

Above Ground Carbon Stock Estimates of Mangrove Forest Using Worldview-2 Imagery in Teluk Benoa, Bali

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Abstract. Mangrove forests have a role as an absorbent and a carbon sink to a reduction CO₂ in the atmosphere. Based on the previous studies found that mangrove forests have the ability to sequestering carbon through photosynthesis and carbon burial of sediment effectively. The value and distribution of carbon stock are important to understand through remote sensing technology. In this study, will estimate the carbon stock using WorldView-2 imagery with and without distinction mangrove species. Worldview-2 is a high resolution image with 2 meters spatial resolution and eight spectral bands. Worldview-2 potential to estimate carbon stock in detail. Vegetation indices such as DVI (Difference Vegetation Index), EVI (Enhanced Vegetation Index), and MRE-SR (Modified Red Edge-Simple Ratio) and field data were modeled to determine the best vegetation indices to estimate carbon stocks. Carbon stock estimated by allometric equation approach specific to each species of mangrove. Worldview-2 imagery to map mangrove species with an accuracy of 80.95%. Total carbon stock estimation results in the study area of 35.349,87 tons of dominant species *Rhizophora apiculata*, *Rhizophora mucronata* and *Sonneratia alba*.

1. Introduction

Vegetation plays an important role in maintaining the stability of the global climate. Carbon can be absorbed into the ecosystem and stored into biomass through photosynthesis of plants or soil [20]. In addition to the role of forests terrestrial / terrestrial sequestration of greenhouse gases has been known, new evidence suggests that carbon can be stored in biomass and sediment ecosystems tidal marsh vegetation such as mangroves and seagrass beds [22]. Coastal vegetation carbon stock is called blue carbon [17]. Mangrove vegetation as one that could absorb carbon has an important role in controlling the levels of CO₂ in the atmosphere. Mangrove can absorb carbon better than terrestrial ecosystems because of its ability to bury carbon in the sediments [14].

Mangrove forest biomass estimation by field surveys combined with remote sensing data is considered ideal and practical method [8]. Remote sensing model based combined with field survey data such as dbh (diameter breast high) and tree height and allometric equations for estimating biomass to develop a model of the biomass of mangrove [18, 26, 21, 9]. Carbon stock assessment with



remote sensing is expected to reduce the destructive method or the destruction that still preserve mangrove forests.

Estimates of biomass or carbon stock mangrove using remote sensing imagery has been done with various images such as Landsat [10, 26], RADARSAT [16], ALOS [25,27], Quickbird [9], IKONOS [23, 2], ICESat [15]. The use of different image resolutions produce different model accuracy. Mapping carbon stocks by remote sensing regardless of the species / species of mangrove vegetation can lead to errors because of different species depending on the density of the canopy which is correlated with the value of carbon on the surface [29]. As a result, in the study of mangrove carbon stocks based remote sensing, different mangrove species showed significant differences in the spectral reflection of the electromagnetic spectrum. High spatial resolution imagery have the opportunity to map carbon stocks in more detail at the level of mangrove species. The species of vegetation should be considered to estimate biomass on the surface that is accurate [18]. Based on the research of [29] also concluded that the identification of mangrove species using WorldView-2 imagery in the study area has the potential to do. Mapping carbon stock value with the image of WorldView-2 which has a spatial resolution of 1.8 meters at nadir is expected to yield higher accuracy than lower spatial resolution.

The transformation of the image of the most common and widely used for mapping and modeling mangrove is the vegetation indices. Each vegetation indices have different sensitivity to the biophysical and biochemical properties of the different vegetation such as Leaf Area Index (LAI), canopy cover, chlorophyll and nitrogen content, fragments of vegetation, biomass, and carbon stock [27]. Different types of vegetation indices have been used in a variety of mangrove mapping carbon stocks [29,26, 27, 24, 7]. Each vegetation indices can produce different level of accuracy of the mangrove carbon stocks modeling in different locations.

The purpose of this study were (1) Comparing the accuracy of the transformation of the vegetation index to map carbon stocks over the surface of the mangrove forests in Teluk Benoa, Bali using the image of WorldView-2 with the distinction of species, and (2) Mapping the value of carbon stocks and estimate the value of the total stock of carbon on the surface of the mangrove forests in Teluk Benoa, Bali.

2. Study Area and Data

The research location is included in the mangrove forest area of Taman Hutan Raya (Tahura) Ngurah Rai is located in the province of Bali. Taman Hutan Raya Ngurah Rai is an area which has been confirmed or established as the Taman Hutan Raya (Tahura), by the Minister of Forestry in 1993 with an area of 1373.5 hectares. All of the area is not used for the existing mangrove area but used for other uses, such as DAM estuary, lagoon, toll roads, and the landfill. Areas to be studied in this research is only part of Tahura Ngurah Rai. A map of the study area is shown in Figure 1.

Geographically, the study area located at 8° 43' S - 8° 44.5' S and 115° 11' E - 115°13' E. Administratively, mangrove forests that were examined included into the South Denpasar District, Denpasar in the East and the District of South Kuta, Badung Regency on the West side. Southern part of the mangrove forests is bordering with Teluk Benoa. This location is strategic located between the city of Denpasar, Kuta and Nusa Dua. In addition, the distance is very affordable from the International Airport I Gusti Ngurah Rai. These conditions make the mangrove forest areas potentially marginalized by development of the city. According Wiyanto and Fiqoh [28], mangrove species found in Teluk Benoa total of 11 species. Eleven species of mangrove is *Rhizophora mucronata* Lam., *Rhizophora stylosa* Griff., *Rhizophora apiculata* Blume, *Avicenia marina* (Forssk.) Vierh, *Avicenia officinalis* L., *Sonneratia alba* J.Sm., *Sonneratia caseolaris* (L.) Engl., *Bruguiera gymnorhiza* (L.) Lam., *Bruguiera cylindrica* Blume, *Xylocarpus granatum* Koen., and *Ceriop tagal* C.B. Rob.

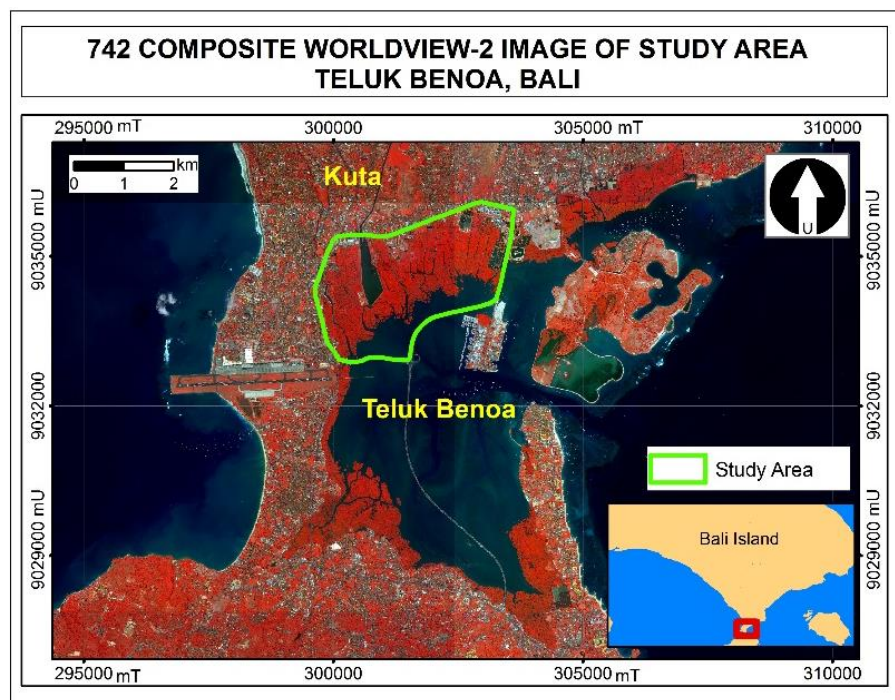


Figure 1. Worldview-2 Composite Image 752 (near infrared 1, red, blue) Study Area

Materials used in the study were WorldView-2 Imagery recording on May 20, 2015 of 16902/8820 rows / columnpart Bali Provincial. Characteristics of the sensor and the band brought in satellite Worldview-2 is shown in Table 1.

Table1.Worldview-2 Imagery Band

Band	Band Wavelength (nm)
Panchromatic	450-800
1. Coastal	400-450
2. Blue	450-510
3. Green	510-580
4. Yellow	585-625
5. Red	630-690
6. Red Edge	705-745
7. Near Infrared 1	760-895
8. Near Infrared 2	860-1040

Source: [5]

3. Method

3.1. Field survey

Field measurements conducted to obtain Diameter Breast High (DBH) data. DBH value is approximated by measuring the perimeter of the trunk at breast height of 1.3 meters. DBH value measurement performed on all individuals in plot size of 10 m x 10 m. The location is determined by the stratified sample is based on lines aligned tracking lines and lines of boats in each class of units of mangrove species. The lines have to be able to follow the tracking path that already exists in the study area, making it easier to reach the location of the current sample field survey. The sample points are given for each line that represents each class of mangrove species. Mangrove species that have a larger

area given the number of more samples. There was 41 plot samples that be distinguished by model samples and accuracy test samples.

Fieldwork was conducted over seven days, which is dated May 18, 2016 until May 24, 2016. The data field is divided into two, namely the data to build the model and the data for accuracy test. The research team consists of three members, the researcher and two assistances that helped identify the species of mangrove and took measurements. Access to reach the location of the sample can be achieved in two ways, by land and water. Path within walking distance to the tracking lines that already exist and are used as travel mangrove path. In addition to tracking path, at some locations there are dikes that can be passed. Waterways have to reach the location of sample far from land and under water is quite high. Waterway reached by boat hired from local fishermen. Accessibility is increasingly an issue of its own in this field activities.

3.2. *Image correction*

The image correction process is not performed geometric correction. Data obtained from Digital Globe Foundation bursts of data 2A level. At this level has been corrected geometric image globally up to 4.6 m with an accuracy of 90%. If imagery base map overlaid with Indonesia which Indonesia Topographic Map (RBI) scale of 1: 25,000, the image has been mend and not shift significantly in appearance imagery and maps. Therefore, without any geometric correction WorldView-2 images can still be used in the study with a small error. Correction radiometric imagery from WorldView-2 is done Digital Number values into spectral value at the object level surface reflectance so the image pixel value represents the value of emission spectral reflectance or the actual object. Modelling using vegetation index transformation that involves the value of each pixel should use the actual spectral values to produce an accurate model. Additionally atmospheric disturbances such as aerosol interference was minimized in the image for easy interpretation.

Worldview-2 image acquired is an image that radiometric correction has not been done to the spectral reflectance of the object. Digital Number value is converted to the value of a top-of-atmosphere spectral radiance. The radiance value is still dominated by the sun reflection values that need to be converted to the value of a top-of-atmosphere spectral reflectance. The reflectance value is still influenced by atmospheric disturbances that need to be converted into at surface reflectance to declare the value of the actual reflection of the object. Atmospheric correction to got surface reflectance used Dark Object Substaction (DOS) method with deep water as the darkest object in the image.

3.3. *Mapping of Mangrove Types*

The number of samples taken for the mapping of mangrove types are 60 samples. The new samples based on observations taken around the samples and during the journey to the planned sample. The entire sample was divided into two, to build a model and to test the accuracy of the resulting model of mangrove types. The field data were used to build the model with a sample size of 39. The model number of the pixel-based classification is done with supervised multispectral classification. Sample results of this field is used as a training area in the supervised classification has three classes of mangrove species.

3.4. *Transformation Vegetation Index*

This study uses vegetation index EVI (Enhanced Vegetation Index), DVI (Difference Vegetation Index), and MRE-SR (Modified Red Edge-Simple Ratio). EVI is one of vegetation indices that built to reduce the influence of the atmosphere and soil. EVI was developed in MODIS imagery which is a modification of the index NDVI (Normalized Difference Vegetation Index) with the background adjustment factor to correct the soil and scattering coefficients of the atmosphere. Compared with NDVI, EVI improve sensitivity in recording high biomass [11]. DVI is an basic vegetation indices using two band algorithm. DVI is a simple vegetation indices that use infrared and red bands are shared by most satellite imagery passive systems. mRE-SR is a modification of the common

vegetation indices ie SR (Simple Ratio). This indices has the advantage on the edge of the red band is used. The red band edge to be more sensitive to vegetation biophysical parameters such as biomass compared to other bands [29]. Besides the red band edge has not been owned by various satellite image but it is owned by Worldview-2. Formula of the three vegetation indices are:

a. EVI

$$EVI = G \frac{\rho_{infrared} - \rho_{red}}{\rho_{infrared} + (C1 \times \rho_{red}) - (C2 \times \rho_{blue}) + L} (1+L) \quad (1)$$

G: gain factor (2,5)

C1 and C2: band correction to atmospheric aerosol scattering(6,0 and 7,5)

L: soil adjustment factor (1,0)

b. DVI

$$DVI = \rho_{infrared} - \rho_{red} \quad (2)$$

c. mRE-SR

$$mRE-SR = \frac{\rho_{rededge} - \rho_{coastal}}{\rho_{red} + \rho_{coastal}} \quad (3)$$

3.5. Modelling Biomass and Carbon Stock

The sample consisted of 41 samples of the same location as the diameter measurement sample. Total mangrove vegetation is sampled 759 mangrove stands. Mangrove stands are then calculated the value of the stock of carbon in the biomass value approach. Reference used was 0.47 from biomass is a carbon stock value according to SNI (Indonesian National Standard) 7724: 2011 [1]. The biomass value obtained by non-destructive methods, namely with methods allometry. Allometric equations were used that specific allometric every species of mangrove that aims to produce a value close to the value in the field (Table 2).

Table2. Above Ground Biomass Allometric for Mangrove Species

Mangrove Species	Above Ground Biomass Allometric	Reference
<i>Bruguiera gymnorhiza</i>	$W_{top} = 0,186 \times DBH^{2,31}$	[4]
<i>Rhizophora apiculata</i>	$W_{top} = 0,235 \times DBH^{2,42}$	[19]
<i>Rhizophora mucronata</i>	$W_{top} = 0,251 \times \rho \times D^{2,46}$, $\rho : 1.020 \text{ kg/m}^3$	[12]
<i>Sonneratia alba</i>	$W_{top} = 0,251 \times \rho \times D^{2,46}$, $\rho : 780 \text{ kg/m}^3$	[12]

3.6. Statistic analysis

The statistics used for data analysis is the correlation and regression. These statistics linking measurement value in the field of value biomass is converted into carbon stock value as the dependent variable and the value of every pixel transformation of the vegetation index as independent variables. Correlation is done to determine the degree of correlation between the value of the stock of carbon in the field and the vegetation indices. This correlation test is a requirement to do regression testing. Regression tests conducted to determine the effect of the two variables and empirical equations generated is used for prediction. Empirical equation is then used to form a new image. Regression used are linear and non linear regression simple. Non-linear regression selected for both variables are assumed to have a threshold so that the relationships are not always linear so suitable to study the phenomena of vegetation.

4. Results and Discussion

4.1. Mangrove Species Classification

The results of the classification algorithm Minimum Distance to Mean produce four classes according to the given training area (Figure 2). The spatial distribution of each class was in line with the conditions on the ground. Species *Rhizophora apiculata* and *Rhizophora mucronata* dominated the artificial mangrove forests, while the mangroves that grow naturally dominated by *Sonneratia alba*. Genus *Rhizophora* especially *Rhizophora apiculata* and *Rhizophora mucronata* is found to dominate the artificial mangrove forest. It is also in accordance with the conditions of conservation of the mangrove forests by Balai Pengendali Perubahan Iklim dan Kebakaran Hutan dan Lahan of Java, Bali and Nusa Tenggara which presently houses the mangrove forest management study areas. Prior to planting mangrove conducted a study to determine the most suitable species or in accordance with the conditions of land. The result is *Rhizophora apiculata* and *Rhizophora mucronata* be selected species to be planted on the land. *Rhizophora mucronata* planted with a number of the most widely because it is considered the most suitable land and is also resistant to the disease. *Sonneratia alba* dominates the mangrove forests that grow naturally. This species is considered suitable to grow in an area close to the sea for as protector of the sea waves. Its roots were shaped roots strong breath serves to resist the wave of the sea that leads to the mainland.

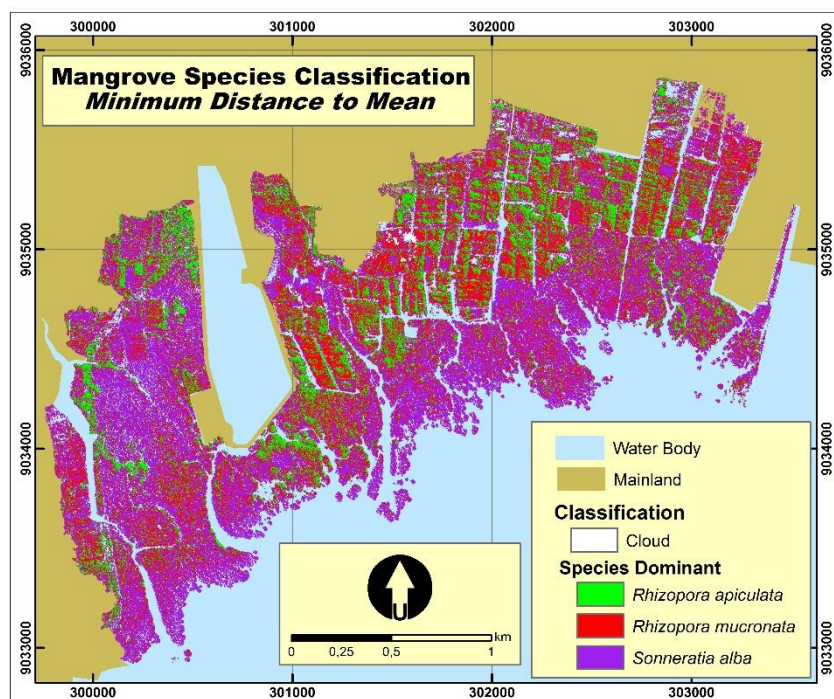


Figure 2. Results of Mangrove Species Classification Algorithm Minimum Distance to Mean

Accuracy test is done by using field samples totaling 21 samples. The method used is the error matrix involving nominal data types in this case is a class of mangrove species (Table 3).

Table 3. Error Matrix Test Accuracy Classification Minimum Distance to Mean

		Field Data			
Classification Data		Ra	Rm	Sa	Row Total
	Ra	4	0	0	4
	Rm	2	6	2	10
	Sa	0	0	7	7
	Cloud	0	0	0	0
Column Total		6	6	9	21

4.2. Modeling Carbon Stock by Vegetation Indices

Modeling carbon stocks performed in each species with DVI, EVI and mRE-SR. Regression analysis is then performed to determine the influence of the independent variable is the vegetation index against the dependent variable is the carbon stocks of each species. The empirical results of regression equation is then used to build a model or predict the value of the carbon in the image. The magnitude of the effect of empirical or predictive power equation expressed by the value of determination (R^2).

Test the accuracy of carbon models each species showed that regression with mRE-SR has the highest accuracy. It can be concluded that mRE-SR is more sensitive to differences mangrove species. mRE-SR is an index that uses a modification of the Simple Ratio red wave edge. The study concluded that mRE-SR index is an index that is best able to predict the stock of carbon in each mangrove species. These results are consistent with previous studies [29] which states that the use of red tide on the edge of the vegetation index can overcome boredom in the estimated biomass of vegetation in the area of dense mangrove. The advantage of using red edge is wave property changes of vegetation will change the curve of reflection on the wave of red edge. In addition, the red wave edges are more sensitive to the calculation of biophysical parameters vegetation than other waves. Therefore, the use of mRE-SR index suitable for estimating carbon stocks at a level mangrove species in the study area.

Table 4. Highest Accuracy Model

Species	Regression	SE (ton/ha)	Accuracy
<i>Rhizophora mucronata</i>	Quadratic mRE-SR	12,89	85%
<i>Rhizophora apiculata</i>	Quadratic mRE-SR	14,52	84%
<i>Sonneratia alba</i>	Quadratic mRE-SR	81,15	64%

Modelling of *Rhizophora mucronata* carbon stock has a high accuracy of 85% (Table 4). Value of the stock of carbon is able to predict quite well through the vegetation index. High vegetation index value indicates the number of leaf vegetation that reflects the electromagnetic wave. The more leaves possessed the more the stock of carbon stored from the process of photosynthesis. Therefore, the carbon stocks of vegetation index predicts fairly well. Values that almost have same accuracy was shown a model of carbon stocks species *Rhizophora mucronata* and *Rhizophora apiculata*. This is caused by both species came from the same genus that has some characteristics of a uniform one carbon sequestration capabilities. Carbon stock value range *Rhizophora mucronata* and *Rhizophora apiculata* is not much different than the carbon stock value range of species *Sonneratia alba*.

Sonneratia alba carbon model has the lowest accuracy compared to other species models. It is influenced by several factors such as the size of the trunk diameter *Sonneratia alba* is very large when compared to other species. Big trunk size resulted in greater biomass owned. *Sonneratia alba* in the study area during recording and field survey turned out to be dominated large trunk has a characteristic size but have lower leaves cover the trunk size is not directly proportional to the number of leaves that

possessed thereby affecting the amount of wave reflection. While having a diameter rods and large biomass, electromagnetic wave reflection actually heavily influenced by the object water is underneath. Therefore, the vegetation indices that highlights the characteristics of the vegetation is unable to predict with good biomass carbon stock impact on the value of the species *Sonneratia alba*.

4.3. Mapping and Carbon Stock Estimation

The total value of the stock of carbon is obtained by summing the pixel values in the form of carbon value per pixel. The total area of mangrove object in the study area were counted, 391.8488 ha. The total stock of carbon on the surface of which is kept by the mangrove vegetation can be seen in Table 5.

The total value of carbon stocks resulting from modeling based species are highly influenced by the species mapping done previously. Rated accuracy is not 100% because there was error in mapping the species so that this error also affects the suitability of modeling results with the value in the field. Therefore, to produce carbon stock value close to the value in the field is required map of mangrove species with high accuracy.

Table 5. Total Stock Carbon

Species	Regression Model	Total Carbon (tons)
<i>Rhizophora mucronata</i>	Quadratic mRE-SR	23.773,28
<i>Rhizophora apiculata</i>	Quadratic mRE-SR	7.369,35
<i>Sonneratia alba</i>	Quadratic mRE-SR	4.207,24
Total		35.349,87

Estimated value of carbon in the study area can be mapped to a scale of 1: 10,000 mapping with an accuracy of up to 85% (Figure 3). Estimated value of carbon in the classified into three classes of carbon values, There are: (1) 0 to 0.023 tons (2) from 0.023 to 0.035 tons, and (3) from 0.035 to 0.686 tonnes. High carbon stock value predominantly distributed in mangroves near the sea. High carbon value one of them caused by the dominance of species *Sonneratia alba* which has a stock of carbon is higher than other species. It also relates ecology, mangrove which a supply of sea and inland water that either has better growth due to supply enough water can accelerate the growth of vegetation.

Values lower carbon stocks, spread over an area of mangroves adjacent to the mainland. The dominance of species that have lower carbon stocks are species *Rhizophora apiculata* and *Rhizophora mucronata*. Low carbon stocks may be affected by human activities such as landfills flowing through the river so it accumulates in mangrove areas. Their wastes human activity is causing inhibition of growth of mangroves adjacent to the mainland due to inhibition of mangroves absorb nutrients from the soil and from pollutants trash. Mangrove growth inhibition led to the ability to store carbon stocks lower. In addition, the low carbon stocks contained in the surrounding area are covered with clouds. Low carbon stocks are influenced by the pixel values are still under the influence of clouds and cloud shadows are thin so that its value is not a reflection of the value of the actual vegetation.

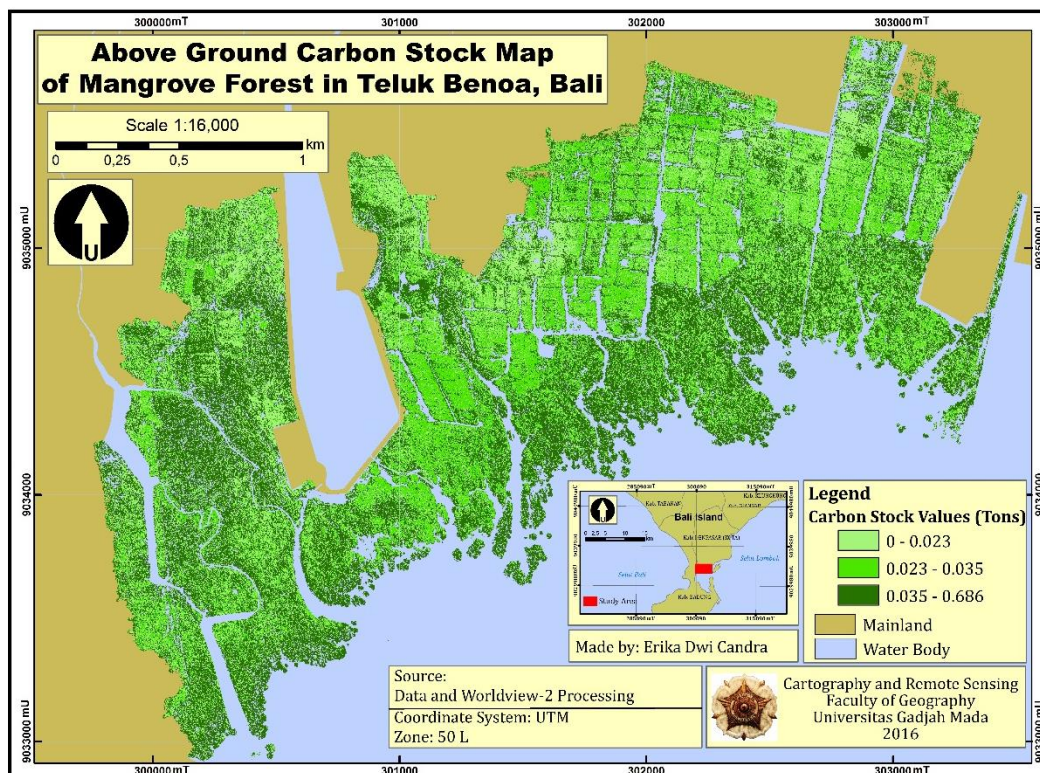


Figure 3. Above Ground Carbon Stock Mangrove Forest Map in Studies Area

5. Conclusion

Based on the research that has been done, it can be concluded that:

1. Mapping carbon stocks in the study area more accurately performed without distinction of species compared to distinguish the species. Vegetation index that has the best accuracy in mapping carbon stocks over the surface of the mangrove forests in the Teluk Benoa, Bali is an index of mRE-SR mapping with an accuracy of 85%, 84%, and 64% for each species *Rhizophora mucronata*, *Rhizophora apiculata*, and *Sonneratia alba*.
2. Estimates of mangrove forest carbon stocks in the Teluk Benoa, Bali can be mapped to a scale of 1:10,000. With high carbon stock value dominated scattered mangrove area adjacent to the sea. Carbon stocks lower value contained in the mangrove area adjacent to the mainland. The total stock of carbon in the study area is 35349.87 tons of mapping carbon stocks of each species in an area of 392 ha.

Acknowledgments

The author would like to thank Digital Globe Foundation for Worldview-2 image granted which the research depended on. Author also would like to express our gratitude to Balai Pengendali Perubahan Iklim dan Kebakaran Hutan dan Lahan wilayah Jawa, Bali, dan Nusa Tenggara for the permit and facilities during field survey. We thank to Widyaniisa Rahmayani and Wulan RT as field survey assistants.

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