangrove chlorophyll-a, biomass and carbon has become important model for the sustainable management of the mangrove ecosystem and mitigation of global warming. This study using the field mangrove leaf chlorophyll-a as the first step based on the assumption of the mangrove growth metabolic function into mangrove biomass and carbon. Then to estimate the field mangrove biomass, the study uses the non-destructive method of diameter at breast height (DBH) measurement. The field data then used to develop the spatial mangrove chlorophyll-a, biomass and carbon content. With this approach model can be used for mangrove conditions evaluation more accurately. The spatial algorithms that have been developed based on field allometric and satellite data have enabled efficient data usage and the development of an integrated spatial data base system. The important steps in the satellite data algorithm development are spatial accuracy, information of mangrove species, biomass and carbon content using a non-destructive method of allometric equations based on the field measurement (Hartoko et al., 2015). Important information on mangrove area cover monitoring, is the exact mangrove species based on a field measurement and sampling data. This can be used for mangrove algorithms development for mangrove biomass and ultimately for mangrove carbon estimations over a wide of mangrove area with a more accurate and efficient way.

The aim of this study is to investigate the mangrove species at Cawan Island and measure the chlorophyll-a, biomass, carbon contents and supported with data of total organic content in mangrove sediment. More specifically is to develop the spatial mangrove biomass and carbon algorithm using Sentinel-2A satellite data. The area of study is mangrove trees at Cawan island in Sumatera. Which is a very specific mangrove ecology in respect the only mangrove can grows and reach to 20 m height in 1 m depth of acidic peat-clay substrates. Which is different in comparison to other common mangrove clay substrate in Indonesia or other tropical wetlands of Asia.

2. STUDY AREA

Mangrove field measurement, sampling and ground check located at Cawan Island, along with the same day of the Sentinel-2A satellite data in 24th December 2019 (**Fig. 1**). Cawan Island is located in area extent of 103^0 33'18'' E and $0^0$05'59''N in the administration of village of Cawan, district of Mandah, Indragiri Hilir regency, Riau province, Sumatera (Lubis et al, 2018). Of its total area of 36.30 km^2, two thirds of it consists of mangrove vegetation (Riau Bureau of Statistic, 2013).

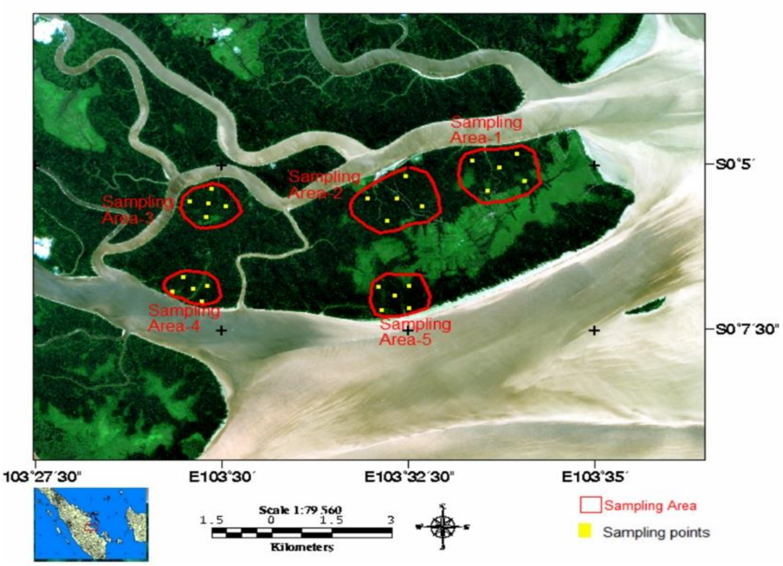

Fig. 1. Five sampling area each with 5 sampling points at Cawan Island.

3. DATA AND METHODS

3.1. Field Sampling

The study established 5 sampling-area, each consist of 5 sampling-points and total of 25 sampling points. In each one sampling-area, there are 1 sampling-point in the centre and 4 sampling-points scattered in the four quarter with 500 m distance as in **Fig. 2** (Hutama et al., 2016).

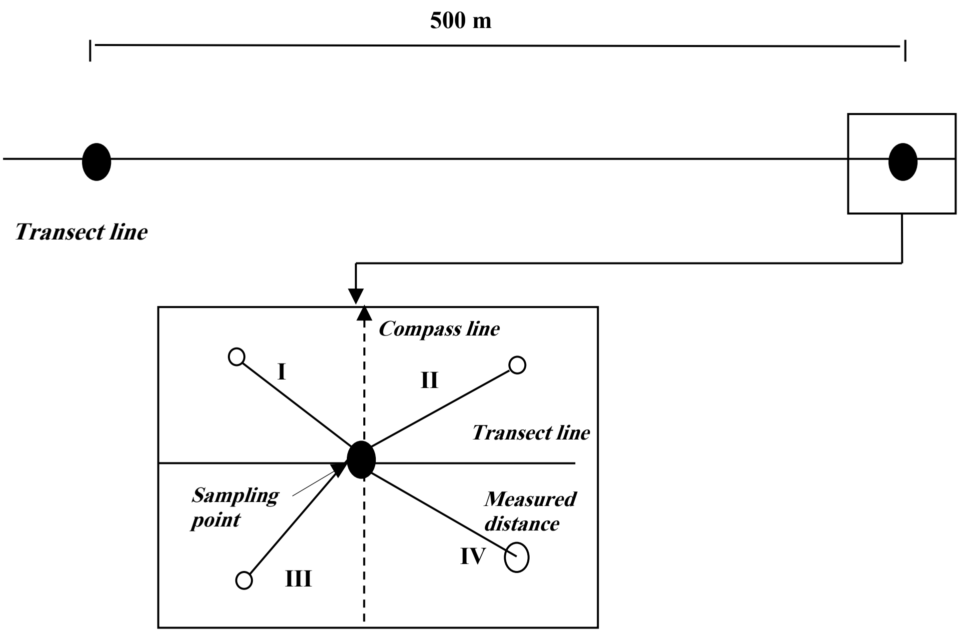

Fig 2. Point Centered Quarter Method (Mitchell, 2007).

This is in order to represents evenly the most area of the mangrove area in the Cawan Island. Each of 25 sampling-points, each have quadrant with size of 20 x 20 m or 400 m^2, with total of 5 sampling-points thus the wide at each sampling-area is 2,000m^2 or 0.2 hectares. Field data variables are mangrove species, number of mangroves in each square, sample of mangrove leafs, and measuring diameter at breast height (DBH). The coordinates at each sampling points were taken as mean value using two (a pair) of field GPS, in order to increase the spatial accuracy.

3.2. Sampling Method

Identification of mangrove species is using the textbook of Noor (2012). Field mangrove samplings and measurements were performed using the point centred quarter method (PCQM) which is combination of a line and quadrant sampling. The mangrove vegetation community sampling and analysis using the method developed by Mitchell (2007) as in **Fig. 2**. This method is the best for a spreading mangrove tree conditions. According to Febrianti et.al., 2013 and Ershad et.al., 2020) the PCQ Method has an advantage of easy and quicker for the composition and domination analysis, but with a disadvantage for a vegetation population with higher cluster or groupings or for a homogenous population. In the study area of Cawan Island, twenty-five randomly spreaded sampling points to represent all mangrove vegetations. The distance among sampling stations were not decided homogenously, but more random with consideration to represent for all mangrove species and different densities.

3.3. Method for Mangrove Data Analysis

The field measurement data or ground check is the most important phase for satellite data analysis and validation process. Each species of mangrove leaf samples was macerated, add with acetone and followed with spectrophotometry chlorophyll-a measurement in the laboratory. The mangrove leaf chlorophyll-a content was determined using the UV-Vis spectrometry method of Jeffrey and Humphrey (1975). The organic biomass and carbon content of mangrove leaf were analysed using furnace heating at 550°C for 4 hour and calculate the loss on ignition ash-furnace method (Jefrey and Humphrey, 1975; Agus et al., 2011). The basic procedure for the Trunk and the branch for mangrove biomass measurement using a 'non-destructive' method. That is measurement of the mangrove trunk diameter so called as diameter at breast height (DBH). Then calculated using the allometric equations (Clough and Scott. 1989; Sutaryo 2009) for the biomass value as in **Table 1**. Based on field survey at Cawan Island that the existing species are *R.apiculata, R.mucronata* and *B.gymnorrhiza*, with dominant species is *R.apiculata* then the height for DBH measurements was standardised at height of 1.3 m (Cintron and Noveli, 1984).

Table 1.

The Above Ground Mangrove Biomass Allometric Equations by Species (tons).

No	**Species**	**(a)Trunk Biomass (WT)**	**(b)Branch Biomassa (WB)**	**(c)Leaf Biomass (WL)**	**Total Biomass (WT+WB+WL)**
1.	*R.mucronata,*	$0.088552 (DBH)^{2.5621}$	$0.012726 (DBH)^{2.6844}$	$0.013896 (DBH)^{2.1072}$	
2.	*R.apiculata* and *R.stylosa*	$0.08855 (DBH)^{2.5621}$	$0.01272 (DBH)^{2.6844}$	$0.01389 (DBH)^{2.1072}$	
3.	*B.gymnorrhiza*	$0.224801 (DBH)^{2.1407}$	$0.031535 (DBH)^{2.2789}$	$0.013896 (DBH)^{1.4914}$	
4.	*C.tagal*	$0.1468 (DBH)^{2.3393}$	$0.01967 (DBH)^{2.5516}$	$0.01175 (DBH)^{2.1294}$	

Reference : Clough and Scott (1989); Sutaryo (2009); Akira et.al (2008).

DBH = Diameter at Breast Hight (cm) WT = Trunk Biomass (tons) WB = Branch Biomass (tons)
WL = Leaf Biomass (tons) TB = Total Biomass (WT+WB+WL)

Then the conversion from mangrove biomass into mangrove carbon using constant of 0.5 (Agus et.al.,2011).

3.4. Method for Sentinel-2A Data Analysis

Sentinel-2A satellite data for Cawan Island was extracted on the date of 24 December 2019, which is the same period with the field sampling and measurements 23 – 25 December 2019. The satellite has 12 spectral bands (ESA, 2015) and three bands of red Band-4 with 0.650 – 0.680 μm wavelength, green Band-3 with 0.543 – 0.578 μm wavelength and blue Band-2 with 0.458 – 0.523 μm was used in this study. This is based on consideration that mangrove chlorophyll-a as plant pigment measurement with 0.6 μm in the laboratory and also used for the Senrinel-2A algorithm development. This RGB-432 composite of the satellite data of Band-4, Band-3 and Band-2 have specified spectral reflectance in the wave-length of 0.6 μm which is the best for vegetation chlorophyll-a measurement (Hartoko et al., 2013; Hartoko et al., 2015; Hartoko et.al. 2021). Spectral noise correction was done by means of atmospheric correction using FLAASH method (Hartoko. A., 2019; Esthi Kurnia, D. and B. Trisakti, 2016) that is excluding the digital numbers or spectral below the minimum value. That is known as atmospheric back-scatter and above the maximum real data value known as cloud. Five purposive sampling-area were used to represent distribution of mangrove vegetations at Cawan Island, with GPS coordinates as shown in **Fig. 1**.

Spatial processing and analysis were performed using ER Mapper 7.0. The raw extracted satellite data with wide area coverage of east central Sumatera region, was then polygon cropped along the coastline of the Cawan Island as the area of interest (AOI) for further image processing. This step is important to increase the spectral accuracy to represent only the mangrove chlorophyll-a reflectance (Hartoko et al., 2015). First step, the field measurement coordinates (with its value of chlorophyll-a and biomass at five stations) were overlaid onto the RGB-432 of Sentinel-2A image data. Then pick up the Sentinel-2A satellite numeric data or digital number (DN) at five stations coordinates. To obtain the algorithm with the best fit to the field (chlorophyll-a and biomass) and Sentinel-2A satellite numeric data, a series of polynomial regressions of the field data to the Sentinel-2A satellite data through four combination of spectral values or digital numbers by single-band use of band-4 (B_4), band-3 (B_3), and band-2 (B_2), band-rationing, band-thresholding and band-average methods (Hartoko et al., 2013; Hartoko et al., 2015). The previous studies are usually using the vegetation index (VI) which give a smaller correlation coefficient (r) value in the regression of the field and satellite DN. In this study use a polynomial regression equation of the real field biomass to the satellite DN data which give the highest correlation coefficient (r). Then the equation was selected to be used for the working algorithm based on consideration as indicating the most accurate correspondence between the field and satellite numeric data (Sugiyono. 2016).

The first step is making a multivariate regression equation between the field data of mangrove chlorophyll-a, biomass and carbon should give a significant correlation. This is the basis of the assumption that these three variables are representing the biological function of the mangrove from mangrove leaf chlorophyll-a into the mangrove biomass and carbon. The fundamental concept in the study is developing spatial algorithm (**Fig. 3**) based on the field mangrove chlorophyll-a pigment measurement in the wave-length of 0.5-0.6 μm which is represented by the use band-3, band-4. While for the red-green-blue algorithm use, we can use either band-2 or band-5 of the Sentinel-2A. The field measurement data is incorporated into a 10 m resolution images of B2, B3, and B4 then made the polynomial regression equations. The highest correlation coefficient (r) polynomial regression would be selected as the working algorithm,

$$\mathbf{Y = a + bX + cX^2}$$

where

Y = calculated mangrove chlorophyll-a, biomass and carbon

X = numeric data of band-4 (B_4), band-3 (B_3) or band-2 (B_2) of Sentinel-2A

= B_4, B_3 or B_2 : single band method

= (B_4/B_3) : band rationing method

= $(B_4 – B_3)$: band thresholding method

= $(B_4 – B_3)/2$: band average method

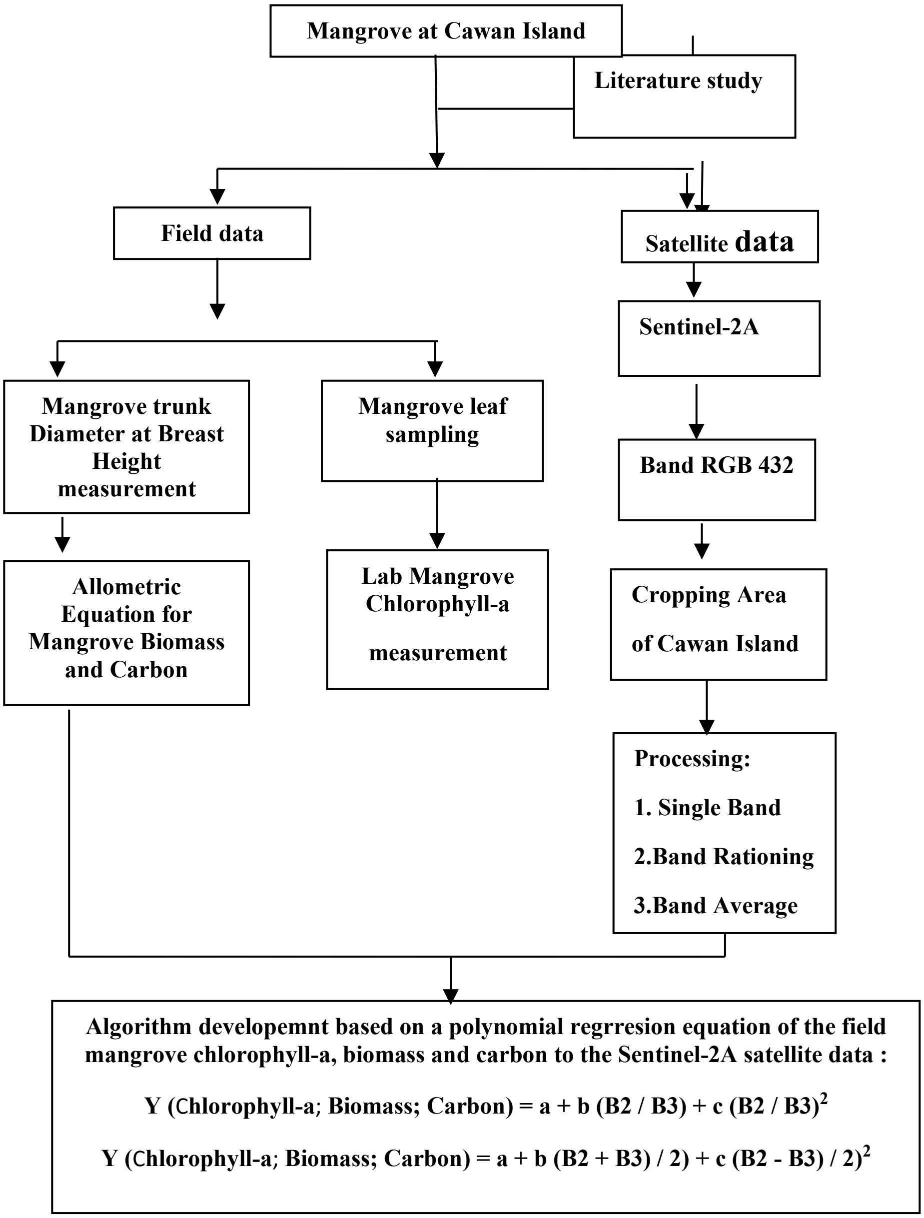

Fig. 3. The working algorithm flow chart.

4. RESULTS AND DISCUSSIONS

4.1. Mangrove Ecosystems

The mangrove species found in Cawan Island are *Rhizophora apiculata*, *Rhizophora mucronata*, *Bruguiera gymnorrhiza* (Rhizophoraceae), *Lumnitzera racemosa* (Combrataceae), *Acrosthicum aureum* (Pteridaceae) and *Nypa fruticans* (Arecaceae). None existence of *Avicenia sp* is considered that the species cannot adapt to the acidic peat substrate. The most dominant species is *Rhizophora apiculata* in all twenty-five sampling points. This is considered as the most important species in the ecological community structure of the area (Adip et al.,2014). The assumption for the spatial and estimate of Chlorophyll-a, biomass and carbon is based on the species of Rhizophora apiculate. The average tree height of 20 m and the biggest tree diameters is up to 1.70 m.

4.2. Mangrove leaf chlorophyll-a content

The field mangrove leaf chlorophyll-a content found in this study is in the range of 14.034-15.767 $mg.ml^{-3}$. Flores-de-Santiago et al. (2013) reported that leaves of the red mangrove *Rhizophora mangle* and black mangrove *Avicennia germinans* in Mexico exhibit no seasonal difference in the chlorophyll-a content. Mangrove leaf chlorophyll-a is recognized to be an important parameter for use in the development of spatial algorithms for all kind of satellite data (Febrianti et al., 2013; Hartoko et al., 2015). Hendrawan et.al (2018) performed mangrove monitoring using green pigment and Pranata et al. (2016) utilized the reflectance of the near infrared spectrum as specific optical measurement of chlorophyll-a. The result from field DBH calculation that the mangrove biomass at range is 66.31– 85.05 $ton.ha^{-1}$, and the carbon ranged from 33.16 – 42.53 $tonC.ha^{-1}$ (**Table 2**).

Table 2.
Mangrove Biomass and Carbon in Cawan Island, Indragiri Hilir, Riau. Indonesia.

Sampling Area (SA)	Area in Each SA (ha)	Biomass Each SA (ton in 0.2ha)	Carbon Each SA (tonC in 0.2ha)	Biomass ($ton.ha^{-1}$)	Carbon ($ton.C.ha^{-1}$)
1	0.2	13.26	6.63	66.31	33.16
2	0.2	13.84	6.92	69,21	34.61
3	0.2	15.72	7.86	78.50	39.29
4	0.2	17.01	8.50	**85.05**	**42.53**
5	0.2	15.65	7.82	78.25	39.12
Total	**1.0**	**75.48**	**37.73**	**377.32**	**188.71**
Average	-	**15.09**	**7.55**	**75.46**	**37.74**

The individual mangrove biomass as total portion of the trunks, branches and leaves of Rhizophora apiculata is in the range of 13.26-17.92 tons and for *Rhizophora mucronata* is 8.92 tons in each sampling-area of 0.2ha. The specific results of the study also revealed that both the value of mangrove biomass and carbon stocks did not always according to the mangrove tree density, this is due to the differences on the individual mangrove trunk and branches. The mangrove tree density range is 390-690 $ind.ha^{-1}$. Biggest trunk diameter is 1.70 m found in *Rhizophora apiculata*. The peat clay substrate on Cawan Island was found to be acidic with pH range of 4 – 6.5. According to Suryono, et.al (2018) biomass and carbon content are dependent mainly on tree diameter, whereby the bigger is the diameter, the higher biomass and carbon contents. The average of the aboveground mangrove carbon content is16.4 tons per sampling-area of 0.2 ha, found that the trunks have the biggest portion which is 77.74 % and the lowest is in the leaves **(Fig. 4).**

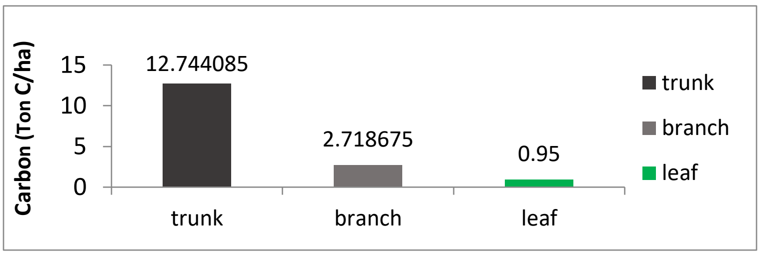

Fig. 4. Average Carbon Proportion of the Trunk, Branch and Leaf ($Ton.ha^{-1}$) represents of one sampling area of 0.2 ha.

Based on data biomass proportion in the trunk among species, we can be calculate that the trunk biomass ratio of *Bruguiera gymnorrhiza* to *Rhizophora apiculata* was determined to be 1 : 5.4 – 16.69 and ratio of *Rhizophora mucronata* to *Rhizophora apiculata* is 1 : 4.8 - 6.3. The highest total mangrove carbon content at the twenty-five sampling stations for *R. apiculata* was 27. 23 tonC from total of 84 sample trees, which is equivalent to 0.32 tonC for each individual trunk (**Fig. 5**).

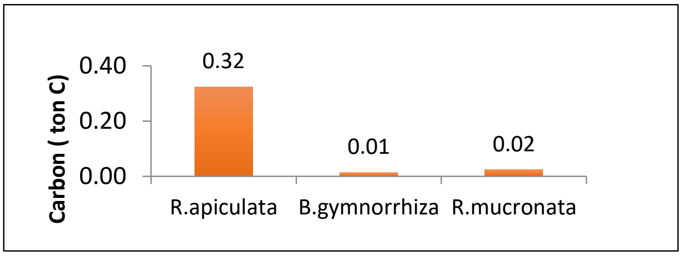

Fig. 5. Carbon contents in the trunks of individual mangrove tree in Cawan Island**.**

The lowest trunk carbon content was found in *B. gymnorriza* with 0.9 tonC from nine sample trees which is equivalent to 0.01 tonC for each trunk. According to Limbong (2009) the high carbon content in the trunks is due to carbon being the main constituent in cellulose cells, lignin and other carbon compound. The study findings revealed that *R. apiculata* had the highest tree carbon content of 0.32 tonC/tree, followed by *R. mucronata* with 0.02 tonC per tree, and the lowest being *B. gymnorrhiza* with 0.01 tonC per tree (**Fig. 6**). Studies by Rachmawati et.al (2014) and Suryono et.al (2018) also found in the genera of Rhizopora to have greater biomass and carbon stock than other species.

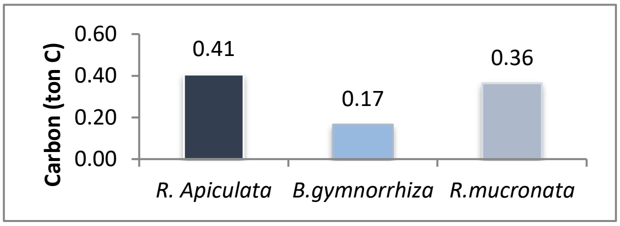

Fig. 6. Total carbon content in individual mangrove trunk, branch and leaf of individual mangrove at Cawan Island.

4.3. Algorithms for Mangrove Leaf Chlorophyll-a, Biomass and Carbon Content

Calculation from field DBH measurement (see Appendix) gives the result that mangrove biomass in 5 sampling areas is 13.26-17.01 tons in each sampling-area of 2000 m^2 or 0.2 ha. The conversion to biomass and carbon per hectare is found in the range of 66.31-85.05 $tons.ha^{-1}$(**Table 2**). The highest biomass found at sampling area-4 with 85.05 $ton.ha^{-1}$ and carbon content of 42.53 $tonC.ha^{-1}$. The lowest biomass per hectare was found at sampling-area 1 with 66.31 $ton.ha^{-1}$ and carbon content is 33.16 $tonC.ha^{-1}$. The total mangrove biomass and carbon content of the five sampling-area on Cawan Island were determined to be 377.32 $ton.ha^{-1}$ and 188.71 $tonC.ha^{-1}$respectively. This biomass value is higher than that reported by Hartoko et.al (2015) for Karimunjawa Island, which had a total biomass of 182.62 $ton.ha^{-1}$ as well as that reported by Suryono et.al (2018) for Perancak-Bali region 187.212 $ton.ha^{-1}$. These allometric results may vary with age, dominant species, and locality.

Globally, tropical mangrove forests are known to have much higher aboveground biomasses than those in temperate areas (Clough and Scott, 1989). The organic carbon content of the mangrove substrate to the depth of 25 cm_was determined by first obtaining the organic content from field samples then converting the result using ration 1/1.724 (Agus et.al, 2011). As a supporting data, the study obtained the highest organic content of mangrove substrate is in sampling-area 2 with 16.323 $ton.ha^{-1}$ and the lowest in sampling-area 3, with 6.793 $ton.ha^{-1}$. According to Sari et.al (2017), the organic content of a substrate is a function of the cumulative deposits of mangrove leaves and the rate of its decomposition processes, which can vary from one location to another. Prior to further analysis, a statistically significant proof is performed to test variable correlations among values of chlorophyll-a, biomass, and carbon. The study develops a step-by-step mangrove biomass and carbon with approach the chlorophyll-a content, since the algorithms development are using an optic Sentinel-2A data, which is assumed correlated to the detection of the mangrove chlorophyll-a pigment, especially in Band-3 and Band-4. The result of the analysis of variance (ANOVA) and a multiple regression analysis was carried out. The three main study variables were confirmed to have a significant correlation with F-count of 143504.235 which is higher than the F-table (3.63). Thus, for further Sentinel-2A bands algorithm development steps relating field mangroves variables to Sentinel-2A satellite data is considered to be valuable and significant estimation. This significant test is important step prior the development of spatial algorithms based on the logical numerical analysis, which is often missed in previous study.

The stepwise algorithm is a series of polynomial regressions of the field and the digital number (DN) or the spectral value of the Sentinel-2A satellite data (**Table 3**). This study is mainly using RGB method using band-4, band-3, and band-2 combination, followed with single-band, band-rationing and band-averaging for the polynomial regression steps. The result with highest correlation coefficient (r) obtained from the polynomial regression is then selected as the operational algorithm to calculate the chlorophyll-a of mangrove leaves, which is the mangrove leaf chlorophyll-a content in its canopy will be represented by the estimated value from the calculated DN of the Sentinel-2A satellite data (Muditha K Heenkenda et al.,2015).

Table 3.

Result of Mangrove Algorithms of Chlorophyll-a, Biomass and Carbon and RMSE Value at Cawan Island, Indragiri Hilir, Riau.Indonesia.

No.	Algorithms	Field Estimation	Satellite Estimation	Threshold	RMSE (ton/0.2ha)
1	Chlorophyll-a (mg.m^3) = 0.0002(B4+B2)/2)^2 – 0.057(B4+B2)/2) + 16.79	SA-1 = 15.77	SA-1 = 15.6.6	0.10	0.115
		SA-2 = 14.62	SA-2 = 14.398	0.22	0.110
		SA-3= 14.95	SA-3= 14.998	-0.04	0.048
		SA-4= 14.45	SA-4= 14.413	0.04	0.050
		SA-5 = 14.03	SA-5 = 14.092	-0.06	0.040
	Average	:			0.072
2	Biomass (tons.ha^{-1}) = 24.69(B4/B2)^2- 47.41(B4/B2)+36.06	SA-1 = 13.26	SA-1 = 13.461	-0.20	0.272
		SA-2 = 13.84	SA-2 = 14.045	-0.21	0.287
		SA-3= 15.72	SA-3= 15.542	0.18	0.309
		SA-4= 17.01	SA-4= 17.510	-0.25	0.500
		SA-5 = 15.65	SA-5 = 15.197	0.45	0.320
	Average	:			0.337
3	Carbon (tons.ha^{-1}) = 10.071(B_4/B_2)^2 – 23.159(B_4/B_2) + 44.233	SA-1 = 6.63	SA-1 = 6.638	-0.01	0.164
		SA-2 = 6.92	SA-2 = 6.947	-0.03	0.184
		SA-3= 7.86	SA-3= 7.709	0.15	0.212
		SA-4= 8.50	SA-4= 8.904	0.08	0.282
		SA-5 = 7.82	SA-5 = 7.486	0.33	0.334
	Average	:			0.235

The series of polynomial regression as shown in **Table 4** reveals that the spectral values of band average of B_4 and B_2 has the highest correlation coefficient (r) of 0.966, which means it is the best fit spectral values of Sentinel-2A satellite data for calculating the field mangrove leaf chlorophyll-a content.

Table 4.

Matrix of mangrove leaf chlorophyll-a algorithms.

No	Band	Algorithms	r
1	B_4	Chlorophyll-a = $-0.0007(B_4)^2 + 0.2355(B_4) – 4.4393$	0.268
2	B_3	Chlorophyll-a = $0.00024(B_3)^2 – 0.1312(B_3) + 32.451$	0.935
3	B_2	Chlorophyll-a = $0.0001(B_2)^2 – 0.0373(B_2) + 16.672$	0.886
4	B_4/B_3	Chlorophyll-a = $56.99(B_4/B_3)^2 – 69.90(B_4/B_3) + 35.71$	0.832
5	B_4/B_2	Chlorophyll-a = $3.743(B_4/B_2)^2 – 9.257(B_4/B_2) + 19.95$	0.726
6	B_3/B_2	Chlorophyll-a = $-1.29(B_3/B_2)^2 + 3.648(B_3/B_2) + 12.48$	0.604
7	$(B_4+B_3)/2$	Chlorophyll-a = $0.0009(B_4+B_3)/2)^2 -0.410(B_4+B_3)/2) + 60.21$	0.845
8	**$(B_4+B_2)/2$**	**Chlorophyll-a = $0.0002(B_4+B_2)/2)^2 – 0.057(B_4+B_2)/2) + 16.79$**	**0.966**
9	$(B_3+B_2)/2$	Chlorophyll-a = $0.00008(B_3+B_2)/2)^2 -0.021(B_3+B_2)/2)+15.24$	0.954

The value of RMSE was calculated based on the five class difference of chlorophyll-a value of the field and the estimated algorithm value. The value of RMSE of 0.072 time to the Sentinel-2A pixel size (B_4, B_3, and B_2) of 10 m thus gives 0.72 m of spatial accuracy.

Chlo-a (mg.m^{-3})= $0.0002((B_4 + B_2)/2)^2 - 0.057((B_4 + B_2)/2) + 16.79$; RMSE : 0.072

Note :
B_4 : Band-4 (red- band, wavelength : 0.665 µm)
B_2 : Band-2 (blue - band, wavelength : 0.490 µm)

The value and spatial distribution of mangrove leaf chlorophyll-a based on algorithm at Cawan island as presented in **Fig. 7**, gives the range from 13.714-16 mg.ml^{-3}, while the field mangrove chlorophyll-a is in the range of 14-15 mg.ml^{-3}. The ‘speckle-looks’ in the image algorithm indicated only the mangrove leaf chlorophyll-a pigment reflectance had been detected and calculated its digital number, in B_4 and B_2 of Sentinel-2A, with pixel size of 10 m. Will not count the reflectance value of non mangrove leaf such as bushes vegetation in the middle area of the Cawan Island.

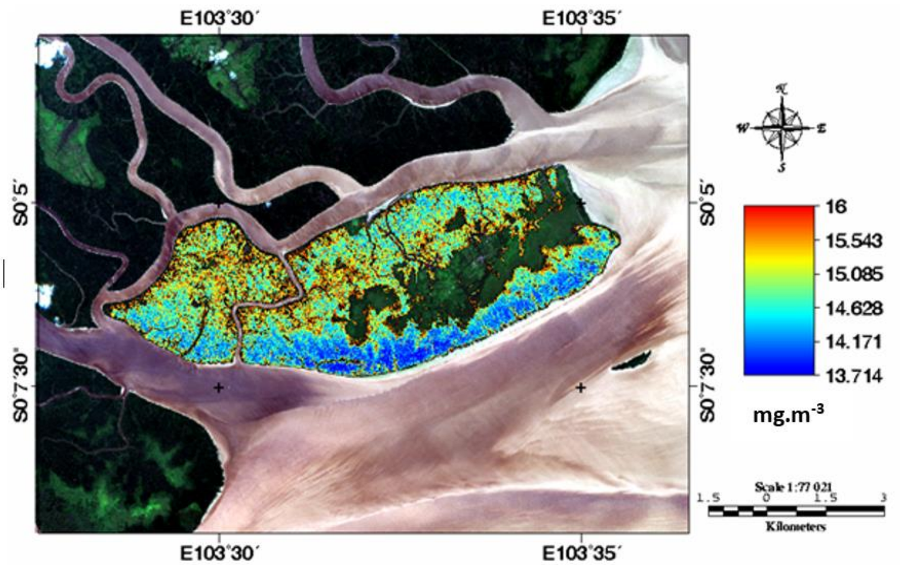

Fig. 7. The content and spatial distribution of mangrove leaf chlorophyll-a at Cawan Island obtained from the algorithm.

Based on the matrix of algorithms shown in **Table 5**, that polynomial regression by the band-rationing of B_4/B_2 of the Sentinel-2A data to the field biomass content had obtained the highest correlation coefficient (r) of 0.94.

Table 5.

Matrix of algorithms for mangrove biomass at Cawan Island.

No	Band	Algorithms	r
1	B_4	Biomass = $0.003(B_4)^2 - 1.116(B_4) + 102.6$	0.738
2	B_3	Biomass = $-0.001(B_3)^2 + 1.103(B_3) - 152.7$	0.906
3	B_2	Biomass = $0.0009(B_2)^2 + 0.3386(B_2) + 46.395$	0.744
4	B_4/B_3	Biomass = $448.0(B_4/B_3)^2 + 472.6(B_4/B_3) + 138.0$	0.901
5	**B_4/B_2**	**Biomass = $24.69(B_4/B_2)^2 - 47.41(B_4/B_2) + 36.06$**	**0.940**
6	$(B_4+B_3)/2$	Biomass = $-0.002(B_4 + B_3)/2)^2 + 0.980(B_4 + B_3)/2) - 106.9$	0.837
7	$(B_4+B_2)/2$	Biomass = $-0.001(B_4 + B_2)/2)^2 + 0.576(B_4 + B_2)/2) - 40.01$	0.593
8	$(B_3+B_2)/2$	Biomass = $-0.0004(B_3 + B_2)/2)^2 + 0.1834(B_3 + B_2)/2) - 13.12$	0.563

As fundamental knowledge that B_4 as red band-4 spectrum with wavelength of 0.650 – 0.680 µm is recognized as having the best fit reflectance for the chlororophyll-a pigment algorithm (Hartoko et al., 2013; Febrianti, et.al., 2013).

Biomass (tons.ha^{-1}) = $24.69(B_4/B_2)^2 - 47.41(B_4/B_2) + 36.06$; RMSE : 0.337

where :

B_4 : Band - 4 (red band, wavelength : 0.665 µm)

B_2 : Band - 2 (blue band, wavelength : 0.490 µm)

The result of algorithm, the value and spatial distribution of mangrove biomass at Cawan island gives the range of 51-90 tons.ha^{-1} (**Fig. 8**), while the actual field mangrove biomass in the range of 66.31-85.05 tons.ha^{-1}. This value is based on the dominant mangrove in Cawan Island is *Rhizophora apiculata*.

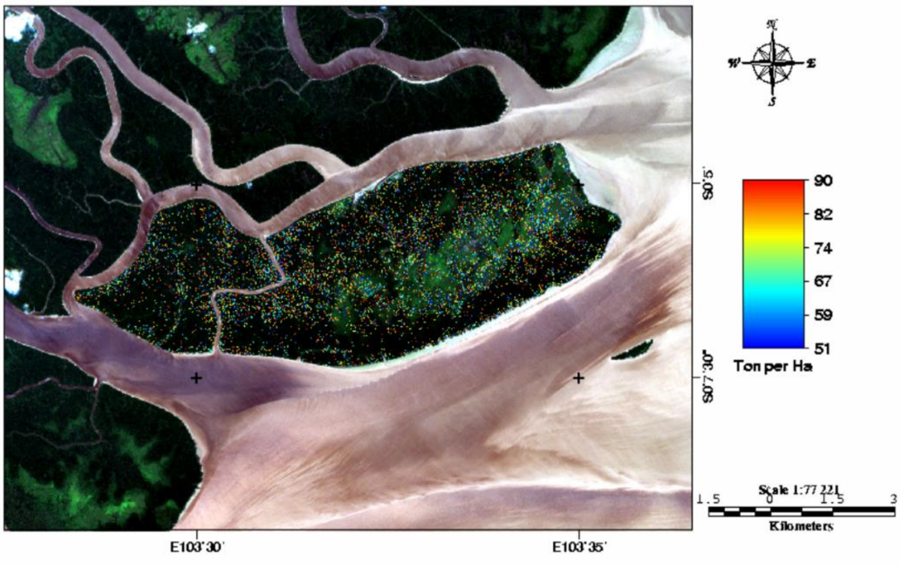

Fig. 8. Mangrove biomass and spatial distribution at Cawan Island (tons.ha^{-1}).

In comparison, earlier study using vegetation index (VI) based on band rationing of 0.740 µm/0.720 µm wavelength hyperspectral data obtained better prediction of chlorophyll-a during the dry season for three species of mangrove (*Rhizophora mangle*, *Avicennia germinans* and *Laguncularia racemosa*) than during the rainy season (Flores-De-Santiago et.al., 2012). This was assumed caused by a better chlorophyll-a reflectance absorption.

The polynomial regression of field carbon to B_4/B_2 band rationing have the highest correlation coefficient (r) of 0.929 (**Table 6**).

Table 6.

Matrix of algorithms for mangrove carbon at Cawan Island.

No	Band	Algorithm	r
1	B_4	Carbon = $0.001(B_4)^2 - 0.562(B_4) + 51.62$	0.740
2	B_3	Carbon = $-0.0009(B_3)^2 + 0.5526(B_3) - 76.551$	0.906
3	B_2	Carbon = $0.0004(B_2)^2 - 0.169(B_2) + 23.197$	0.743
4	B_4/B_3	Carbon = $224.7(B_4/B_3)^2 - 237.0(B_4/B_3) + 69.23$	0.901
5	$\mathbf{B_4/B_2}$	**Carbon =** $\mathbf{10.071(B_4/B_2)^2 - 23.159(B_4/B_2) + 44.233}$	**0.929**
6	$(B_4+B_3)/2$	Carbon = $-0.002(B_4 + B_3)/2)^2 + 0.980(B_4 + B_3)/2) - 106.9$	0.837
7	$(B_4+B_2)/2$	Carbon = $-0.001(B_4 + B_2)/2)^2 + 0.576(B_4 + B_2)/2) - 40.01$	0.593
8	$(B_3+B_2)/2$	Carbon = $-0.0004(B_3 + B_2)/2)^2 + 0.1834(B_3 + B_2)/2) - 13.11$	0.563

This result is attributable to the use of the B_4 red spectrum with wavelength of 0.665 µm for chlorophyll-a reflectance, from which we obtained the biomass and carbon values. Band-2 (B_2) with the shorter wavelength of 0.490 µm was used in the algorithm for its leaf material penetration capability and contrasting spectral values for vegetated and non-vegetated areas.

$$\boxed{\textbf{Carbon (tons.ha}^{-1}\textbf{)} = 10.071(B_4/B_2)^2 - 23.159(B_4/B_2) + 44.233; \quad \textbf{RMSE : 0.226}}$$

Note :
B_4 : Band 4 (red band, wavelength : 0.665 µm)
B_2 : Band 2 (blue band, wavelength : 0.490 µm)

Fig. 9 shows the carbon content and spatial distribution in mangroves carbon per station (0.2 hectars) at Cawan Island as obtained by the algorithm ranges of 31-42 tonC.ha^{-1}, while actual field mangrove carbon is in the range of 33.16-42.53 tonC.ha^{-1}.

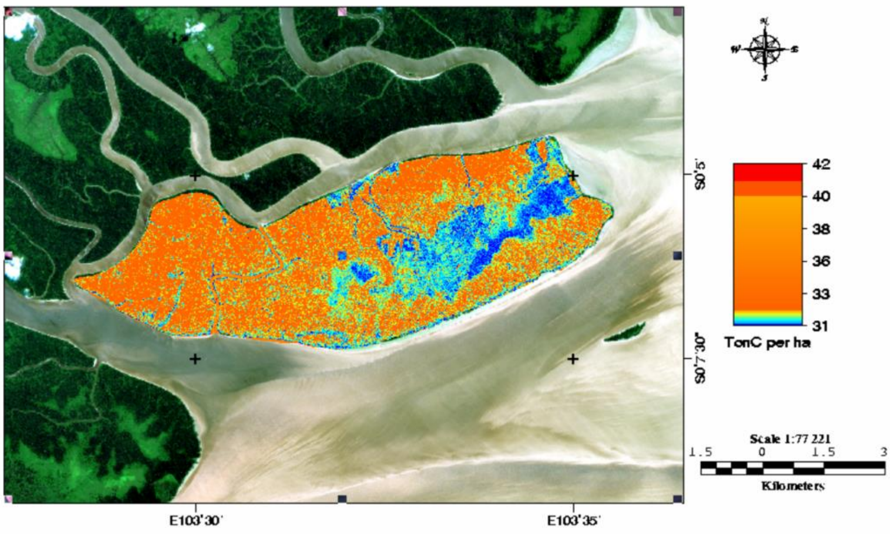

Fig. 9. Carbon content and spatial distribution in mangroves at Cawan Island (tonC.ha^{-1}).

5. DISCUSSION

In the process of algorithm development based on field data with respect to satellite data, the fundamental philosophy is the use wavelength as for the target spectral reflectance. This because satellite units use different name category of bands and its wavelengths. According to Tarigan., et.al. (2013) chlorophyll-a absorbs the visible spectrum of photosynthetic process. Vegetation absorbs spectral wavelengths in the range of 0.400 – 0.700 μm. Wavelength of 0.665 μm for the red band would be accurate for the reflectance for vegetation chlorophyll-a such as the mangrove. Not all light spectrum is absorbed by chlorophyll-a in the photosynthetic process, only 70% of the blue spectrum and 90% of the red spectrum will be absorbed (Jefrey, S.W., and G.F Humphrey, 1975). Flores de Santiago et al., (2015) mention that vegetation index of R_{740}/R_{720} during the dry season measurement give a better mangrove chlorophyll-a estimation. According to Hartoko et.al., (2019) and Hendrawan et.al., (2018), satellite data can be used for field data algorithm development, when the right band wavelengths are used. Furthermore, band combinations such as single-band, band-rationing, band-thresholding or the band- averaging method will lead to identify the algorithm with the best fit.

Statistically based point of view the numeric results any of the above four methods should fit the numeric values of real field data distributions. The band-rationing method will overcome limitation associate with the use of the single-band method. Band-4 and Band-2 rationing (B_4/B_2) can be used to deliniate the vegetation canopy coverage. Algorithms that use a single-band method will have a lower correlation coefficient (r), compared with those that use of two-band combination, the (r) value of which will be much near to a value of one (Hartoko et.al., 2015; Hartoko et.al., 2019). The best regression methods should have a correlation coefficient (r) higher than 0.6 or near to a value of one (Sugiono, 2016).

The use of Sentinel-2A as reliable and controlable image processing for spatio-temporal for effective and countinuesly coastal habitat monitoring. The use of three bands (band-4, band-3 and band-2) of Sentinel-2A data with pixel size of 10 m is in a medium state of spatial accuracy. The research use the Sentinel-2A of B_2,B_3 and B_4 with spatial reslution of 10 m, which is spatially better than the use of the Landsat-TM with pixel size of 30 m as low spatial accuracy. According to Guzman.Julio Pastor et al., (2015) that spectral bands around the red edge (705–753 nm) were more sensitive to mangrove leaf chlorophyll-a content, although Sentinel-2 will improve mangrove monitoring at higher spatial and temporal resolutions. But Sentinel-2A data is spatially still lower accuracy in comparison to other optical satellite data such as IKONOS with 1 m pixel size, Quickbird data with 0.6 m pixel size (Hartoko et.al., 2013; Hartoko et.al., 2015). Thus, the key factor is then to increase the spatial as well as spectral accuracy by means of best fit algorithm of the key field variable such as chlorophyll-a up to a level of mangrove species and satellite data use of 0.6 μm wavelength spectral reflectance of chlorophyll-a. Sentinel-2A data is a choice with free aquisition (with permission) with 10 m pixel size can be used to cover a single of mangrove canopy with diameter of about 10 m by species based on the field sampling coordinates. Since this is an optical data, then a minimum or possibly cloud free images would be a prerequisite for further analysis.

6. CONCLUSIONS

The current study revealed that *Rhizophora apiculata* identified as the dominant species with ecological importance in the mangrove community structure on Cawan Island. The twenty-five sampling points on the island, mangrove leaf chlorophyll-a content is in the range of 14.034-15.767 mg.ml^{-1}. The highest mangrove biomass value is 381.53 ton.ha^{-1} and the highest carbon content is 190.77 tonC.ha^{-1}. Result of algorithms for the mangrove at Cawan Island, Indragiri Hilir, Riau, Sumatera for chlorophyll-a = $0.0002(B_4 + B_2)/2)^2 – 0.057(B_4 + B_2)/2) + 16.79$; biomass = $24.69(B_4/B_2)^2 - 47.41(B_4/B_2) + 36.06$; carbon = $10.071(B_4/B_2)^2 – 23.159(B_4/B_2) + 44.233$.

The new insight in this study is that the algorithm developments can be applied for mangrove chlorophyll-a content, biomass and carbon content estimation using any optical satellite data based on its relevant spectral range. This algorithm development is an open approach method based on highest correlation coefficient on regression equation of the field and the satellite spectral value. The algorithms resulted from this study can be applied over wide and in any area in the tropics.

ACKNOWLEDGMENT

The authors would like to express sincere thanks to the European Space Agency (ESA) for the use of the Sentinel-2A satellite data, and to the Institute for the funding support by Research and Community Development, Diponegoro University contract No. 233-39/UN7.6.1/PP/2022 and all parties who had assisted in this study and the writing of the manuscript.

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Appendix:

Left – DBH measurement, Right – species observation in a deep acidic peat substrate sampling at Cawan Island, Sumatera, Indonesia.