九州大学学術情報リポジトリ
Kyushu University Institutional Repository

Modeling Carbon Storage and Sequestration in Taguibo Watershed, Butuan City, Philippines using GIS and InVEST Technology

Aljon E. Bocobo
Deparment of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University

Cristal Mae M. Salte
Deparment of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University

Maryellyneith B. Tagaro
Deparment of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University

https://doi.org/10.5109/7323292

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 10, pp.399-405, 2024-10-17. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：
権利関係：Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International

KYUSHU UNIVERSITY

Modeling Carbon Storage and Sequestration in Taguibo Watershed, Butuan City, Philippines using GIS and InVEST Technology

Aljon E. Bocobo[1,2], Cristal Mae M. Salte[1], Maryellyneith B. Tagaro[1]
[1]Deparment of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University, Butuan City 8600, Philippines
[2]Center for Resource Assessment, Analytics and Emerging Technologies (CReATe), Caraga State University, Ampayon, Butuan City 8600, Philippines
Corresponding author email: aljunwarriorb@gmail.com

Abstract: *The study aimed to model and estimate carbon storage in this ecologically valuable area using the InVEST Carbon Storage and Sequestration modeling software. This tool was utilized to quantify ecosystems services within the watershed. The results indicated a substantial carbon storage capacity, with the area storing 2,735,254.56 Mg of C in 2023 and a predicted increase to 2,757,867.73 Mg of C by 2033. Notably, forests, which make up over 90% of the total carbon in the region, play a crucial role in carbon sequestration. The spatial distribution of carbon storage varied among different Land Use and Land Cover (LULC) types, with areas rich in vegetation exhibiting higher carbon storage per hectare. These findings underscore the vital role of forests in carbon sequestration and highlight the importance of preserving these ecosystems to combat climate change effectively.*

Keywords: Taguibo Watershed, Carbon storage and sequestration, InVEST Model, GIS Technology

1. INTRODUCTION

Carbon storage and sequestration are crucial components in mitigating climate change by regulating the concentration of carbon dioxide in the atmosphere [1] . Crucially, watersheds serve as integral components of the global carbon cycle, which describes the movement of carbon through the Earth's atmosphere, oceans, land, and living organisms. The watershed contributes to carbon dynamics by being a place for carbon sequestration, storing, releasing, and influenced by both natural processes and human activities. Watersheds, such as the Taguibo Watershed located in Butuan City, Philippines, play a vital role in this process. It hosts diverse ecosystems, including forests, palm areas, and agricultural lands, contributing significantly to its carbon storage and sequestration potential. However, the watershed faces numerous challenges, including illegal logging activities and land conversion, which diminish its carbon storage capacity. Rapid land use and land cover changes, deforestation, urbanization, and agricultural expansion within the watersheds can alter carbon stocks, affecting the balance between carbon storage and emissions threaten the integrity of these ecosystems, leading to carbon emissions [2].

Previous studies, utilizing advanced modeling techniques such as the InVEST Model, have emphasized the impact of land use changes on carbon storage in various regions worldwide [3]. However, there remains insufficient understanding of the extent of carbon storage within the Taguibo Watershed and its evolving dynamics. Additionally, the potential economic benefits derived from carbon sequestration efforts in this region remain largely unexplored. The lack of awareness among local communities about these opportunities hampers the adoption of sustainable practices, contributing to environmental degradation and further jeopardizing the watershed's carbon storage capacity and resilience to climate change impacts.

Therefore, this study aims to address these knowledge gaps by evaluating the present status and future projections of carbon storage and sequestration in the Taguibo Watershed, employing GIS technology and the InVEST Model, and validating the findings through field-based methods. Through an extensive examination of land use and land cover changes, combined with carbon dynamics modeling, this research seeks to offer insights into the spatial distribution, volume, and economic implications of carbon sequestration activities within the watershed. Additionally, this study aims to carry out field-based validation methods focused on verifying the carbon storage estimates generated by the model.

2. MATERIALS AND METHODS

The study involves collection of primary and secondary data and field survey to evaluate carbon storage and sequestration in the Taguibo Watershed, Butuan City, leveraging GIS technology and the InVEST Model.

2.1 Data collection

The study integrates primary and secondary data to comprehensively analyze carbon storage and sequestration dynamics in the Taguibo Watershed. Secondary data, including image classification maps from CSU-CreATe and USGS Earth Explorer, establish contextual frameworks and land cover patterns. Additionally, secondary data comprises carbon pool values and economic valuation from various studies, following InVEST Model guidelines. Aboveground biomass values for Philippine forests are based on GIS estimates [4], while regional soil carbon estimates are from the 2006 IPCC report [5]. Dead organic matter values for forests and agricultural land are from a study in Mount Makiling Forest Reserve, Laguna, Philippines [6]. Carbon pool values for agricultural land LULC class are derived from the RACSA Implementation in Wahig-Inabanga Watershed, Bohol, Philippines [7]. Palms' carbon pool values are from a study in Uva province, Sri Lanka, titled "Modeling predictive assessment of carbon storage using InVEST Model" [8] due to a lack of Philippine data.The data collected from these references can be adopted as these areas belongs to tropical regions same with the study area.

2.2 Land cover generation

Landsat 8 OLI images, with a spatial resolution of 30m x 30m, covering paths 112 and row 53 for 2013 and 2015, were downloaded from the USGS Earth Explorer website for image processing. Pre-processing of satellite data was required due to potential errors. A supervised SVM classifier in ArcGIS 10.8 was used for base LULC mapping, delineating vegetative (agricultural land, palm, forest), non-vegetative (settlement areas), bare soil, and water bodies. Training and validation points were selected based on 2013 land cover classification schemes, verified through ground validation. Manual adjustments were made to align with expected satellite imagery capacity, enhancing overall map accuracy. For the Taguibo Watershed, covering approximately 57.3489 km^2, a minimum of 50 random points per class was chosen. A confusion matrix tracked pixel count for different land cover combinations, ensuring classification accuracy met a reliability threshold typically set at over 85%. A nonparametric Kappa coefficient method assessed accuracy. Additionally, the study integrated the MOLUSCE module to enhance predictive capabilities by evaluating various LULC types. The model aimed to predict LULC for 2033, calibrated and validated using simulated data for 2023, with LULC raster datasets from 2013 and 2015.

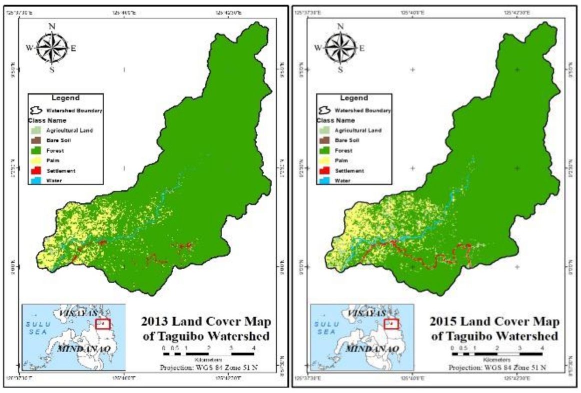

Fig. 1. Generated Map of Taguibo Watershed Land Cover Map for the years: (a) 2013, and (b) 2015

2.3 Application of InVEST model carbon storage and sequestration.

The study utilized the InVEST carbon storage and sequestration model to estimate carbon storage, sequestration, and economic carbon rate for 2023 and 2033 in the Taguibo Watershed. This model tracks the carbon cycle, summing carbon pool values for each Land Use and Land Cover (LULC) type [9] [10]. The carbon density for each LULC type is determined by the model, as depicted in the following equation.

$$C_i = C_{i(above)} + C_{i(below)} + C_{i(soil)} + C_{i(dead)} \qquad (1)$$

Where C_i - the carbon density of each LULC type, $C_{i(above)}$ - the carbon density of aboveground biomass in the ith LULC type (tons/ha), $C_{i(below)}$ - the carbon density of belowground biomass in the ith LULC type (tons/ ha), $C_{i(soil)}$ - the carbon density of soil organic matter in the ith LULC type (tons/ha), $C_{i(dead)}$ - the carbon density of dead organic matter in the ith LULC type (tons/ha).

The model software calculates the total carbon storage for the study area through the following equation:

$$C_t = \sum_n^i C_i + A_i \qquad (2)$$

Where C_t - the total carbon storage in the study area (tons), n - the number of LULC types in the study area, A_i - the area of each LULC types (ha).

2.3.1 Eeconomic valuation of the model

The model's economic valuation focuses on carbon sequestration rather than storage, accounting for carbon prices primarily related to sequestration. It estimates the economic value based on three parameters: social price of carbon, annual market discount rate, and annual rate of change in carbon price. Inflation rates from 2013 to 2033 are also considered for each scenario. Model outputs are in metric tons of carbon per pixel, with an option to include sequestration value in currency units per pixel. The formula for calculating the value of carbon sequestration over time for a given parcel x

$$value\_seq_x = V \frac{s_x}{q-p} \sum_{t=0}^{q-p-1} \frac{1}{(1+\frac{r}{100})^t(1+\frac{c}{100})^t} \qquad (3)$$

Where V = price per metric ton of carbon, s_x = amount of carbon, in metric tons, sequestered on parcel x, q = future year, p = current year, r = yearly market discount rate for the carbon price, c = yearly rate of change in the price of carbon.

2.3.2 Vvalidation of carbon storage results

The carbon storage results from the INVEST model were validated using the relative error (RE) method [11] [12]. Their studies confirmed that the simulated carbon storage by the InVEST Model adequately represents the actual carbon storage in the study area. This is denoted as:

$$RE = \frac{Rs - Ra}{Ra} \times 100 \qquad (4)$$

Where RE = Relative Error, Rs = the simulated results by the InVEST Model, Ra = results from another independent source, in this case, the results obtained from the manual or actual carbon storage estimation which utilized the biomass and carbon conversion equations.

2.3.3 Non-destructive method

In the study, researchers used non-destructive methods, employing allometric biomass equations to estimate aboveground and belowground biomass [13] . However, logistical constraints, such as limited resources and technical difficulties, prevented consideration of soil organic and dead organic biomass. Accessing the upper watershed for validation was challenging due to permissions required from the tribal group in Brgy. Anticala, and financial constraints hindered manual validation due to the necessity of bringing offerings and gifts to residents.

2.3.4 Carbon storage validation

Site selection involves careful consideration of geographical features, accessibility, and representativeness to align with research objectives. The methodology integrates random and systematic sampling techniques, ensuring the chosen site accurately reflects the broader study area, enhancing validity and reliability.

2.3.4.1 Allometric biomass equations

Specific allometric equations were used for estimating Above Ground Biomass (AGB) for different tree species. For Coconut palm trees, equations were derived from [11] and for Mahogany, equations were adapted from [12]. For tree species lacking species-specific equations, the recommended model [13] was utilized, known for its suitability across various forest types and bioclimatic conditions for DBH values ranging from 5 to 156 cm.

Coconut Palm trees:

$$AGB\,(kg) = 4.5 + 7.7 \times H \quad (5)$$

Mahogany trees:

$$AGB\,(kg) = 0.11 \times (\rho \times D^{2.62}) \quad (6)$$

Other tree species:

$$AGB\,(kg) = 0.0673 \times (\rho \times D^2 \times H)^{0.967} \quad (7)$$

Where AGB = estimated tree above ground biomass in (kg), ρ = wood specific gravity in (g cm– 3), D = tree trunk diameter at breast height (m), H = total tree height (m).

Estimating belowground biomass (BGB) presents challenges due to its labor-intensive nature. Indirect estimation methods, using equations based on aboveground biomass, are commonly employed. Equations provided by [8] and [9] were used.

For Broadleaf Vegetation:

$$BGB\,(kg) = AGB\,(kg) \times 0.30 \quad (8)$$

For Coniferous Vegetation:

$$BGB\,(kg) = AGB\,(kg) \times 0.25 \quad (9)$$

For Tree Species not fitting any categories:

$$BGB = AGB \times 0.2 \quad (10)$$

Where BGB = below ground biomass (kg), AGB = aboveground biomass (kg) 0.25, 0.30, and 0.20 = conversion factor (or 25%, 30% or 20% of AGB).

Total tree biomass (TTB) was standardized to a per-hectare basis by dividing the cumulative sum of tree biomass in megagrams (Mg) by the total area in hectares.

$$TTB\,(kg) = AGB\,(kg) + BGB\,(kg) \quad (11)$$

The carbon content of biomass in the Philippines is estimated at approximately 45%, following recommendations from previous studies.

$$TCS\,(Mg\,C/ha) = TBD\,(Mg/ha) \times 0.45\,C \quad (12)$$

The manual value for the 1-hectare sampled validation plot was compared with values derived from the InVEST carbon storage outcomes for the same plot. Using Geotag coordinates, the validation plot was constructed as a polygon in Google Earth Engine, then saved as a Kmz file and imported into ArcGIS. After adding the Total Carbon Storage raster for 2023 to the plot, values were analyzed using the Spatial Analyst Tool - Zonal Statistics as Table, summarizing raster values within the zones of another dataset and reporting results to a table.

Table 1. Values of Wood Specific Gravity of Different Trees

Tree Species		Wood Specific Gravity (g/cm^{-3})
Common Name	Scientific Name	
Coconut palm	*Cocos nucifera*	0.50 [a]
Falcata	*Parserianthes falcataria*	0.30 [b] , 0.25 [a]
Ipil-ipil	*Nephelium lappaceum*	0.64 [a] , 0.84 [b]
Lanzones	*Lansium domesticum*	0.70 [b]
Mahogany	*Swietenia macrophylla*	0.54 [b]
Rambutan	*Nephelium lappaceum*	0.71 [b]

Source: (a) Appendix 1- List of wood densities for tree species. (n.d.)., (b) World Species. (n.d.).

3. RESULTS AND DISCUSSION

In this chapter, the research findings and discussions are presented, divided into four main sections: (1) Generating Land Use and Land Cover (LULC) Maps for 2023 and predicting 2033, (2) Estimating the volume of carbon storage in the Taguibo Watershed at different time points, (3) Assessing the economic value of carbon sequestered, and (4) Validating the calculated carbon storage.

3.1 Land Use and Land Cover Maps prediction

Utilizing Landsat 8 imagery (30m resolution) and a supervised SVM classifier, a land cover map for the Taguibo Watershed in 2023 was generated (Figure 2). Six classes (Agricultural Land, Bare Soil, Forest, Palm, Settlement, Water) covering 5,734.89 ha were identified. A change simulation model, based on 2013 and 2015 data, predicts future land cover patterns iteratively. The 2023 Land Use and Land Cover Map achieved 91.51% overall accuracy and a kappa coefficient of 0.89. Validation of the predicted 2033 map showed an 80.48% overall accuracy and a kappa of 0.75, indicating a statistically significant agreement with ground truth, acceptable for land cover assessments.

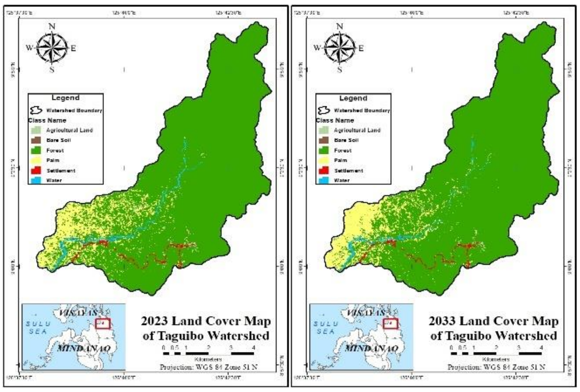

Fig. 2. Generated Map of Taguibo Watershed Land Cover Map for the years: (a) 2023, and (b) 2033

3.1.1. LULC change analysis in Taguibo Watershed

Shown in the figure below is a transformation in specific areas, likely indicating transitions between different land cover types.

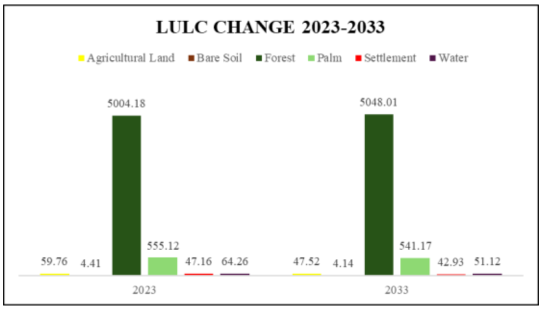

Fig. 3. LULC Classes Area changes in Hectares (2023 and 2033)

Over the years, agricultural land in the Taguibo Watershed decreased from 59.76 hectares in 2023 to 47.52 hectares in 2033, attributed to forest clearing for farming. Similarly, bare soil coverage decreased from 4.41 hectares in 2023 to 4.14 hectares in 2033, contrasting with a previous increase reported by [14]. Forest cover expanded from 5,004.18 hectares in 2023 to 5,048.01 hectares in 2033, aligning with Bermoy [15] (2023)'s projections.
Palm cultivation, covering 555.12 hectares in 2023 and 541.17 hectares in 2033, reflects its significance, as noted by [16]. Settlement cover remained stable, ranging from 47.16 hectares in 2023 to 42.93 hectares in 2033, mirroring urban expansion trends observed elsewhere. Water bodies decreased from 64.26 hectares in 2023 to 51.12 hectares in 2033, possibly due to shifts in rainfall patterns or water management strategies. Historical logging activities in the 1960s continue to influence the watershed's landscape, underscoring the importance of understanding past and present factors driving land cover changes for effective conservation strategies.

3.2 Total carbon storage in Taguibo Watershed at different years

The upstream regions of the watershed exhibit significantly higher carbon storage due to dense forest cover, which has a greater capacity for carbon sequestration through photosynthesis [17]. This aligns with global research showing that natural forests have higher carbon storage capacity compared to other land cover types [18] . In contrast, downstream areas feature palm plantations, settlements, water bodies, bare soil, and agricultural land, collectively contributing to lower carbon storage levels [19].
While palm plantations contribute to total carbon storage, they do not match the capacity of forests due to limited tree species diversity [20]. Agricultural land's contribution depends on crops planted, with corn and rice having limited carbon storage capacity in the Taguibo Watershed [21]. Bare soil, settlements, and water bodies have negligible carbon storage due to lack of vegetation [22] and urban infrastructure , emitting CO2 and methane. Studies consistently show zero carbon capacity for these land classes.

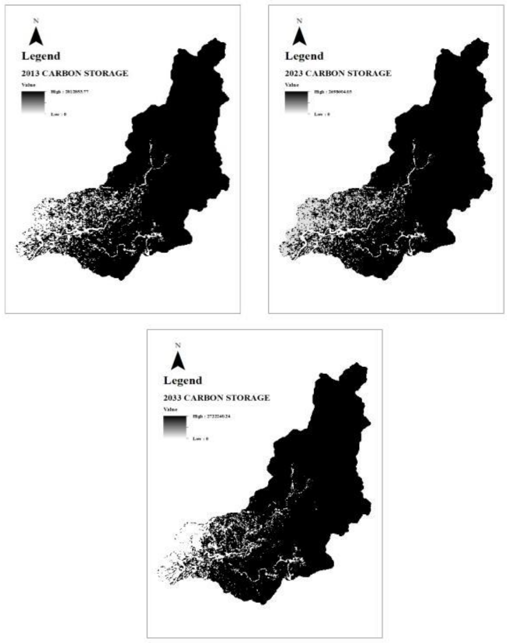

Fig. 4. Carbon Storage Maps of the Taguibo Watershed from 2013-2033

Table 2. Total Carbon Stored in Different LULC Class at Different Years

LULC Class	Total Carbon Storage (in Mg C)		
	2013	2023	2033
Agricultural Land	329.18	567.72	451.44
Bare Soil	0	0	0
Forest	2812853.77	2698604.03	2722240.24
Palm	27255.15	36082.80	35176.05
Settlement	0	0	0
Water	0	0	0
TOTAL	2840438.10	2735254.56	2757867.73

3.2.1 Change in the Total Carbon Storage: Loss or Gain (Sequestered)

The carbon dynamics in the Taguibo watershed reveal fluctuations across different land use and land cover (LULC) types over time. Remarkably, there was a significant carbon loss of -105,183.54 Mg from 2013 to 2023, indicating complex interactions among environmental factors like deforestation and land use changes. Forests have consistently been the primary carbon sink, accounting for over 90% of the total carbon stock from 2013 to 2033, despite a marginal decrease from 2,812,853.77 Mg in 2013 to 2,698,604.03 Mg in 2023. This decline is attributed to factors like deforestation and land use alterations. Notably, forest coverage decreased rapidly from 5,216.04 hectares in 2013 to 5,048.01 hectares in 2023 due to various land use changes.

Illegal logging and mining activities have further exacerbated environmental degradation in the watershed. Instances of illegal logging date back to 2008, with ongoing reports indicating persistent challenges in safeguarding forested areas. Additionally, illegal mining, particularly manganese mining, has been reported since 2005, leading to habitat loss and disruption of ecosystem services. Destructive practices like kaingin farming, small-scale mining, and quarrying operations release stored carbon and contribute to greenhouse gas emissions, exacerbating climate change. Addressing these activities through stricter regulations and sustainable land use practices is crucial for mitigating climate change impacts and conserving biodiversity in the region.

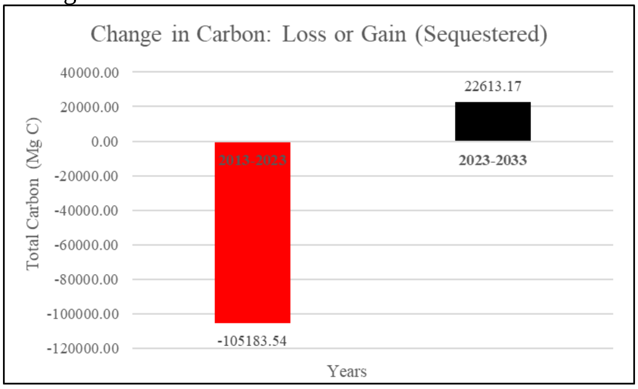

Fig. 5. Change in the Total Carbon Storage in Taguibo Watershed

3.2.2 Total Carbon Sequested

Between 2023 and 2033, carbon sequestration in the Taguibo Watershed increased by 22,613.17 Mg of C, suggesting improved land management or conservation efforts. The slight rise in forest cover from 2023 to 2033 likely contributed to this trend. This surge is attributed to the agro-forestry reforestation project, a collaboration between various organizations from 2011 to 2020. Significant reforestation efforts occurred in multiple locations, enhancing the watershed's carbon sequestration capabilities. Spearheaded by the Butuan City government, these initiatives have fostered thriving forest ecosystems, mitigating carbon emissions and bolstering ecosystem resilience. Overall, these proactive endeavors showcase effective environmental stewardship, reinstating nature's balance and enhancing the region's capacity to combat climate change.

3.3 Economic valuation of carbon sequestration

The cost-benefit analysis shows a negative net present value (NPV) of carbon sequestration from 2013 to 2023, amounting to approximately -US$4,812,755.34 or -Php277,722,453.27. This indicates an economic loss from carbon sequestration initiatives. Despite starting in 2013, the large-scale project in the Taguibo Watershed faced challenges, including severe storms damaging newly planted trees in 2015, resource constraints, land use conflicts, and limited community engagement, hampering project effectiveness.

In contrast, from 2023 to 2033, carbon sequestration in the Taguibo Watershed shows a positive net present value (NPV) of US $1,149,648.30 or Php 66,311,713.94, indicating economic viability. This contrasts with the 2013-2023 period where costs exceeded benefits. In 2023, the Butuan City government launched a successful carbon sequestration project, planting trees, improving land management, and restoring ecosystems. The project led to increased carbon sequestration, better ecosystem services, and economic benefits, demonstrating the importance of project efficiency and time horizon in determining economic feasibility.

Table 3. Estimated Net Present Value of Carbon Sequestered from 2023-2033

Scenario	Net present value (US$)	Net present value (Php)
2013-2023	-4812755.34	-277,722,453.27
2023-2033	1149648.30	66,311,713.94

3.4 Validating carbon storage

The study aimed to validate the InVEST Model's Carbon Storage outcomes in the Taguibo watershed. It found 195 tree species contributing to carbon storage in a 1-hectare plot, with biomass values converted using a 45% conversion factor. Each tree species has a unique capacity for carbon storage influenced by factors like size and growth rate. This research compared InVEST Model outcomes with manual measurements, aiding understanding of carbon storage dynamics.

Table 4. Comparison of Manual and Model Carbon Storage in 1-hectare sampled plot within Taguibo Watershed

Carbon Storage from Different Pools	Manual Estimation (Mg C/ha)	InVEST Model Estimation (Mg C/ha)
Aboveground Carbon Storage	38.12	32.00
Belowground Carbon Storage	7.91	11.84
Dead Organic Carbon Storage	---	0.17
Soil Organic Carbon Storage	---	4.53
Total Carbon Storage:	46.03	48.54

Table 4 highlights a significant difference in carbon storage estimates for a 1-hectare sample plot in the watershed (see Figure 33). Manual validation yielded 46.03 Mg C/ha, while the InVEST Model projected a higher value of 48.54 Mg C/ha. This variation stems from methodological differences. The InVEST Model offers a comprehensive assessment, considering all four carbon pools: aboveground biomass (32.00 Mg C/ha), belowground biomass (11.84 Mg C/ha), dead organic carbon (0.14 Mg C/ha), and soil organic carbon (3.59 Mg C/ha). Conversely, the manual validation method was limited to aboveground (38.12 Mg C/ha) and belowground biomass (7.91 Mg C/ha) due to non-destructive techniques. Disparities also exist within specific carbon pools. The manual method underestimates aboveground and belowground carbon storage by 6.12 Mg C/ha and 3.93 Mg C/ha, respectively, compared to the InVEST Model.

3.5 MODEL VALIDATION

The study assessed the InVEST carbon storage model by comparing its predictions with observed values. Results showed a strong linear relationship ($y = 1.0556x - 1.8145$, $R^2 = 0.930$, $p = 0.171$, RMSE = 4.36), indicating that 93% of observed carbon storage variance is explained by the model. The small RMSE of 4.36 Mg C suggests reliable predictions, despite the non-significant p-value. The slope of 1.0556 indicates proportional predictions, while the intercept of -1.8145 suggests slight underestimation. These findings affirm the model's reliability but suggest room for enhancement.

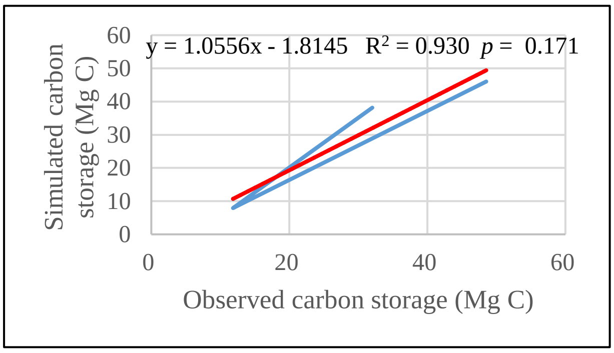

Fig. 6. Model Validation

4. CONCLUSION

This study explored the influence of land use changes on the Taguibo Watershed's capacity for carbon storage and sequestration in Butuan City, Philippines. The research employed Geographic Information Systems (GIS) technology and the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) Model to analyze this relationship. The findings demonstrated a dynamic link between how the land is used and how much carbon the watershed can store. In other words, the ability of the watershed to store carbon fluctuates depending on land use activities, particularly deforestation and agricultural expansion.

5. REFERENCES

[1] Friedlingstein, P., O'Sullivan, M., Jones, M.W., Andrew, R.M., Zaehle, S., (2020). Global Carbon Budget 2020. Earth Syst. Sci. Data 12, 3269–3340

[2] Nabuurs, G.J., O. Masera, K. Andrasko, P. Benitez–Ponce, R. Boer, M. Dutschke, E. Elsiddig, J. Ford–Robertson, P. Frumhoff, T. Karjalainen, O. Krankina, W.A. Kurz, M. Matsumoto, W. Oyhantcabal, N.H. Ravindranath, M.J. Sanz Sanchez, & X. Zhang. 2007. Forestry. In B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (Eds.). Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

[3] He, C., Zhang, D., Huang, Q., Zhao, Y. (2016). Assessing the potential impacts of urban expansion on regional carbon storage by linking the LUSD-urban and invest models. Environmental Modelling & Software 75: 44-58.

[4] Macandog, D. M., Delgado, M. E. M., Ty, E., Villarin, J. R. T. (2006). A GIS-based model to improve estimation of aboveground biomass of secondary forests in the Philippines. Journal of Tropical Forest Science 18(1): 8–21..

[5] Lasco, R. D., Guillermo, I. Q., Cruz, R. V. O., Bantayan, N. C., Pulhin, F. B. (2004). Carbon Stocks Assessment of a Secondary Forest in Mount Makiling Forest Reserve, Philippines. Journal of Tropical Forest Science 16(1): 35–45.

[6] Reyes, JR. T. D., Ludevese, E. G. (2015). Rapid Carbon Stock Appraisal (RACSA) Implementation in Wahig-Inabanga Watershed, Bohol, Philippines. International Journal of Environmental and Rural Development 6(2): 102–109.

[7] Piyathilake, Udara & Udayakumara, E.P.N. & Ranaweera, Lalindra Vishwajith & Gunatilake, Sunethra. (2022). Modeling predictive assessment of carbon storage using InVEST model in Uva province, Sri Lanka. Modeling Earth Systems and Environment. 8. 1-11. https://doi.org/10.1007/s40808-021-01207-3.

[8] Sharp, R., Tallis, H. T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D. W. S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D. A. K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C. K., Guannel, G., Papenfus, M., Toft, J., Marsik, M. B. J., Grifn, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M., Mandle, L., Hamel, P., Vogl, A. L. R. L., Bierbower, W., Denu, D., Douglass, J. (2018). InVEST 3.7.0. user's guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

[9] IPCC [Intergovernmental Panel on Climate Change]. (2005). Special report on carbon dioxide capture and storage. Cambridge University Press, U. K.

[10] Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M., Troxler, T. (2014). 2013 supplement to the 2006 IPCC guidelines for national greenhouse gas inventories. Wetlands IPCC, Switzerland.

[11] Shen, Q., Chen, Q., Tang, B. S., Yeung, S., Hu, Y., Cheung, G. (2009). A system dynamics model for the sustainable land use planning and development. Habitat Int. 33 (1):15-25.

[12] Maanan, Mohamed., Karim, M., Kacem, Hicham., Soukaina, Ajrhough., Rueff, Henri., Snoussi, Maria., Rhinane, Hassan. (2019). International Journal of Sustainable Development & World Ecology Modelling the potential impacts of land use/cover change on terrestrial carbon stocks in north-west Morocco

Modelling the potential impacts of land use/cover change on terrestrial carbon stocks in north-west Morocco. The International Journal of Sustainable Development and World Ecology. 26. https://doi.org/10.1080/13504509.2019.1633706.

[13] Petersson, H., Holm, S., Ståhl, G., Alger, D., Fridman, J., Lehtonen, A. (2012). Individual tree biomass equations or biomass expansion factors for assessment of carbon stock changes in living biomass – a comparative study. For. Ecol. Manage.270, 78–84..

[14] Ugay, F. M. L., Santillan, J. R., & Makinano-Santillan, M. (2017). Sediment yield assessment of taguibo watershed using remote sensing image analysis and gis-based hydrologic modeling techniques. Wordpress.com. Retrieved May 15, 2024, from https://scitech4dev2017.wordpress.com/wp-content/uploads/2017/06/sample_full_paper.pdf.

[15] Bermoy, Monalaine & Cacayan, V. & Carido, J. & Apdohan, Arnold & Cacayan, Antonietto Jr. (2023). PREDICTION OF FUTURE LAND USE LAND COVER (LULC) AND ASSESSMENT OF ITS IMPACT ON THE WATER SUPPLY AVAILABILITY OF BUTUAN CITY-TAGUIBO RIVER WATERSHED AND FOREST RESERVE (TRWFR), PHILIPPINES. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XLVIII-4/W6-2022. 81-86. Researchgate.net. https://doi.org/10.5194/isprs-archives-XLVIII-4-W6-2022-81-2023.

[16] Smith, L. M., Sohl, T. L., & Vina, A. (2019). Dynamics of land-use and land-cover change in the United States: A synthesis. Journal of Land Use Science, 14(1), 1-24.

[17] Hayes, D.J.; Turner, D.P., Stinson, G., McGuire, A.D., Wei, Y., West, T.O., Heath, L.S., De Jong, B., McConkey, B.G., Birdsey, R.A. (2012). Reconciling estimates of the contemporary North American carbon balance among terrestrial biosphere models, atmospheric inversions, and a new approach for estimating net ecosystem exchange from inventory-based data. Glob. Change Biol. 18, 1282–1299.

[18] Castellano, G. R., Santos, L. A., & Menegário, A. A. (2022). Carbon soil storage and technologies to increase soil carbon stocks in the South American Savanna. Sustainability, 14(9), 5571. https://doi.org/10.3390/su14095571.

[19] Crämer, Bondeau, Schaphoff, Lucht, Smith, Sitch. (2004). Tropical forests and the global carbon cycle: impacts of atmospheric carbon dioxide, climate change and rate of deforestation. Retrieved from https://doi.org/10.1098/rstb.2003.1428.

[20] Udara, K. B. K., Senaratne, S., & Vithanage, M. (2021). Effects of land-use changes on soil organic carbon stocks in a tropical watershed. Journal of Soils and Sediments, 21, 1379-1388.

[21] Buraka, T., Elias, E., & Lelago, A. (2022). Soil organic carbon and its' stock potential in different land-use types along slope position in Coka watershed, Southern Ethiopia. Heliyon, 8(8), e10261. https://doi.org/10.1016/j.heliyon.2022.e10261.

[22] Yan, Y., Kuang, W., Zhang, C., & Chen, C. (2015). Impacts of impervious surface expansion on soil organic carbon – a spatially explicit study. Scientific Reports, 5(1). https://doi.org/10.1038/srep17905.

[23] Rensselaer Polytechnic Institute (RPI). (2015, September 3). Role of freshwater lakes, reservoirs in the global carbon cycle. Science Daily.https://www.sciencedaily.com/releases/2015/0 9/150903160644.htm.

[24]. Valmoria, A., Bala, LV., Orag,M., Suitability Mapping for White-fleshed (Hylocereus undatus) and Red-fleshed (Hylocereus costaricensis) Dragon fruit Farming in Butuan City Using Multi-Criteria Decision Analysis and GIS. Proceeding of International Exchange and Innovation Conference on Engineering & Sciences (IEICES) 9 (2023).

[25] Valmoria, A., Cejuela, CJ., Dagohoy ,R., GIS-Based Land Suitability Analysis for Adlai Grits (Coix Lacryma-Jobi L.) Cultivation in Agusan Del Sur Using Multi-Criteria DecisionMaking Approach – Analytical Hierarchy Process Technique. Proceeding of International Exchange and Innovation Conference on Engineering & Sciences (IEICES) 9 (2023).

.