ABOVEGROUND BIOMASS ESTIMATION OF MANGROVES IN SIARGAO ISLAND, PHILIPPINES USING SENTINEL-1 IMAGE

Meriam Makinano-Santillan (1,2), Charlene G. Bolastig (1), Jojene R. Santillan (1,2)

[1] Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University, Butuan City, 8600, Philippines
[2] Caraga Center for Geo-Informatics, Caraga State University, Butuan City, 8600, Philippines
Email: mmsantillan@carsu.edu.ph, jrsantillan@carsu.edu.ph

KEY WORDS: Mangroves, Above-ground Biomass (AGB), Sentinel-1, Siargao Island, Philippines

ABSTRACT: Above ground biomass (AGB) of mangroves is considered as an important ecological and habitat management indicator of various environmental conditions and processes in mangrove ecosystems. In this study, Sentinel-1 images were used to model and estimate AGB of mangroves in Del Carmen, Siargao Islands, Philippines. There were three predictor variables derived from the Sentinel -1 image used for modeling the AGB: the backscatter value from VV polarization, backscatter value from VH polarization, and the combination of the backscatter values from VV and VH polarizations. The modeling was done through linear regression between the field-measured AGB and the predictor variables, and the coefficient of determination (R^2) and root mean square error (RMSE) were determined. Among the three predictor, the combination of the VV and VH polarizations produced a better model compared to the two predictor variables as it obtained the highest R^2 of 0.43 and the lowest RMSE of 12.65 Mg/ha. Based on the developed model, a map of AGB of mangroves in the study area was generated. The generated map showed that AGB of mangroves in the study site ranges from 73.37 Mg/ha to 225.51 Mg/ha with an average of 140.2 Mg/ha. The AGB model derived in this study can be used for multi-temporal monitoring of mangroves in the study area using Sentinel-1 images.

1. INTRODUCTION

Mangrove forests play an important role in our ecosystem, and the need to conserve them continues to be important due to the threats and impacts of sea level rise to coastal areas brought about by global warming. Among the many essential services provided by mangrove forests include food and fuel resources; nursery grounds for fish, mammals and other semi-terrestrial and aquatic fauna; depocenters for sediment, carbon and other elements; and protection of coastal areas from erosion due to tsunamis and intense tropical storms (Alongi, 2012). The enormous capacity of mangrove forests for sucking up carbon dioxide and other greenhouse gases offers a potential in greenhouse gases emission mitigation and plays an important role in carbon sequestration relative to other tropical forest ecosystem due to its ability to grow faster compared to other forest types (Sanderman et al., 2018).

Siargao Island in Mindanao, Philippines is not only famous for being one of the best surfing sites in the world, but also because of its declaration as one of the largest protected area in the Philippines through the National Integrated Protected Area System Act (The LawPhil Project, 2018). Of the 8,600 hectares of mangroves in the island, approximately 4,000 hectares can be found in the municipality of Del Carmen, and is reported to be the largest contiguous mangrove forest in the Philippines (Gonzaga, 2014).

Siargao Island is also abundant with marine life and a sanctuary of the endangered Saltwater Crocodile (*Crocodylus porosus*). However, its mangrove stands has shown signs of degradation and needs protection from poachers/firewood gatherers to recover, while gaps within mangrove areas need rehabilitation due to absence of natural regeneration (DENR-B+WISER, 2015). On the other hand, because of its location in the eastern side of the Philippines and facing the Pacific Ocean, Siargao Island is constantly under the threats of sea level rise and storm surges. While mangroves in the island may reduce the impacts of these phenomena, they also pose a threat to the future of the mangrove ecosystem. With these concerns, monitoring mangroves in the island is therefore essential.

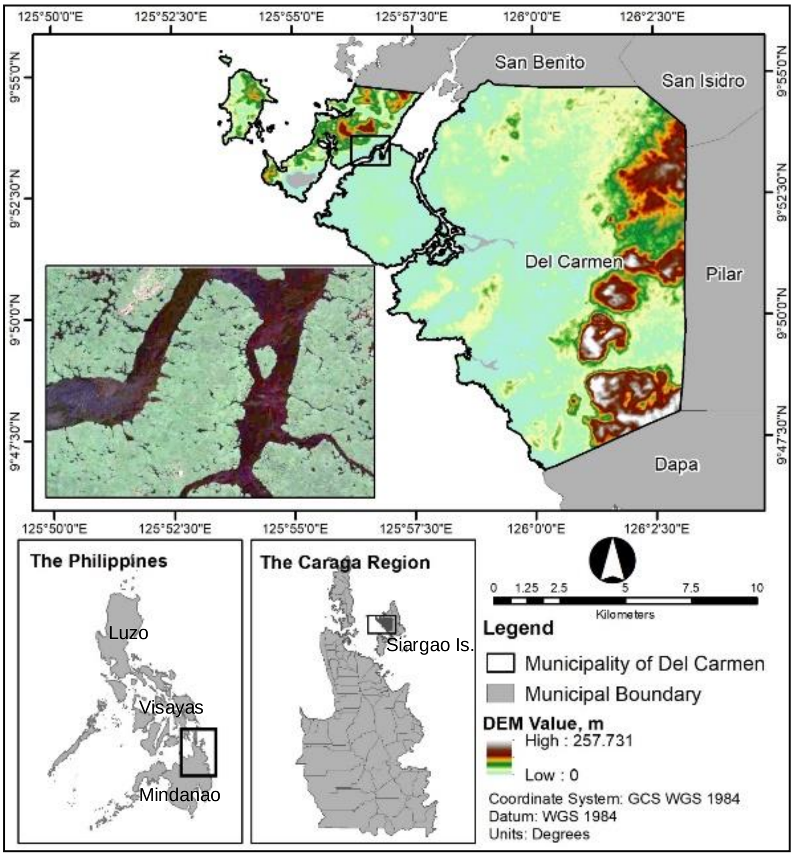

Figure 1. The study area in Del Carmen, Siargao Island, Mindanao, Philippines.

Among many indicators, above ground biomass (AGB) is considered as an important ecological and habitat management indicator of various environmental conditions and processes in mangrove ecosystems. AGB refers to the dry weight of organic material that has been produced and stored in living vegetation which is above the soil including stems, stumps, branches, bark, seeds, and foliage (The REDD Desk, 2019). Estimation of AGB has received significant attention over the last few decades because of increased awareness of global warming due to climate change; and the important role forest biomass plays in carbon sequestration and release of greenhouse gases due to deforestation (Kumar and Mutanga, 2017). AGB can be estimated by destructive sampling where the trees are actually cut down and weighed; or by non-destructive methods that include estimation based on allometric equations developed using tree dimensions such as diameter at breast height (dbh) and tree height, or through remotely-sensed imagery (Kumar and Mutanga, 2017). In particular, satellite image-based biomass estimation models can be derived from radar backscatter polarizations, multispectral bands, vegetation index, and vegetation cover biophysical variables such as Leaf Area Index (LAI) (Castillo et al., 2017). Synthetic Aperture Radar (SAR) images have been a popular choice to estimate AGB due to its cloud penetration capability and its sensitivity to forest spatial structure and standing biomass. The use of backscatter values from SAR images is considered to be the most convenient and simplest method. In this approach, the biomass estimation model is developed by correlating radar backscatter values, (including their derivatives), at different polarizations with field-measured AGB (Castillo et al., 2017; Argamosa et al., 2018; Van Pham et al., 2019). The use of Sentinel-1 imagery for AGB estimations has recently caught attention of researchers looking for alternatives to long-wavelength SAR data (e.g., ALOS PALSAR products) that are considered more suitable for forest applications since it is more penetrating than shorter wavelengths SAR such as that of Sentinel-1 (Argamosa et al., 2018). In a study conducted by Castillo et al. in 2017, backscatter values provided by single-date Sentinel-1 SAR images in VH (vertical transmit –vertical receive) polarization had better correlations with biomass ($r = 0.48–0.51$) than VV polarization.

The objective of this study is to estimate the AGB of mangroves in the Municipality of Del Carmen, Siargao Island, Philippines (Figure 1) using Sentinel-1 images. The specific objectives are (i.) to demarcate the boundary of the mangrove area in the study site; (ii) to develop a model that will estimate aboveground biomass; and (iii) to estimate the mangrove AGB based on the model created and map its spatial distribution.

2. METHODOLOGY

2.1 Sentinel-1 Image Acquisition and Processing

Sentinel-1 SAR image of the study area acquired on February 28, 2019 and in Ground Range Detected (GRD) processing level was downloaded from Copernicus Open Access Hub (https://scihub.copernicus.eu/). The image was in Interferometric Wide Swath Mode with VH and VV polarizations, and pixel size of 10 m. The Sentinel Application Platform (SNAP) was used for image preprocessing that includes image sub-setting, application of orbit file, radiometric calibration, speckle reduction, and Range-Doppler terrain correction.

2.2 Mangrove Area Mapping

The boundary of mangrove areas in the study site was manually demarcated using year 2019 high resolution images available in Google Earth. The mangrove area boundaries were converted into shape file and were overlaid to the Sentinel-1 backscatter VV and VH images as an input for clipping to demarcate the mangrove area on the backscatter images.

2.3 Field Measurements of Mangrove AGB

A total of sixty-eight randomly selected 10m x 10m sample plots were established on the study site. Fifty (50) of the plots were used for the AGB modelling while the remaining 18 plots were used for validation of the model. In each plot, diameter-at-breast-height (DBH) was measured for all mangroves using a tape measure. The geographic (WGS84) coordinates of each plot centers were recorded using a Garmin handheld global positioning system (GPS) receiver. The actual field survey was conducted on March 7-10, 2019. Only mangrove trees with height of $\geq$ 1.3 m and DBH of $\geq$ 5 cm were considered (Argamosa et al., 2018).

To estimate the aboveground biomass for each measured DBH, the following allometric equation developed by Ong et al. (2004) was used:

$$log_{10}AGB\ (kg) = 2.42*log_{10}DBH - 1.832 \quad (1)$$

This equation was chosen since it was developed for *Rhizophora* mangrove species, which was also the dominant species present in the study area. Moreover, the range of the DBH used in developing this equation (15cm to 77cm) fits the range of the DBH of the mangrove measured in the study site. Due to a high result of $R^2 = 0.98$ between the aboveground biomass and DBH obtained by Ong et al (2004), this equation may be reliable in estimating aboveground biomass using DBH in the study site.

The equation shown above was applied to each tree in the established plot, and the sum is obtained to determine the aboveground biomass at each plot. The unit of the total sum of the aboveground biomass at each plot is in kg/100 m^2, it was then converted to Megagrams per hectare (Mg/ha) since most of the studies in biomass estimation used the unit Mg/ha.

2.4 Modeling the Relationship between Field Measured AGB and Backscatter Value

The three predictor variables from the Sentinel-1 image, namely the backscatter value from VV polarization image, backscatter value from VH polarization image, and the combination of the backscatter values from the VV and VH polarization images were used in the model development. The coordinates of the 50 training plots established in the field were projected in the Sentinel-1 VV and VH polarizations and the corresponding backscatter value of the 50 plots were identified using ArcMap software. Linear regression was performed between the measured above ground biomass and the aboveground biomass estimation predictor variables. The coefficient of determination (R^2) and the root mean square of error (RMSE) of each model were noted and compared. The model with the highest R^2 and lowest RMSE was used in estimating the aboveground biomass of the entire study area. The modelling was implemented in Microsoft Excel. The RMSE was calculated as $RMSE = \sqrt{\frac{\sum_i (y_i - y_i')^2}{n}}$, where y_i and y_i' are the observed and predicted AGB of each plot respectively and n is the number of plots.

2.5 Estimating the AGB of Mangrove and Accuracy Assessment

The AGB of mangroves in the Municipality of Del Carmen was estimated based on the best model developed based on the R^2 and RMSE values. The model in equation form was used as input in Raster Calculator in ArcMap Software to produce a new raster in which the value of each pixel is the estimated AGB value. The image was used in creating the aboveground biomass map of mangrove for the Municipality of Del Carmen. The accuracy was obtained using the remaining eighteen 10m x 10m validation plots located outside the training plots used for model development. The R^2 and RMSE between the field measured AGB from the validation plots with the predicted AGB generated using the model was examined.

3. RESULTS AND DISCUSSIONS

3.1 Mangrove Boundary

The boundary of mangrove area in the Municipality of Del Carmen is shown in Figure 2. The boundary was overlaid to the VV and VH polarization backscatter images to clip the mangrove area in the two images (Figure 3).

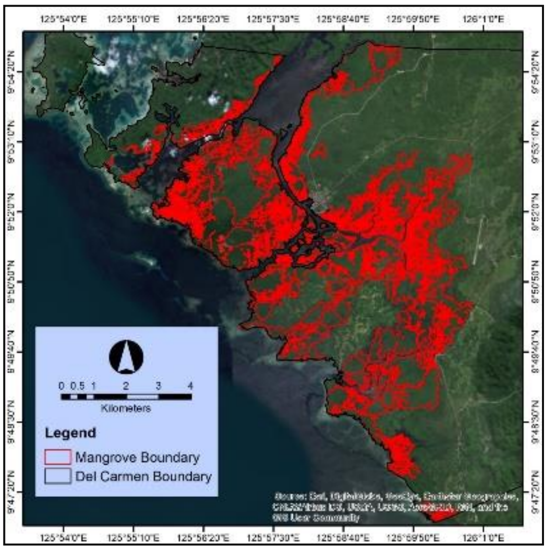

Figure 1. Boundary of Mangrove Area

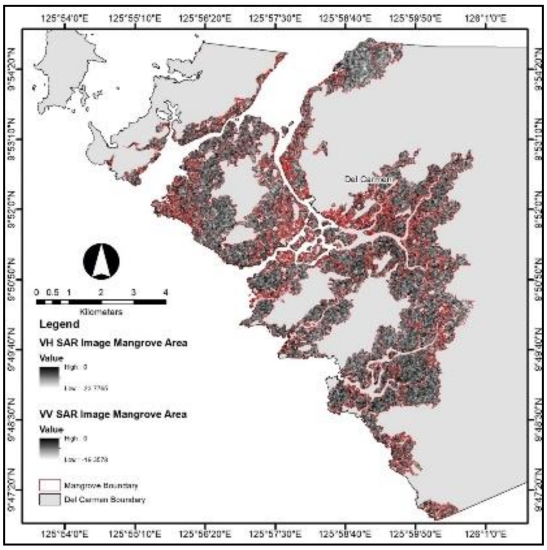

Figure 2. Boundary of Mangrove Area on VV and VH polarizations

3.2 Field Data Result and the Backscatter Value

The sixty-eight plots established on the ground (Figure 4) were divided into two groups: for modelling which is composed of 50 plots and for validation of the model which is composed of 18 plots. For modelling, a total of 804 mangrove trees were recorded in the 50 plots which ranged from 9 to 25 trees per plot. The average diameter at breast height (DBH) for each plot ranged from 24.68cm to 43.27cm. The total AGB in Mg/ha ranged from 84.31Mg/ha to 162.45Mg/ha with an average of 131.39Mg/ha.

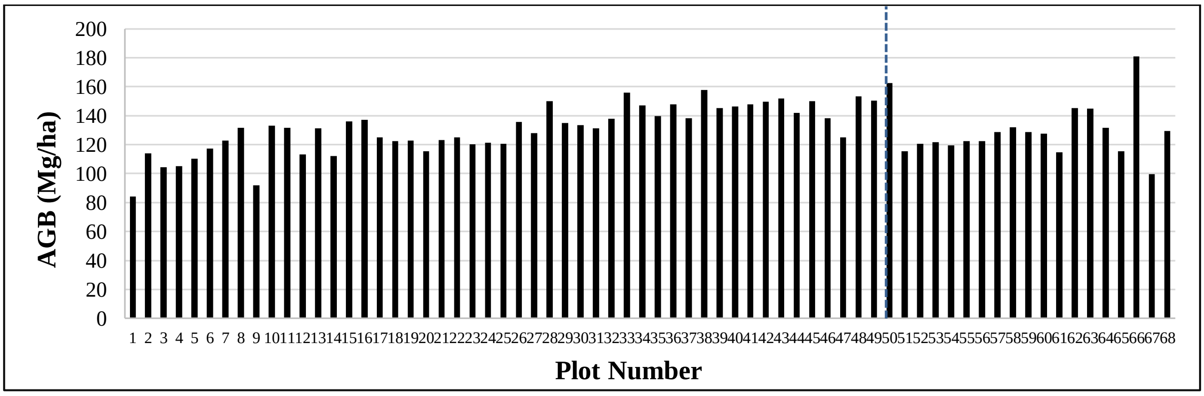

Figure 3. Estimated aboveground biomass of mangrove for each plot.

The backscatter value of each plot for modelling is shown in Figure 5. The average backscatter value in the VH image is -14.89(dB) in which the minimum is -19.31 dB and the maximum is -10.73 dB. The average backscatter value in the VV image is -8.90 dB, with -13.31dB as the minimum and -5.84 dB as the maximum.

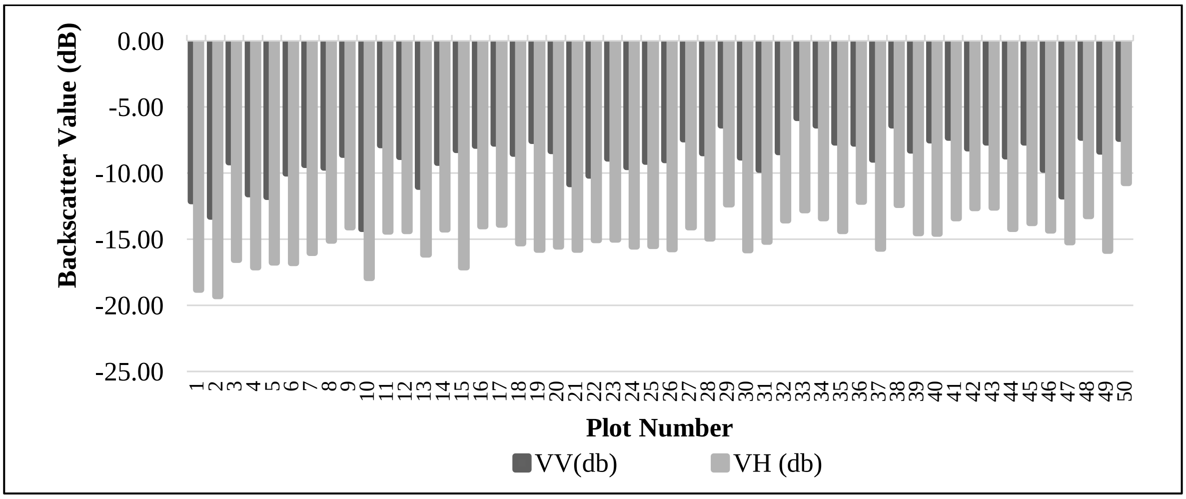

Figure 4. Backscatter Value of each plot

3.3 Regression Result between Field Measured Aboveground Biomass and Backscatter Values

Figure 6, Figure 7, and Figure 8 shows the linear regression between the field measured AGB and the backscatter value from VV polarization, from VH polarization, and the combination of backscatter value on the VV and VH polarizations, respectively.

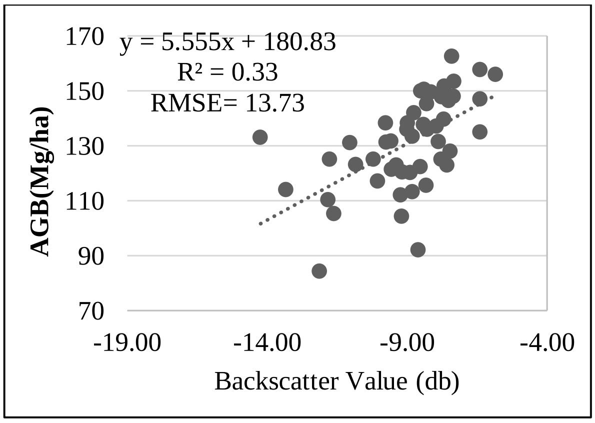

Figure 5. Linear Regression Result between Field Measured AGB and Backscatter Value on VV Polarization.

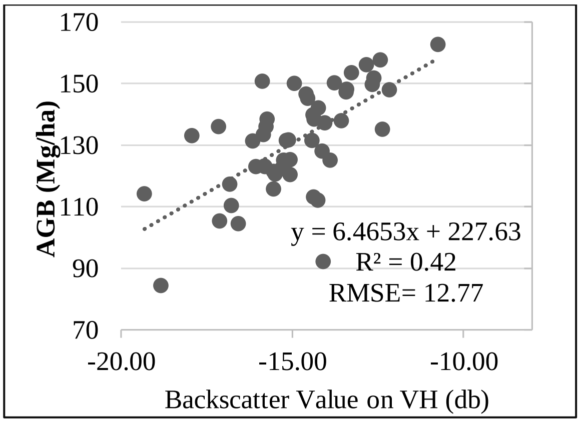

Figure 6. Linear Regression Result between Field Measured AGB and Backscatter Value on VH Polarization.

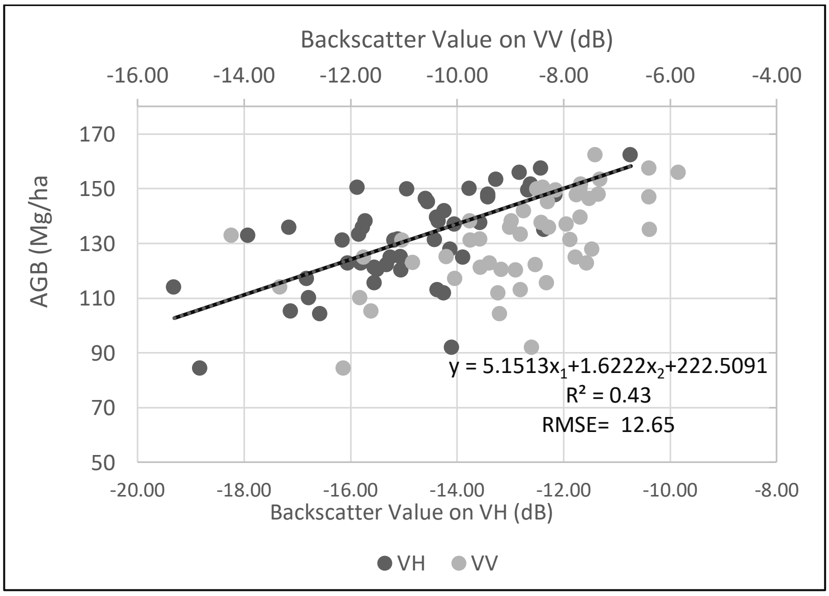

Figure 7. Multiple Linear Regression Result between Field Measured AGB and the Combination of Backscatter Value on VV and VH polarization.

Table 1 summarizes the results of the linear regression between the field measured AGB and the predictor variables. Based on the result, VH polarization has higher R^2 and lower RMSE compared to the VV polarization. However among the three, the combination of the two polarizations had a much better result. The highest R^2=0.43 and the lowest RMSE= 12.65 Mg/ha were obtained with the AGB model based on the combined backscatter value of VV and VH polarization. Thus, the model that will be used in estimating the AGB of mangroves for the entire study site is based on the combination of VV and VH backscatter value, as shown in Equation 3.

$$AGB(Mg\ ha^{-1}) = 5.1513 * VH + 1.6222 * VV + 222.5091 \quad \text{Equation 3}$$

Table 1. Summary of the Result of Linear Regression between AGB and Predictor Variables

Predictor Variables	Equation	Coefficients of Determination, r^2	RMSE (Mg/ha)
VV	y = 5.555x + 180.83	0.33	13.73
VH	y = 6.4653x + 227.63	0.42	12.77
VH(x_1)and VV(x_2)	y = $5.1513x_1+1.6222x_2+222.5091$	0.43	12.65

3.4 Aboveground Biomass Map

Using the best model, a map of the aboveground biomass for the study area was generated (Figure 9). The estimated AGB of the mangrove in the study site ranges from 73.37 Mg/ha to 222.51Mg/ha with average value of 140.2 Mg/ha.

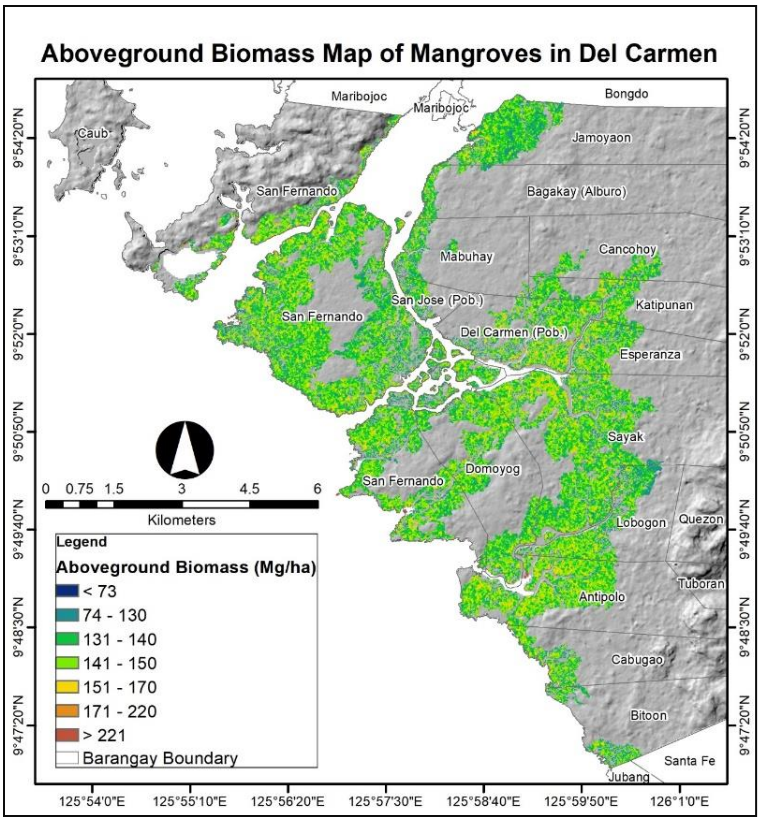

Figure 8. Aboveground Biomass Map of Mangrove in the Municipality of Del Carmen

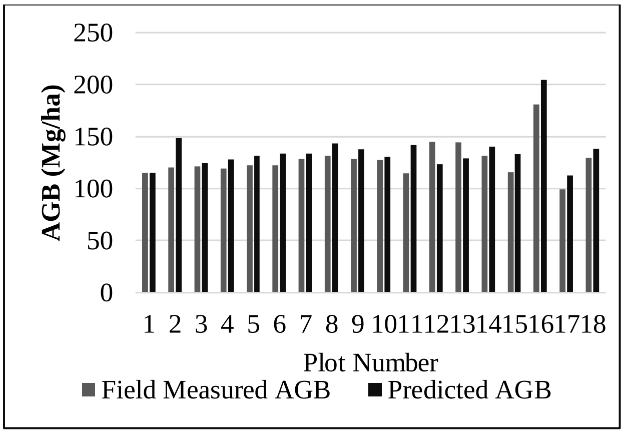

Figure 9. Comparison between Field Measured AGB and the Predicted AGB derived from the Generated Map

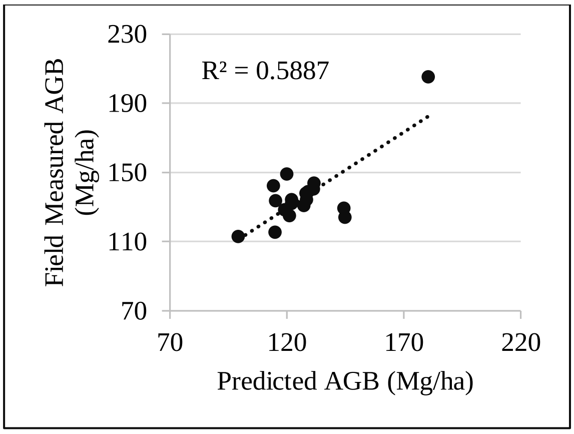

Figure 10. Scatter Plot between Field Measured AGB and the Predicted AGB derived from the Generated Map

3.5 Model Validation

The accuracy of the AGB map created based on the derived model was assessed by using the eighteen 10m x 10 m validation plots. These plots were not included in the model development to test the accuracy of the estimated aboveground biomass from the model when it will be correlated to a sample outside the plots used in the model development. The field measured aboveground biomass for each plot ranges from 99.46Mg/ha to 180.86Mg/ha with an average of 127.724Mg/ha; while the predicted aboveground biomass for each plot ranges from 112.454Mg/ha to 204.739Mg/ha with an average of 136.152Mg/ha. The maximum difference between the field measured AGB and the predicted AGB is 28.141 Mg/ha and the smallest is

0.162 Mg/ha. Figure 11 shows the scatter plot between the field measured AGB and the predicted AGB derived from the generated map and its coefficients of determination R^2 is 0.59. Also, the comparison between field measured AGB and the predicted AGB derived from the generated map is shown in Figure 10 and its RMSE is 14.92 Mg/ha. This value is lower than the value (28.36 Mg/ha) reported by Castillo et al who used the same image in estimating AGB, hence this study showed a satisfactory result.

4. CONCLUSIONS AND RECOMMENDATION

This study estimated the AGB of mangroves in the Municipality of Del Carmen, Siargao Island, Mindanao, Philippines and to map its spatial distribution. Using three input predictor variables from the Sentinel-1 image a model was developed through linear regression between the predictor variables and the estimated AGB of the fifty 10m x 10m plots established on the field. Through linear regression of the predictor variables and the field measured AGB , the VH polarization had a better result since it has higher R^2 which was 0.42 and lower RMSE which was 12.77Mg/ha compared to the VV polarization R^2=0.33 and RMSE = 13.73Mg/ha. However, the combination of the two polarization gives the better model compared to the two predictor variables since its R^2 was 0.4301 and RMSE was 12.65 Mg/ha. This was supported by the study of Castillo et al who observed similar result for Sentinel-1 image where VH had better result compare to VV, and the combination of VH and VV had better result compared to VH and VV only. The result was considered acceptable since the AGB model was developed linearly and R^2 of 0.4 to 0.6 is acceptable for both simple linear regression and multiple linear regressions. Moreover, due to outliers and large values, the RMSE of the model was high and most of the studies in developing AGB models that used remote sensing techniques and various datasets had similar result (Vafaei et al, 2018). But nonetheless, the RMSE of the generated AGB model in this study showed satisfactory result and it is much lower compare to the study of Castillo et al who also used Sentinel-1 images with an RMSE of 28.36 Mg/ha. Based on the developed model, a map of AGB of mangroves in Del Carmen, Siargao Island was generated. The generated map showed the estimated AGB value per pixel throughout the study site and it ranges from 73.37 Mg/ha to 225.51 Mg/ha with an average of 140.2 Mg/ha. The developed map had a RMSE of 14.92 Mg/ha and R^2 of 0.59.

The accuracy of the model might be improved if different predictor variables will be tested and different algorithms such as machine learning techniques will be used in developing the model. Moreover, some of the factors that may also affect the accuracy of the developed model were the number of the samples used and the correctness of the manual digitization of the mangrove boundary demarcation. Also, it was acknowledged that the accuracy of the model created depends on how accurate the field-measurements were, thus, the correctness of the field survey can really affect the accuracy of the model. Furthermore, in doing the field measurement, it is suggested to at least get the coordinates of the corner of the plots upon establishing the plots to ensure that the plots correspond to the exact pixel in the image used.

5. ACKNOWLEDGEMENTS

This work is an output of the Geo-SAFER Agusan Project, one of the component projects of the Geo-SAFER Mindanao Program (Geo-informatics for the Systematic Assessment of Flood Effects and Risks towards a Resilient Mindanao), a research program supported and funded by the Philippine Council for Industry, Energy and Emerging Technology Research and Development of the Department of Science and Technology (PCIEERD-DOST). We gratefully acknowledge PCIEERD-DOST for the financial support. The Field Survey Team of the Geo-

SAFER Agusan Project especially Engr. Ronald Makinano, Engr. Almer Cris Estorque and Engr. Jared Culdora are also acknowledged for their assistance during the field surveys.

6. REFERENCES

Alongi, D.M., 2012. Carbon sequestration in mangrove forests. Carbon Management, pp. 313-322.

Argamosa, R.J.L., Blanco, A.C., Baloloy, A.B., Candido, C.G., Dumalag, J.B.L.C., Dimapilis, L.L.C. and Paringit, E.C., 2018. Modelling above ground biomass of mangrove forest using Sentinel-1 imagery. ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences, 4(3), pp. 13-20.

Castillo, J. A. A., Apan, A. A., Maraseni, T. N., Salmo, S. G., 2017. Estimation and mapping of above-ground biomass of mangrove forests and their replacement land uses in the Philippines using Sentinel imagery. ISPRS Journal of Photogrammetry and Remote Sensing, 134, pp. 70–85.

Gonzaga, 2014. 1st Mangrove Protection and Information Center in the Philippines opens in Siargao, Department of Environmenta and Natural Resources (DENR) – Caraga Region Website, http://caraga.denr.gov.ph/index.php/96-region-news-items/latest-news/418-1st-mangrove-protection-and-information-center-in-the-philippines-opens-in-siargao

Kumar, L., Mutanga O., 2017. Remote sensing of above-ground biomass, Remote Sensing, 9, 935, pp. 1-8.

Ong, J.E., Gong, W.K., Wong, C.H., 2004. Allometry and partitioning of the mangrove, Rhizophora apiculata. Forest Ecology and Management, 188, pp. 395-408.

Sanderman, J., Hengl, T., Fiske, G., Solvik, K., Adame, M. F., Benson, L., Duncan, C., 2018. A global map of mangrove forest soil carbon at 30 m spatial resolution. Environmental Research Letters, 13, 055002.

The LawPhil Project, 2018. Republic Act No. 11038, An Act Declaring Protected Areas and Providing for Their Management, Amending for This Purpose Republic Act No. 7586, Otherwise Known as the "National Integrated Protected Areas System (NIPAS) Act of 1992" and for Other Purposes, https://www.lawphil.net/statutes/repacts/ra2018/ra_11038_2018.html

The REDD Desk, 2019. Above-Ground Biomass. https://theredddesk.org/encyclopaedia/above-ground-biomass

Van Pham, M., Pham, T.M., Du, Q.V.V., Bui, Q.T., Van Tran, A., Pham, H.M., T.N., Nguyen, 2019. Integrating Sentinel-1A SAR data and GIS to estimate aboveground biomass and carbon accumulation for tropical forest types in Thuan Chau district, Vietnam. Remote Sensing Applications: Society and Environment, 14, pp.148-157.

Vafaei, S., Soosani, J., Adeli, K., Fadaei, H., Naghavi, H., Pham, T., Bui, D.T., 2018. Improving accuracy estimation of forest aboveground biomass based on incorporation of ALOS-2 PALSAR-2 and Sentinel-2A imagery and machine learning: a case study of the Hyrcanian Forest Area (Iran). Remote Sensing, 10(2), pp. 172.