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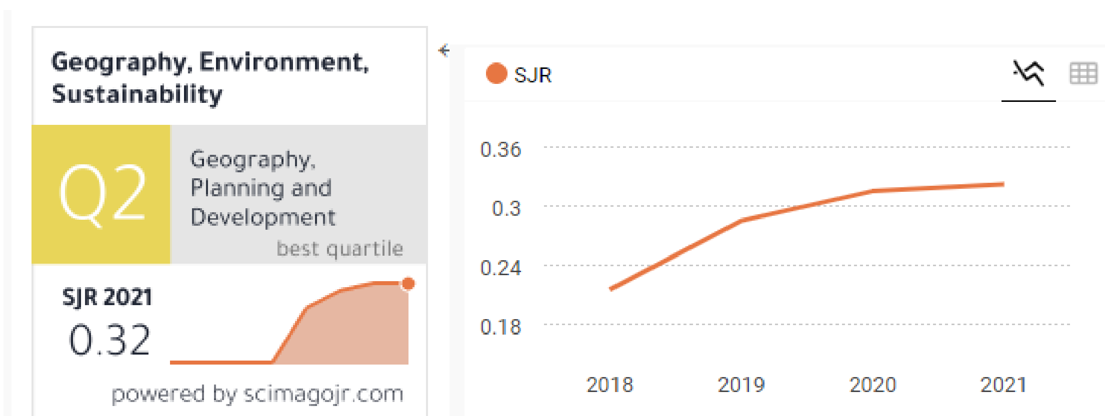

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GES Manuscript Review Request

1 message

Dr. Alexey A. Maslakov <no-reply@subs.elpub.science> Thu, Jan 13, 2022 at 11:36 PM
Reply-To: "Dr. Alexey A. Maslakov" <ges-journal@geogr.msu.ru>
To: Abdul Malik <abdulmalik@unm.ac.id>

Dear Abdul Malik!

We have received the following manuscript to be considered for publication in the Geography, Environment, Sustainability journal:

"Spatial Distribution of Carbon Stock in Southern Bali"

Abstract

Climate change occurs due to an increase in greenhouse gases that accumulate in the atmosphere. Vegetation has an important role in reducing the impact of greenhouse gases as a carbon sink. This study aims to produce a regression model between the vegetation index using NDVI and the carbon stock of vegetation so that carbon stock can be identified easily from Sentinel 2-A satellite imagery and analyze their spatial distribution in Southern Bali. The distribution of carbon stocks was analyzed using a combination of the vegetation index approach and statistical regression analysis. The vegetation index used is NDVI obtained from processing the Sentinel 2-A satellite imagery in 2015 and 2021. The value of vegetation biomass values is derived from allometric equations. After getting the amount of biomass, a regression model was built with the vegetation index. The model with the highest level of accuracy is used to estimate the distribution of carbon stocks in Southern Bali. The results of this study indicate that the best regression model for predicting the value of carbon stock is a quadratic regression model with the NDVI vegetation index variable. The spatial distribution of carbon stocks in southern Bali is in line with the value of the vegetation index. The denser the vegetation index from 2015 to 2021, the higher the carbon stock in the region.

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Mon, Mar 28, 2022 at 11:52 PM

Dear Abdul Malik!

Thank you for completing the review of the submission "Spatial Distribution of Carbon Stock in Southern Bali," (ID 2209) for GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY.

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Research Paper

Spatial Distribution of Carbon Stock in Southern Bali

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Muhammad Dimyati[1], Winda Cantika Putri[2], Astrid Damayanti[3]

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ABSTRACT. Climate change occurs due to an increase in greenhouse gases that accumulate in the atmosphere. Vegetation has an important role in reducing the impact of greenhouse gases as a carbon sink. This study aims to produce a regression model between the vegetation index using NDVI and the carbon stock of vegetation so that carbon stock can be identified easily from Sentinel 2-A satellite imagery and analyze their spatial distribution in Southern Bali. The distribution of carbon stocks was analyzed using a combination of the vegetation index approach and statistical regression analysis. The vegetation index used is NDVI obtained from processing the Sentinel 2-A satellite imagery in 2015 and 2021. The value of vegetation biomass values is derived from allometric equations. After getting the amount of biomass, a regression model was built with the vegetation index. The model with the highest level of accuracy is used to estimate the distribution of carbon stocks in Southern Bali. The results of this study indicate that the best regression model for predicting the value of carbon stock is a quadratic regression model with the NDVI vegetation index variable. The spatial distribution of carbon stocks in southern Bali is in line with the value of the vegetation index. The denser the vegetation index from 2015 to 2021, the higher the carbon stock in the region.

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KEYWORDS:
carbon stock
NDVI
regression model
remote sensing
Sentinel 2-A

ACKNOWLEDGEMENTS

We are grateful to the Ministry of Research and Technology/National Research and Innovation Agency for support and research funding through SIMLITABMAS (Management Information Systems for Research and Community Participation) with the contract number NKB-2649/UN2.RST/HKP.05.00/2020. We also thank the members of the Department of Geography, Universitas Indonesia, for their encouragement.

CONFLICTS OF INTEREST

"The authors reported no potential conflicts of interest."

INTRODUCTION

In the last few decades, environmental issues regarding global warming have become an issue and the center of public attention. Global warming is a threat to the survival of various ecosystems on earth (Abdullah, 2009). Global warming is a form of ecosystem imbalance characterized by an increase in the temperature of the atmosphere, sea, and land (Hasan, 2016). Climate change occurs due to an increase of greenhouse gases that accumulate in the atmosphere (Griggs, 2002). The greenhouse effect keeps the earth's temperature higher than direct heating by the sun (Kweku, et al, 2017). Mitigation of greenhouse gas emissions is carried out as an effort to reduce the negative impact of global warming (Wahyudi, 2016). Various efforts to mitigate climate change have been carried out. Vegetation has an important role in reducing the impact of greenhouse gases as a carbon sink. Carbon sequestration is needed to reduce greenhouse gases in the atmosphere. Increased carbon stocks can reduce the impact of climate change (Nugroho, et al, 2012). On the other hand, the depletion of carbon stocks in an area causes an increase in greenhouse gas emissions (Setiawan, et al, 2020).

Plants absorb carbon and store it in the form of biomass, so increasing carbon stocks value can be done by planting trees and keeping the land vegetated (Zikri, 2015). Monitoring of vegetated land needs to be done to determine carbon stocks in an area. Southern Bali, is in a strategic location, which is at the center of business and tourism growth, so this condition has a major impact on vegetated land in the four districts (Kurniawan, 2019). The conversion of land into built-up lands such as settlements, recreation, and tourism areas, trade and shopping centers, and industrial centers is increasing, especially in urban areas (Sinaga, et al, 2018). The spatial description of land use change in Bali Province shows that the areas experiencing the largest land use changes are the central to southern regions of Bali Province (As-syakur, 2011). In this study, the researcher used remote sensing methods to estimate the distribution of carbon stocks in Southern Bali. Remote

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Sensing together with Geography Information System applications can provide quantitative information to determine the spatial distribution of vegetation (Giri, et al, 2008). To calculate the biomass estimation using remote sensing, it is done by connecting the biomass value obtained from the results of field measurements with the transformation of the vegetation index in the image (Nabila, 2019). The researcher uses the non-harvesting data collection method to collect vegetation biomass data and uses remote sensing and regression analysis to calculate the estimated carbon stock value because it is considered a potential method and also a practical method (Heumann, 2011).

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Several previous studies related to carbon stock estimation were used as a reference in this study. Allometric equations for each type of vegetation were obtained in the research of (Marwah, et al, 2008) and (Nabila, 2019). Comparison of Landsat 8 OLI and Sentinel 2-A images for carbon stock estimation by (Astriani, et al, 2017). Research on forest carbon stock estimation was conducted by Widhi in Tesso Nilo National Park, Riau using Landsat 8 Imagery (Widhi, et al, 2014). Research by Simarmata, Elyza, & Vatiady in 2019 to examine the use of SPOT 7 imagery to estimate carbon stocks in mangrove forests as an effort to mitigate climate change in South Lampung (Simarmata, et al, 2019). Research by Suhardiman & Mardiyatmoko in 2017 to estimate carbon stocks in the Tenggarong urban area using the NDVI method on Sentinel Image 2-A (Suhardiman, et al, 2017). Research by Frananda, Hartono, & Jatmiko in 2015 in comparing the vegetation index for the estimated carbon stock of mangrove forests in Alas Purwo National Park Banyuwangi, East Java (Frananda, et al, 2015). Research by Pambudhi, Murti, & Zuharnen to estimate forest carbon stock in Long Pahangai District, West Kutai Regency using Alos Avnir-2 Image in 2012 (Pambudhi, et al, 2012). Research conducted by Nabila is also related to carbon stock estimation by using Sentinel 2-A imagery for the development of a model for estimating carbon stocks in vegetation stands in Kendari City (Nabila, 2019). The difference between this research with the previous researches in the previous researches just researched the distribution of carbon stocks in a region with a high accuracy model but did not research further to see carbon stock changes, so that in this study technically usability the geography information system was able to explain spatial phenomena that occurred in the research area.

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The aims of this study are: (1) determine the best regression model in estimating carbon stocks with the highest level of accuracy, and (2) map the distribution of carbon stocks in southern Bali. The difference in this study with previous research is the combination of the use of 2-A sentinel data statistical analysis to estimate carbon stocks and research about the carbon stock changes, so that this study technically use the geographic information system to explain the spatial phenomena

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Commented [AM9]: The aims of the study should be improving to “detect of biomass carbon stock changes in Southern Bali from 2015 to 2021” that occurred in the research area. The NDVI vegetation index data (Normalized Difference Vegetation Index) is used as the main input to estimate carbon stock by applying statistical regression for Southern Bali.

MATERIALS AND METHODS

Study Area and Variable

The research location was conducted in Southern Bali which included Badung Regency, Gianyar, Tabanan, and Denpasar City. Geographically, the province of Bali is located on the island of Bali at114° 25' 53" - 115° 42' 40" BT dan 8° 3' 40" - 8° 50' 48" LS. The province of Bali consists of 8 districts and 1 city, named Tabanan, Badung, Gianyar, Jembrana, Klungkung, Bangli, Buleleng, Karangasem Regency, and Denpasar City (BPS, 2016). The satellite image data used in this study is the 2-A sentinel image obtained from USGS in March 2015 and 2021. The 2-A sentinel image has a wavelength ranging from 443 Nm to 2190 nm. These satellites are equipped with multi-spectral instrument sensors (MSI) to measure a reflection of 13 spectral bands (Adini, 2018).

Mapping land cover and vegetation density in Southern Bali

Land cover classification is processed using the supervised classification method and maximum likelihood analysis. Supervised classification was chosen because it is considered to be easier to recognize particular objects. This classification technique is done using several pixel sampling methods for each class or object, so it gets the characteristics of pixels in each class or object. All pixels that are not used as samples will be grouped with pixel values of sample characteristics by applying statistical calculations (Kiefer & Lillesand, 1990). The classification of land cover is divided into 5 classification classes, which are waters, built area, forests, bare land, and agriculture (Badan Standardisasi Nasional, 2012).

To process the land cover classification using supervised classification, the steps taken are to make the data training set become a classification reference. In this study, researchers took 30 points of land cover training in each classification class with even distributions in Southern Bali. After classification, validation by comparing data training sets with 50-point accuracy test data divided into each classification class with even distribution. To map the vegetation density in Southern Bali, NDVI is the algorithm that used in this study to transform the vegetation index. NDVI is a signal processing algorithm used to observe the state of vegetation. Every vegetation density found a collection of varying individuals that cover the surface of the land [26]. NDVI has a value ranging from -1.0 to 1.0 (Arhatin, 2007). The transformation of the NDVI vegetation index is carried out by entering the formula or algorithm and calculated using Google Earth Engine. The results of the calculation of the NDVI value will then be used for regression analysis in determining the model that has high accuracy and is used to estimate the value of carbon stock in southern Bali. The NDVI vegetation index is calculated on each pixel based on the difference between Band 4 (Red) and band 8 (NIR). The calculation of the NDVI formula can be seen in equation 3 (Khoirunnisa, et al, 2020).

$$NDVI = (NIR-R)/(NIR+R) \qquad (3)$$

NIR: near-infrared band; and R: red band

To analyze the health of vegetation and density, the vegetation density class is divided into 5 classes as in Table 1, which is non-vegetated area, very low, low, medium, high (Vision of Technology (VITO), 2017). The calculation of the NDVI formula can be seen in equation 3 (Khoirunnisa, et al, 2020).

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Table 1. Vegetation Density Class

Class	Density Class	NDVI Value	Land Cover
1	Non-Vegetated Area	-0,79 – 0,12	Waters, Bare Land
2	Very Low	0,12 – 0,22	Built Area
3	Low	0,22 – 0,42	Agriculture
4	Medium	0,42 – 0,72	Agriculture
5	High	0,72 - 1	Forest

Source: *Vision of Technology* (VITO), 2017

Data Normality Test

The data normality test in this study needs to be done before making carbon stock distribution maps. It aims to see normality in field data obtained as a condition before conducting regression analysis. Regression analysis can be done if the data is normally distributed (Sukestiyarno, 2017). The normality test is used in this study to find out the variables that will be tested, namely the NDVI vegetation index and field carbon stocks are normally distributed or not. The normality test was carried out using the 5% test rate ($\alpha = 0.05$) (Jonatan, 2018). The normality test is done by KS Test (Kolmogorov-Smirnov) using the SPSS application. The Kolmogorov-Smirnov test was used in this study due to the more appropriate Kolmogorov-Smirnov test used for samples of more than 50 (Dahlan, 2009). This equation uses a hypothesis, namely, Ho is rejected or the data is not normally distributed if the P-value <0.05, while Ho is accepted if p-value> 0.05 or normal distribution data (Faradiba, 2020). Tests are carried out using the Kolmogorov Smirnov test with a formula in equation 4.

$$KS = |Fn\ (Yi-1) – Fo\ (yi)| \qquad (4)$$

KS: The value of Kolmogorov-Smirnov; Fn (Yi-1): The frequency of the percentage of cumulative at the time before I; and Fo (yi): frequency of normal distribution data at the time i.

Carbon Stock Modelling

Carbon stock models are carried out using regression analysis. The simple regression model was used in this study because this study only has one independent variable (x) (Hijriani, 2017). This regression model is used to express functional relationships between one or several independent variables (predictors) of one bound variable (response) (Imran, 2014). In regression analysis, estimates the parameters automatically estimate the regression model (Tarno, 2007). Some regression methods used for estimates are as follows (Hartono, 2011):

a. Linear model

y = a.x + b (5)

b. Exponential model

y = a.eb.x (6)

c. Logarithmic model

y = a + b In(x) (7)

d. Quadratic model

y = ax2+bx+c (8)

The regression model was chosen by Karnea assumed that there was a linear connection between carbon stocks and the vegetation index. The four regression models were chosen to be used in this study because the four models were previously studied in research related to the appropriate regression method for forecasting studied by Hermanto & Rizqika, 2019. The formation of the regression model is carried out using the SPSS (statistical product and service solutions) application. The model of carbon stock value is built using the NDVI pixel value. The selection of the regression model is best tested based on the R2 value obtained with equation 9 and the accuracy test with RMSE (Root Mean Standard Error) in equation 10. The regression method selected from this method is the regression method that produces the largest R2 value and the smallest RMSE value which will be used for the estimation of biomass and carbon stock in this study.

$$R^2 = \frac{Number\ of\ quadratic\ regression}{Number\ of\ Quadratic\ Regression} \times 100\% \quad (9)$$

Accuracy Test and Mapping of Carbon Stock

The model accuracy test is done by comparing the measurement data from field data samples with predictive data or regression models. Carbon stock field data is calculated using the allometric model to calculate plant biomass, and then the biomass value is converted into the carbon stock value. The RMSE value is obtained by conducting a validation test to determine the irregularities of the carbon value estimated based on the four regression models built with carbon stocks in the

Commented [AM11]: I don't found data samples from field. How to measure data from field?

field. A validation test is done to find out the model that has the best accuracy of all the models that have been built. The validation test is carried out with the RMSE test (Root Mean Standard Error), which is calculated using the formula in equation 10 (Syariz, 2015).

$$\text{RMSE} = \sqrt{\frac{(y - y')^2}{n - 2}} \qquad (10)$$

y: field carbon stock; y ': carbon stock model; and n: sample point number.

After the accuracy test is carried out, the regression model that has the smallest RMSE value will be used to map the distribution of carbon stocks in southern Bali. The distribution of carbon stocks in southern Bali is obtained by entering the best regression equation (Wijaya, 2017). This calculation was carried out with a 2-A sentinel satellite image in the 2015 research year and 2021.

RESULTS AND DISCUSSION

Vegetation Indices Classification

The results of Sentinel-2A image processing with NDVI algorithm calculations produce pixel values ranging from 0 to 1. **Fig. 1.** shows that the Southern Bali region is dominated by medium to high vegetation density that dominates in the southern and north of the research area. Whereas the class of very low and low density dominates in the central part of the research area which includes Denpasar City and Central Badung Regency which covers Kuta District. The low-density class is also spread in the southern part of Badung Regency which includes South Kuta District and the southern part of Gianyar Regency.

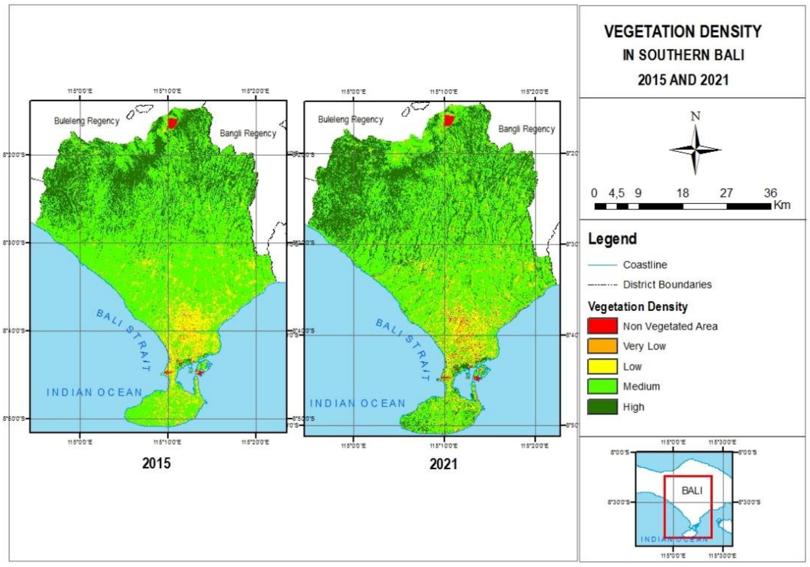


Fig. 1. Classification of Vegetation Density with NDVI

Data Normality Test

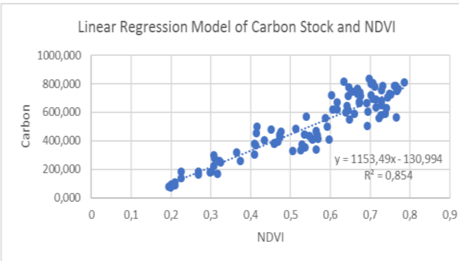
Based on **Table 2**, it is known that the significance in the KS test is 0.200 and the SW test is 0.564 which means greater than 0.05, so it can be said that the data is normally distributed with a significance value of more than 0.05. After the data used is known to be normally distributed, it can use the regression model.

Table 2. Normality Test

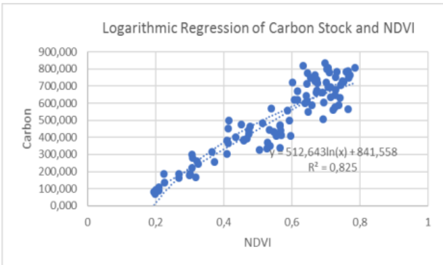
. Item	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	0,064	100	0,200*	0,989	100	0,564
Note: *. This is a lower bound of the true significance; and a. Lilliefors Significance Correction						

Carbon Stock Modelling by Vegetation Indices

The regression model was formed using the pixel values of the NDVI vegetation index. The models formed are as many as 4 models, namely linear, logarithmic, quadratic, and exponential models**. Fig. 2.a** shows the regression model between carbon stock and NDVI value using linear regression has an R^2 value of 0.854. Meanwhile, **Fig. 2.b** shows the logarithmic regression between carbon stock and the NDVI value has an R^2 of 0.825. **Fig. 2.c** shows the quadratic regression between carbon stock and NDVI value, which has an R^2 value of 0.854. **Fig. 2.d** shows the regression model between carbon stock and NDVI value using exponential regression has an R^2 value of 0.844. Based on this regression model, the linear and quadratic regression models have the highest R^2 value between the other models.



(a)



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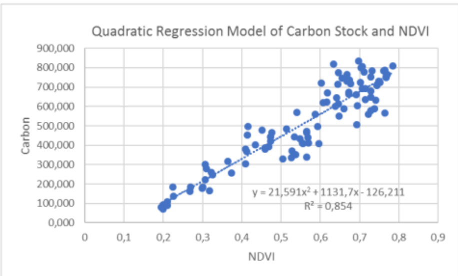

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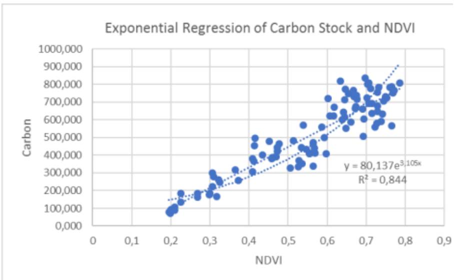

(d)

Fig. 2. (a) Linear Regression Model, (b) Logarithmic Regression Model, (c) Quadratic Regression Model, and (d) Exponential Regression Model

Accuracy Test

Table 3 shows the results of the RMSE calculation of the carbon stock regression model. The four models each have an RMSE value which is 81.58 for the linear regression model, 88.79 for the logarithmic regression model, 81.28 for the quadratic regression model, and 99.20 for the exponential regression model. Based on the RMSE calculation between the 4 regression models and the field carbon stock, the lowest RMSE value was found in the quadratic regression model which is 81.28. This value indicates that each carbon stock produced by the model has an average value difference of 81.28 or equal to 81.28 kg per 100 m^2 in 1 plot size.

The results of this data processing indicate that the best regression model for mapping the distribution of carbon stocks in Southern Bali is quadratic regression analysis with the model equation $y = 21.591x^2 + 1131.7x - 126.211$. This regression analysis has a coefficient of determination (R^2) of 0.854 and has the smallest RMSE value compared to the other three models, which is 81.28.

Table 3. RMSE Calculation of Carbon Stock Regression Model

No.	Regression Model	Model	RMSE
1.	Linear	y = 1153,49x - 130,994	81,58
2.	Logarithmic	y = 512,643ln(x) + 841,558	88,79
3.	Quadratic	$y = 21,591x^2 + 1131,7x - 126,211$	81,28
4.	Exponential	$y = 80,137e^{3,105}$	99,20

Source: Data processing, 2021

Distribution of Carbon Stock in Southern Bali

Based on the calculation of carbon stock using a raster calculator on Sentinel 2-A images that have been transformed into Vegetation Density Class (NDVI) in Southern Bali 2015 and 2021, the carbon stock values range from 0 to more than 700 kg/pixel. The map of the carbon stocks distribution in Southern Bali 2015 (Figure 3) shows that carbon stocks in the range of 0-100 kg to 200-300 kg dominate in Denpasar City and Central Badung Regency which includes Kuta District. Carbon stocks in the range of 200-300 kg and 300-400 kg are scattered in the southern part of Badung Regency which includes Kuta and Mengwi Districts, and in the southern part of Gianyar Regency. Carbon stocks in the range of 400-500 kg dominate in the southern part of Badung Regency, the eastern part of Badung Regency, and the southern part of Gianyar Regency. Carbon stocks in the range of 500-600 are scattered in the southern part of Badung Regency which includes South Kuta and Mengwi Districts, the eastern part of Tabanan Regency, and the southern part of Gianyar Regency. Carbon stock in the range of 600-700 to >700 dominates in the western and northern parts of Tabanan Regency, the northern part of Badung Regency, and northern part of Gianyar Regency.

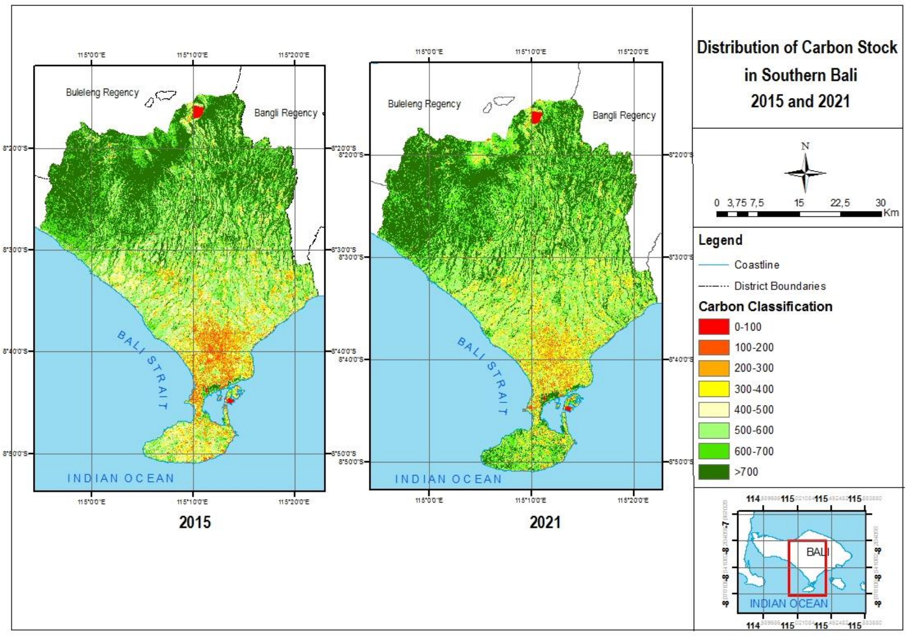

Fig. 3. Carbon Stock Distribution of Southern Bali in 2015 and 2021

Source: Data Processing, 2021

The map of the carbon stocks distribution in Southern Bali 2021 shows an increase of the carbon stocks value in Southern Bali which is marked by changes in light yellow and light green colors to green and dark green in the southern part of Badung Regency, decreasing dark orange and red colors to orange, light and yellow in Denpasar City, and a light yellow color change to light green in the eastern part of Tabanan Regency and the southern part of Gianyar Regency. The increase in carbon stock is also seen in the mangrove forest area in Benoa Bay which changes its color from green to dark green.

Table 4. Area of Carbon Stock Classification in 2015 and 2021

Carbon Stock (Kg)	Area (Ha)		Area (%)	
	2015	2021	2015	2021
0-100	527,13	535,66	0,30	0,30
100-200	3930,11	2331,71	2,23	1,32
200-300	8982,87	6277,65	5,09	3,56
300-400	13047,43	12165,183	7,39	6,89
400-500	23237,89	21541,49	13,16	12,20
500-600	36383,62	32469,02	20,61	18,39
600-700	35737,44	37308	20,24	21,13
>700	54692,133	63916,23	30,98	36,20
Total	176538,623	176544,943	100	100

Source: Data Processing, 2021

The area of carbon stocks in 2015 and 2021 is shown in **Table 4**. The table shows a very visible dominance in the range of carbon stock values of more than 700 kg. Based on these data, this shows that the classification of carbon stocks that experienced changes in the area was mostly experienced in the range of >700 kg which increased by 5.22% of the total area of the study area.

Commented [AM12]: Why this is happened? Please provide arguments for this

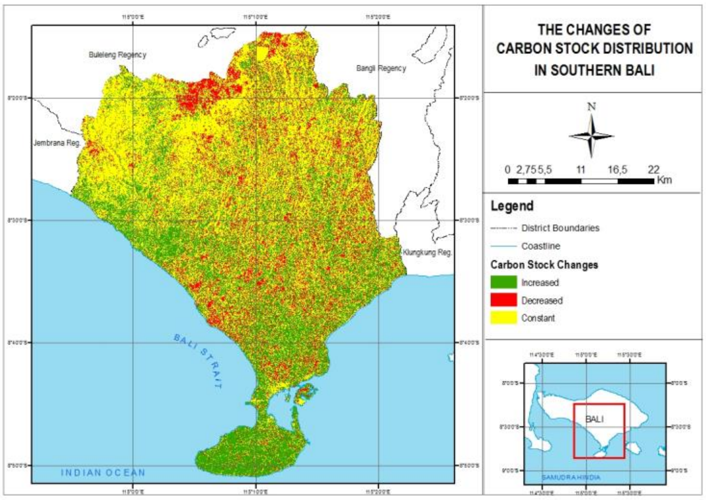

Fig. 4. Changes of Carbon Stock Distribution in Southern Bali 2015 and 2021

Source: Data Processing, 2021

The changes in Carbon Stock Distribution value in Southern Bali are classified into 3 classification classes, namely increasing, constant, and decreasing (**Fig. 4.**). Changes in carbon stocks that have increased are found in the southern part of Badung Regency which includes South Kuta District, the southern part of Tabanan Regency, the southern part of Gianyar, and northern part of Denpasar City. Changes in carbon stocks that have decreased are found in the southern and eastern parts of Denpasar City, the northern part of Tabanan Regency, and spread in the northern part of Badung Regency, and the central to the northern part of Gianyar Regency. Data analysis using the overlay technique to see changes in carbon stocks is an advantage of this study, in previous studies conducted by Nabila [13]; Mardiyatmoko & Suhardiman [19]; Frananda, Hartono, Jatmiko [20] were only to map the distribution of carbon stocks in areas with high accuracy models but did not investigate further to see changes in carbon stocks so that in this study the technical use of Geographic Information Systems can explain spatial phenomena that occur in the research area.

Commented [AM13]: Need arguments for this statement!

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Table 5. Area of Carbon Stock Changes in 2015 and 2021

Changes of Carbon Stock	**Area (Ha)**
Increased	59455,42
Decreased	19247,34
Constant	87454,78

Source: Data Processing, 2021

Overall, the results of processing data (**Table 5**) on the change of carbon stocks distribution shows that Southern Bali has a carbon stock that tends to increase. Carbon stocks that experience a constant value also tend to increase, this is because, under normal conditions, the age of vegetation will increase every year so that carbon stocks will continue to increase. The increase in carbon stock is in line with changes in the vegetation index from low to high, as shown in **Figure 1**.

Commented [AM15]: Need empirical data and/or references for support this statement!
Many of previous findings stated the Diameter Breast High (DBH) size of trees have a great influence to carbon stocks. Also, dense of tree and anthropogenic activities can impact carbon stocks of tree.

CONCLUSIONS

The best regression model to predict the value of carbon stock is a quadratic regression model with NDVI vegetation index variable. The regression model produces good predictive power and has good accuracy for estimating the spatial distribution of vegetation carbon stocks in Southern Bali. Overall, the carbon stocks value in Southern Bali tends to increase from 2015 to 2021 and the spatial distribution of carbon stocks in Southern Bali is in line with the distribution of the vegetation index. The denser the vegetation index from 2015 to 2021, the higher the carbon stock in the region

Commented [AM16]: This statement contrast with the argument in the discussion part!

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