ARTICLE

Land cover change and carbon loss: A case study of the Pagsanjan-Lumban and Baroro watersheds in Luzon, Philippines

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ABSTRACT

The unequivocal increase in global surface temperature underscores the urgency to take drastic actions to halt the continuous accumulation of greenhouse gases (GHGs) in the atmosphere. One of the top five sectors contributing to global GHG emissions is agriculture, forestry, and other land uses (AFOLU). Despite being a significant carbon source, the FOLU sector is also a substantial carbon sink. Like other tropical countries, the Philippines' FOLU sector, particularly the watersheds, has great potential to store significant amounts of carbon. However, these watersheds experience land cover change over time, affecting their carbon storage capacity. This paper analyzes the land cover change in the Pagsanjan-Lumban Watershed (PLW) and Baroro Watershed (BW) in the Philippines from 2000 to 2020, assesses the impact of these changes on the amount of carbon stored, estimates the economic value of carbon sequestration, and recommends measures to enhance the role of the two watersheds in climate change mitigation. Google Earth Engine was used to classify a collection of remotely sensed optical and radar-derived terrain rasters into land use and land cover (LULC) maps, while Integrated Valuation and Ecosystem Services and Tradeoffs (InVEST) software estimated the carbon stocks of the watersheds. In addition, the social cost of carbon (SCC) was employed to provide economic insights into future climate change impacts of current carbon emissions. Results revealed that the total estimated carbon stocks in 2020 in the PLW and BW are 6.41MtC and 2.01 MtC, respectively. An overall decline in carbon sequestration in both watersheds was observed over the two-decade period, and it was primarily due to forest cover reduction for urban and agricultural expansion. PLW exhibited an overall economic benefit, while BW faced economic costs associated with land cover changes. These findings highlight the influence of watershed management on carbon storage capacity; hence, developing site-specific strategies through appropriate management measures and interventions is critical to increasing or at least recovering its former carbon stock potential. The research output can be an effective additional input in spatial planning and decision-making in the study sites.

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KEYWORDS

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INTRODUCTION

The global surface temperature is increasing through time. Global surface temperatures for the period 2001 – 2020 and 2011 – 2020 were observed to be higher than the period 1850 – 1900 by 0.99°C and 1.09°C, respectively (IPCC 2023). The 1.0°C increase in temperature was reached in 2017 and is currently on track to increase by 1.5°C between 2030 and 2050 at a current warming rate of 0.2°C per decade (IPCC 2018). Unless drastic actions are carried out to halt the continuous accumulation of greenhouse gases (GHGs) in the atmosphere, global surface temperature will continue to increase.

Among the top five sectors contributing to global GHG emissions, including energy systems, industry, buildings, and transport, is the agriculture, forestry, and other land uses (AFOLU) sector (Ritchie et al. 2020). Of these sectors, energy contributed the largest (34% or 20 GtCO2e), while buildings contributed the least (6% or 3.3 GtCO2e). The industry contributes 24%, or 14 GtCO2e, while AFOLU's and transport's shares are 22% or 13 GtCO2e and 15% or 8.7 GtCO2e, respectively.

In the Philippines, the FOLU sector emitted 0.045 GtCO2e during the inventory year 2020. This was primarily due to forest degradation and deforestation. High carbon density land covers such as closed and open forests are converted into low carbon density land covers such as grassland, brush/shrubland, or agriculture (FMB 2023). Deforestation in the Philippines is caused by several natural (e.g., typhoons and landslides) and anthropogenic drivers (e.g., kaingin or slash-and-burn farming, mining, road construction, conversion into settlements, and other built-up areas, legal and illegal logging, charcoal making, and timber poaching) (Carandang et al. 2013).

While the FOLU sector is a significant carbon source, it is worth noting that it is also a significant sink of carbon. Each year, FOLU sequesters 112 – 169 PgC (Sha et al. 2022), sequestering about 15% of the carbon emissions caused by human activities (Rammig and Lapola 2021). Forests store carbon in different reservoirs, including trees, understorey, roots, litter, dead wood, and soil (Haraiah et al. 2010).

Notably, the FOLU sector in the Philippines, much like its counterparts in other tropical countries, holds immense potential for carbon storage. Based on the 2020 GHG inventory for the FOLU sector of the Philippines, about 0.071 GtCO2e was sequestered (FMB 2023). One of the key carbon reservoirs in the Philippines is watersheds, which comprise around 90% (14.22Mha) of the country's total classified forestlands (FMB 2021). However, these watersheds experienced land cover change over time, affecting their capacity to store carbon. Globally, recent studies (e.g., Sarathchandra et al., 2021; Liu et al. 2021; Fernandes et al. 2021; Liu et al. 2022; Xu et al. 2023) assessed the intricate relationship between land cover change and carbon stocks in various landscapes. In the Philippines, however, studies by Lasco et al. 1999; Lasco et al. 2000; Lasco and Pulhin, 2006; Lasco et al. 2007; Racelis et al. 2008; Racelis et al. 2019 are limited to a specific land cover or ecosystem (i.e. forest) or carbon pool component (e.g., soil carbon, biomass). Therefore, this study addresses the gap in exploring the effect of land cover change on how much carbon these ecosystems can store in Philippine watersheds.

This paper analyzes the land cover change in the Pagsanjan-Lumban and Baroro watersheds in the Philippines over the last two decades, from 2000 to 2020. It assesses the impact of these changes on the amount of carbon stored in the watersheds and estimates the economic value of carbon sequestration in the study areas. The paper also recommends measures to enhance the role of the two watersheds in climate change mitigation.

MATERIALS AND METHODS

Study Area

The selected study sites were the Baroro Watershed (BW) in La Union province and the Pagsanjan-Lumban Watershed (PLW) in portions of Laguna and Quezon provinces (Figure 1).

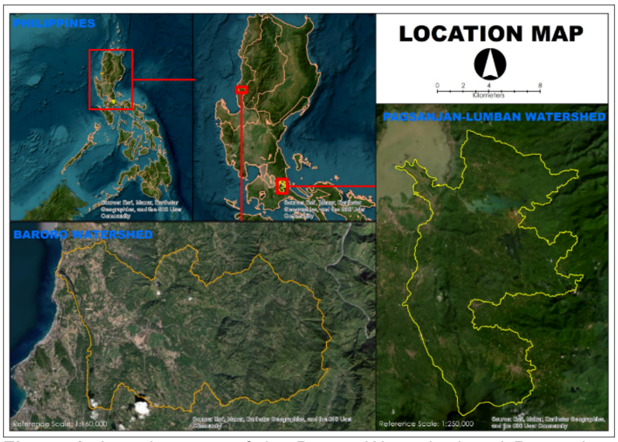

Figure 1: Location map of the Baroro Watershed and Pagsanjan-Lumban Watershed, Philippines

The BW is in the northeastern part of the La Union province. It covers the municipalities of Bacnotan, Bagulin, San Gabriel, San Juan, Santol, and the city of San Fernando, with approximately 19,407.40 ha of total area. It comprises flat to rolling hills and steep mountains with elevations ranging from 0 to 1,415 masl. The modified Corona Classification categorizes the watershed as Climate Type I, characterized by two distinct seasons (dry and wet). According to the DENR Region 1 (2019), the watershed is one of the main sources of irrigation and domestic water supply in the entire Ilocos region. Food, livelihood, and recreation are also some of the benefits of the watershed (Cruz 2014). In terms of farming practices, the Indigenous group of Kankanaey, the original settlers of the upper portion of the watershed, are still practicing rice terracing in the sloping areas, contributing significantly to the preservation of its water provisioning function, while commercial agriculture is the dominant practice for the rest of the watershed (Ramirez et al. 2022).

Eighty-three barangays, divided among six municipalities, are within the watershed. The municipality of San Juan has the most barangays within the watershed, with 31, followed by Bacnotan and San Gabriel, with 19 and 15, respectively. Based on the Philippine Statistics Authority (PSA) census data, it had a total population of 71,202 in 2010 and increased to 79,767 in 2020 with an annual growth rate of 1.14%. San Juan has the highest population among the six municipalities, with 19,406 in 2010 and 22,359 residents in 2020, accounting for 27.25% and 28.03% of the total population within the watershed, respectively. In contrast, Santol has the lowest population, with 3,004 residents in 2010 (4.22% of the total) and 3,537 residents in 2020 (4.43% of the total).

Conversely, the PLW is in the southeastern portion of the Laguna de Bay basin, surrounded on the east by Paete, Pangil, and Pakil watersheds, and on the west by Sta. Cruz watershed, north by the east Bay of Laguna Lake, and the south by Mt. Banahaw. It has an estimated area of 41,576.10 ha, composed primarily of eight municipalities, including Cavinti, Kalayaan, Luisiana, Lumban, Magdalena, Majayjay, and Pagsanjan in Laguna and Lucban in Quezon province.

The PLW has a relatively flat to rolling topography with an elevation ranging from 10 to 2,158 meters above sea level (masl). About 20% of the lake's freshwater inflow is discharged from the watershed (Hernandez 2006). The watershed is divided into two climate types, wherein Cavinti, Lumban, and Majayjay are characterized by a short or almost indistinct dry season and a pronounced maximum rainy during October to December, while municipalities around Magdalena exhibit two pronounced seasons, which are dry (November to April) and wet (May to October). The coconut-based agroforestry systems are the dominant production system in the watershed and are considered the primary source of livelihood and income for its inhabitants (Cruz et al. 2012). The watershed consists of 145 barangays within its eight primary municipalities. Majayjay has the highest number of barangays within the watershed, with 40, followed by Lucban and Cavinti, with 26 and 19, respectively. According to PSA census data, the watershed had a total population of 196,011 in 2010 and increased to 218,415 in 2020, with an annual growth rate of 1.09%. Lucban has the highest population, with 43,369 (22.13%) and 49,298 (22.57%) in 2010 and 2020, respectively. This was followed by Lumban with 28,490 (14.53%) and 31,242 (14.30%) and Pagsanjan with 27,562 (14.06%) and 30,182 (13.82%) in 2010 and 2020, respectively.

Land Use and Land Cover Mapping

Google Earth Engine was used to classify a collection of remotely sensed optical and radar-derived terrain rasters (Table 1) into land use and land cover (LULC) maps using random forest classifiers. Multiyear composites incorporated temporal variance and ensure cloudless mosaics for each study site.

Table 1: Sources, temporal range, and number of remotely sensed data used in the study

Image Collection	Composite Year	Years
Landsat5 Collection2 Level2 Tier1	2000	1998 - 2000
	2005	2004 - 2006
	2010	2009 - 2011
Landsat8 Collection2 Level2 Tier1	2015	2014 - 2015
	2020	2019 - 2020
ALOS GDSM (AW3D30) v3.2	All years (static)	None (Jan 2021 update was used)

Random forest was used since it tends to outperform other ensemble learning algorithms in multicategory classification, and it is also the most commonly used classifier for LULC mapping (Gaur and Singh 2023; Thanh et al. 2017). Multi-hyperparameter tuning ensured that the classifiers had optimal performance and a majority filter post-process was used to reduce noise caused by misclassified pixels. (He et al. 2018; Scornet 2017; Huang et al. 2014).

Ground control points (GCP) were gathered by sampling readily available secondary maps and verifying them with high-resolution satellite and aerial images from Google Earth. A series of participatory mapping activities with key informants and focus groups were also conducted with the municipal agricultural, environmental, and planning representatives, and representatives from regional government agencies. These were done to verify the secondary land cover data used for training and testing from August to September 2022.

An 80:20 hold-out validation was used to compute multiple accuracy metrics (Mitchell 2011; Verma et al. 2020). The resulting LULC maps showed > 92% overall accuracy (OA), cohen's kappa > 0.90, and F1-scores > 0.85.

Landsat images underwent reduction into 20th percentile, 50th percentile, and 80th percentile, rainy season, and dry season spectral band composites, which were then used to compute for composites of 10 spectral indices. The ALOS GDSM determined the topographic features of the site, particularly elevation, slope, and aspect. All of these methods resulted in 84 features and were used as input features for the classifiers (Table 2).

Table 2: Input features used for land cover classification

Input Features	No Reduction Composites	Reduction Composites				
		20th Percentile	50th Percentile	80th Percentile	Rainy Season	Dry Season
Blue		○	○	○	○	○
Green		○	○	○	○	○
Red		○	○	○	○	○
Near Infrared		○	○	○	○	○
Shortwave Infrared 1		○	○	○	○	○
Shortwave Infrared 2		○	○	○	○	○
Shortwave Albedo		○	○	○	○	○
Enhanced Vegetation Index		○	○	○	○	○
Two Band Enhanced Vegetation Index		○	○	○	○	○
Green Chlorophyll Index		○	○	○	○	○
Global Vegetation Moisture Index		○	○	○	○	○
Modified Bare Soil Index		○	○	○	○	○
Normalized Difference Built-up Index		○	○	○	○	○
Normalized Difference Vegetation Index		○	○	○	○	○
Normalized Difference Water Index		○	○	○	○	○
Soil Adjusted Vegetation Index		○	○	○	○	○
Elevation	○					
Slope	○					
Aspect	○					

Carbon Storage and Sequestration Modeling using InVEST

In estimating the carbon stocks of the study sites, InVEST software, particularly the carbon storage and sequestration model, was used. The total carbon stock was calculated by the model utilizing user-defined carbon pool values assigned for each land cover category (Sharp et al. 2020).

The total carbon stock (C_{total}) in the watersheds were computed as the sum of the product of the total carbon density for each LULC category i and its corresponding area (A_i), with n number of LULC types (Li et al. 2022).

$$C_{total} = \sum_{i=1}^{n}\left(C_{AGB_i} + C_{BGB_i} + C_{SOC_i} + C_{DOM_i}\right) \times A_i$$

Consequently, carbon sequestration is quantified simply as the difference in C_{total} between two time periods.
The values of carbon density used for the carbon pool of each LULC category were gathered and processed from various available literature and references (**Error! Reference source not found.**).

Table 3: Carbon density values (tC ha^{-1} yr^{-1}) assigned to the carbon pools of different LULC classes

Land Cover Category	Aboveground Biomass (C_{AGB})	Belowground Biomass (C_{BGB})	Soil organic cCarbon (C_{SOC})	Dead Organic Matter (C_{DOM})
Annual Crop	3.1 [a]	0	149.6 [j]	0.45 [c]
Brush/ Shrubs	29 [b]	10.73 [c] (based on reported root/shoot ratio)	35.57 [c]	2.92 [l]
Built-up	0	0	0	0
Closed Forest	306 [c]	137.7 [c] (based on reported root/shoot ratio)	109.43 [c]	40.43 [c]
Fishpond	0	0	0	0
Grassland	28.5 [b] 7.77 [a] 12.1 [b] 2.78 [d] **Ave = 12.79**	20.46 [c] (based on reported root/shoot ratio)	34.86 [k] 134.7 [j] **Ave = 84.78**	0.47 [d]
Inland Water	0	0	0	0
Open Forest	54 [c] 65.78 [e] **Ave =59.89**	19.98 [c] (based on reported root/shoot ratio)	109.43 [c]	40.43 [c]
Open/ Barren	0	0	0	0
Perennial Crop	35.22 [f] 66.62 84.3 [b] 43.6 [b] 113.4 [b] 115.23 [g] 43.81 [h] **Ave = 71.74**	0.28 [i] 8.93 [h] **Ave =4.605**	35.37 [g] 68.12 [i] 92.51 [h] 155.3 [j] **Ave =87.825**	0.99 [i] 9.4 [j] **Ave =5.195**

Valuation of Carbon Sequestered

The social cost of carbon (SCC) estimates the incremental global damage costs linked to the emission of an extra ton of carbon into the atmosphere (Watkiss et al. 2005). It serves as a method to quantify the impacts of climate change, assisting decision-makers in understanding the economic consequences of decisions that either increase or decrease emissions (Rennert and Kingdon 2019).

Error! Reference source not found. shows the Global SCC at two different discount rates representing the highest and lowest possible, limited to the options provided in Rennert & Kingdon's Explainer in 2019, economic cost/benefit associated with an additional CO_2 emission in the atmosphere. Understanding the options for high and low discount rates is crucial as they provide opposite policy options. A higher discount rate leans on short-term benefits, while a lower discount rate indicates greater consideration of long-term future impacts.

Table 4: Discount rates and their associated Global SCC values used in the valuation

Discount Rate	Global SCC (USD per ton CO_2, in 2019)
2.5%	75
7%	5

The model's valuation equation calculates the economic value of sequestration by considering factors such as the unit value of carbon, the discount rate, and the change in the value of carbon sequestration over time. Since the existing carbon prices are limited to carbon sequestration, the valuation of the carbon model only applies to sequestration rather than storage. The discount rate is set at 10% aligning with the Social Discount Rate for the Philippines, which was approved and confirmed by the Investment Coordination Committee (ICC) and the NEDA Board in 2016, respectively (NEDA 2016).

To value carbon sequestration, first, the carbon stock was converted into CO_2 equivalent. One molecule of carbon dioxide carries a weight that is 3.67 times greater than a carbon molecule due to the additional weight of the two oxygen atoms (Eggleston et al. 2006) using the equation below:

$$CO_2 - eq. = C \times 3.67$$

Then the present value of sequestration is computed using the following formula:

$$TPV\_seq_x = V \frac{seq_x}{yr_l - yr_e} \sum_{t=0}^{yr_l - yr_e - 1} \frac{1}{\left(1 + \frac{r}{100}\right)^t \left(1 + \frac{c}{100}\right)^t}$$

where:
V = price per metric ton of carbon
seq_x = total carbon sequestered over an x time period
yr_l = later year
yr_e = earlier year
r = discount rate
c = rate of change in the price of carbon

RESULTS AND DISCUSSION

Land Use and Land Cover Change Analysis

Table 5 and Table 6 summarize the land cover types and annual change rate from 2000-2020 with five-year intervals of the Baroro Watershed and Pagsanjan-Lumban Watershed, respectively.

Table 5: Land cover area and annual rate of change of the Baroro Watershed

LULC type	Area (ha)					Annual Change Rate (%)				
	2000	2005	2010	2015	2020	2000-2005	2005-2010	2010-2015	2015-2020	2000-2020
Open Forest	867.8	763.3	392.9	511.8	330.6	-2.5	-12.4	5.4	-8.4	-4.7
Shrubland	11,525.8	11,752.1	11,958.7	11,948.3	12,311.9	0.4	0.3	-0.02	0.6	0.3
Grassland	176.3	141.3	150.4	37.9	40.9	-4.3	1.3	-24.1	1.5	-7.1
Annual Crop	6,575.3	6,443.9	6,555.4	6,484.8	6,317.6	-0.4	0.3	-0.2	-0.5	-0.2
Fishponds	33.8	38.9	34.2	50.9	24.7	2.8	-2.6	8.4	-13.5	-1.6
Built	183.5	223.5	273.0	328.0	351.5	4.0	4.1	3.7	1.4	3.3
Bare	9.4	11.6	4.7	0.6	4.9	4.4	-16.7	-33.0	50.5	-3.2
Water	60.7	58.0	63.5	70.2	50.7	-0.9	1.9	2.0	-6.3	-0.9
TOTAL			19,432.5							

Table 6: Land cover area and annual rate of change of the Pagsanjan-Lumban Watershed

LULC type	Area (ha)					Annual Change Rate (%)				
	2000	2005	2010	2015	2020	2000-2005	2005-2010	2010-2015	2015-2020	2000-2020
Closed Forest	666.6	1,070.5	1,151.9	1,063.4	1,124.1	9.9	1.5	-1.6	1.1	2.7
Open Forest	4,598.1	4,101.6	5,190.2	4,245.4	4,954.8	-2.3	4.8	-3.9	3.1	0.4
Shrubland	6,715.1	5,776.0	7,304.0	8,946.0	8,598.1	-3.0	4.8	4.1	-0.8	1.2
Perennial Crop	20,886.6	22,120.4	19,758.6	18,631.7	18,235.2	1.2	-2.2	-1.2	-0.4	-0.7
Annual Crop	6,054.3	5,499.5	5,113.9	5,381.1	5,531.3	-1.9	-1.4	1.0	0.6	-0.5
Built	843.6	1,428.3	1,321.9	1,372.1	1,144.2	11.1	-1.5	0.8	-3.6	1.5
Bare	20.4	16.5	11.1	9.4	54.9	-4.2	-7.6	-3.3	42.5	5.1
TOTAL			41,604.9							

Baroro Watershed is dominated by shrublands and annual crops, accounting for 63% and 33% of the watershed, respectively (Figure 2). Annual crops, composed primarily of rice and vegetables, despite a net decrease of 3.62%, exhibited a roughly constant land area, showing its critical economic contribution to the watershed in particular and the province in general as a primary source of income and livelihood for the people. On the other hand, grassland had the largest net decrease of 76.82%, attributed to its conversion to shrublands and annual crops. Open forests experienced variations during the observation period. Specifically, its cover shrank from 867.78 ha to 330.57 ha, or a massive net decrease of 62%, which was primarily converted to shrublands. Among the LULC in the watershed, only the built-up area displayed continuous expansion, rendering a significant net increase of 91.52% from 2000 to 2020.

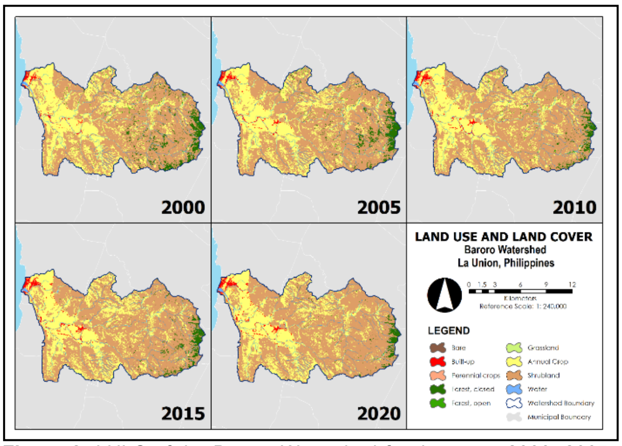

Figure 2: LULC of the Baroro Watershed for the years 2000, 2005, 2010, 2015, and 2020

Pagsanjan-Lumban Watershed, on the other hand, is predominantly composed of perennial crops (Figure 3). Coconut trees covered approximately 44% of the watershed. Closed and open forests experienced fluctuations during the observation period but still, exhibited a net annual increase of 2.65% and 0.374%, respectively. Notably, only the agriculture sector, particularly the perennial crop and annual crop areas, showed net decreases during the two-decade observation. The perennial crop was reduced by 2,651.40 ha (12.7%), while the annual crop diminished by 522.99 ha (8.6%). The largest gainers from perennial crop and annual crop losses were brushland and built areas. Brushland had a net increase of 1,882.98 ha (28%), while the built area expanded from 843.57 ha to 1,144.17 or a net increase of 35.6% from 2000 to 2020.

Both watersheds experienced widespread land use and land cover conversion in the last two decades. It was evident that forest cover decreased due to natural and mostly anthropogenic factors. Timber harvesting, agricultural expansion, rising market demand for agricultural production, urban growth, and population increase are some of the identified key drivers of deforestation in the Philippines (Geist and Lambin 2002; Pailagao et al. 2010; Keenan et al. 2015; Estoque et al. 2018; Shrestha et al. 2018; Encisa-Garcia et al. 2020). Moreover, upland migration aggravated by landlessness and limited livelihood opportunities in the lowlands is considered a fundamental reason for the degradation of watersheds (Ramirez et al. 2019). The reliance of the upland communities on extractive activities may be attributable to their socio-economic condition, with the upland area considered the home for the poorest of the poor (Cruz et al. 1988).

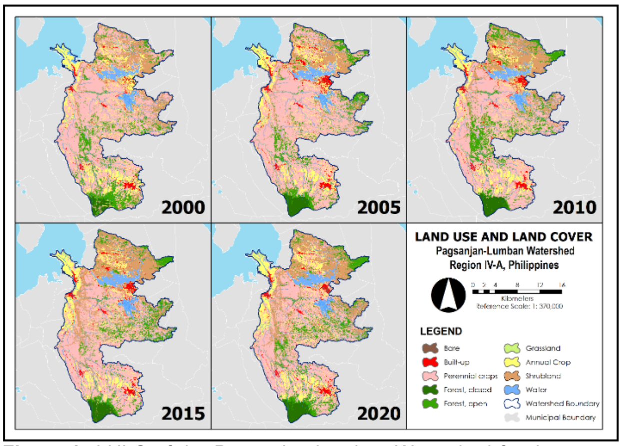

Figure 3: LULC of the Pagsanjan-Lumban Watershed for the years 2000, 2005, 2010, 2015, and 2020

Over the years, to arrest and amend the alarming rate of deforestation, numerous reforestation projects, and programs and policies for safeguarding forests, have been implemented (Harrison et al. 2004; Lasco et al. 2013; Estoque et al. 2018). In 2011, two landmark Executive Orders were issued in the Philippines, namely Executive Order No. 23 (Declaring a Moratorium on the Cutting and Harvesting of Timber in the Natural and Residual Forests and Creating the Anti-Illegal Logging Task Force) and Executive Order No. 26 (Declaring an Interdepartmental Convergence Initiative for a National Greening Program). In 2015, EO 26 was further expanded under Executive Order No. 193 (Expanding the Coverage of National Greening Program). Though minimal, the positive contribution of these programs, among other reforestation initiatives and efforts on the national and local levels, is apparent in both watersheds. Open forests in Baroro Watershed increased between 2010 and 2015 but decreased again between 2015 and 2020.

Similarly, although the increase in both closed and open forests in the entire Pagsanjan-Lumban Watershed was reflected later (from 2015 to 2020), areas within NGP sites in the watershed also exhibited the same trend wherein an increase was observed from 2010 to 2015 but declined from 2015 to 2020. The trend in both watersheds is similar to the findings of Perez et al. in 2020, where forest loss from 2011 to 2015 decreased while an increase from 2016 to 2018 within the NGP sites in Northern Luzon was observed. These findings highlight that the country's forest protection is program-driven and not sustainable.

In La Union, where Baroro Watershed is located, one of the main problems faced in implementing the reforestation program was the availability of areas to be developed. According to a key informant, forestlands in the province and several other provinces and regions in the Philippines (DENR Mimaropa 2022; Issuing tax declarations on timberlands unlawful: DENR 2019) are "tax-declared," indicating that these lands have claimants who usually cultivate the area for personal benefits. In light of this problem, DENR Memo No. 2018-214 was issued, prohibiting local government units from issuing certificates of real property tax declarations for forestlands to individuals. These regulations align with the provisions of PD 705 Section 84, which stipulates that a Certificate of Real Property Tax cannot be issued without prior certification from the DENR. As this only restricts new ownership, DENR Administrative Order No. 2020-18 was also issued to encourage private landowners, among others, to establish tree plantations in production forest lands to accelerate the forest cover expansion of the country.

Moreover, despite the environmental and socio-economic benefits that reforestation projects may provide, it still receives some resistance in some upland areas in Baroro Watershed, particularly in Bagulin and San Gabriel, as it was perceived that forest trees are not compatible with tiger grass. Tiger grass or soft broom production is one of the main livelihoods in several municipalities in the area. Similar findings were observed by Landicho et al. (2020) in some upland farms in Romblon, where the sites are dominated by tiger grass, on the perception that integration of other crops, particularly of trees, would cause shading, which could affect the production and yield of tiger grass. The key informants also mentioned that the short-term benefits of tiger grass and other high-value crops (e.g., vegetables, coffee) were likely more appealing to residents than woods, which take years to harvest.

Carbon Stocks of Pagsanjan-Lumban and Baroro Watersheds

The total estimated carbon stocks for 2020 in the Pagsanjan-Lumban and Baroro Watersheds are 6.41MtC and 2.01 MtC, respectively. On a per hectare basis, the Pagsanjan-Lumban Watershed stores 160 tC while the Baroro Watershed contains 103 tC. Compared with the amount of carbon stored in the Kaliwa Watershed, these values are higher but way below what the La Mesa Watershed stores. The Kaliwa Watershed contains 96 tC ha^{-1} (Lasco et al. 2007), while the La Mesa watershed holds 518 tC ha^{-1} (Lasco and Pulhin 2006). The results reveal that the capacity of the watershed to store carbon depends largely on how the watershed is being managed and the type of land use in the area. Since the La Mesa Watershed is well-managed and dominated by forest trees, the amount of carbon stored is very high. If the Pagsanjan-Lumban and Baroro Watersheds are managed similarly to the La Mesa Watershed, prioritizing forest vegetation, the potential for carbon storage would significantly increase.

Cover Stock Change

Analysis of the trend over the five-year intervals indicates a general decrease in carbon stocks within the Baroro Watershed. From 2000 – 2005, there was a decrease of 1.44%, while from 2005 – 2010, the amount of carbon went down by 2.42%. From 2010 to 2015, however, there was a slight increase (0.12%), but the amount of carbon in the Baroro Watershed decreased again by 1.88% from 2015 to 2020. From 2000 -2020, the Baroro Watershed's estimated carbon stock diminished from 2.13 MtC to 2.01 MtC or a net decrease of 5.5%. The generally decreasing trend of the amount of carbon in the Baroro Watershed is due to open forest conversion to shrubland and grassland. The open forest has a higher carbon density value than shrubland and grassland; thus, converting the former land cover into the latter will result in carbon loss/emission. Moreover, the area covered by built-up areas doubled in 2020. Conversion of land cover with the potential to store carbon into built-up, which does not contain any carbon, results in carbon loss.

For the Pagsanjan-Lumban Watershed, there is no clear carbon gain or loss trend. From 2000 to 2005, there was a carbon gain of 2.73%, but from 2005-2010 and 2010-2015, the carbon gains were 0.62% and 4.42%, respectively. From 2015 to 2020, there has been a carbon gain of 2.03%. Overall, the Pagsanjan-Lumban Watershed has a carbon loss of 0.44%. From 6.44 MtC in 2000, carbon stock in the Pagsanjan-Lumban watershed decreased to 6.41 MtC by 2020 (**Error! Reference source not found.**). The seemingly unpredictable carbon gain or loss trend was due to the fluctuations of areas covered by the different land covers. The carbon gain was due to the conversion of land cover with low carbon density into land cover with high carbon density values. In contrast, carbon loss was brought about by the conversion of land cover with high carbon density into land cover with low carbon density.

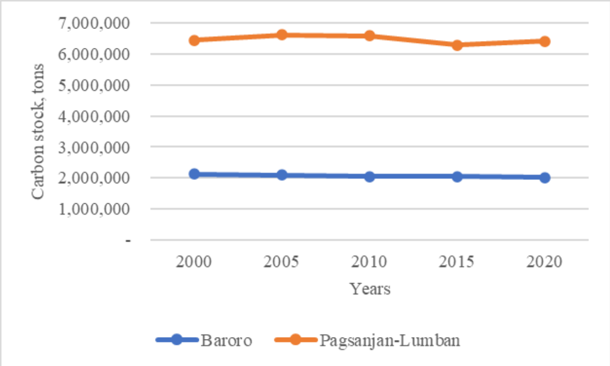

Figure 4: Total estimated carbon stock in Baroro Watershed and Pagsanjan-Lumban Watershed for years 2000, 2005, 2010, 2015, and 2020

In the Pagsanjan-Lumban Watershed, perennial crops mirrored its land cover extent in having the highest percentage share, accounting for 48% in 2020. Despite the considerable contribution, its estimated carbon stock continuously declines over the years primarily due to its shrinking land cover class. Closed and open forests both exemplified high carbon stock potential amounting to 28% when combined, doubling its land cover, which is only 14% of the watershed.

For individual land cover contribution, annual crops and brushland have the highest in Baroro Watershed. In contrast, perennial crops, open forests, and annual crops were the dominant contributors in the Pagsanjan-Lumban Watershed. It is noticeable, however, that in both sites, even though brushland has a larger total area, the annual crop has higher carbon stock, signaling higher carbon pool values, particularly for annual crops compared to brushland. The carbon density of agricultural soil was five times larger (149.6 tC ha^{-1}) than that of brushland (35.57 tC ha^{-1}). Moreover, both sites exhibited a significant increase in built-up areas, which means that former vegetated areas with the ability to store carbon were being converted into a class without carbon stock potential, decreasing the total carbon stock of the watersheds.

Impact of LULC Change on Estimated Carbon Stocks Using the InVEST Model

The carbon sequestration process is considered the most popular among all the ecosystem services (Pechenec 2018). Different types of carbon stock studies have been conducted in the past. In the Philippines, there are carbon assessments and quantifications of different vegetation types (Lasco et al. 2004; Lasco and Pulhin 2006; Labata et al. 2012; Ocampo and Zamora 2016; Pulhin et al. 2017; Racelis et al. 2019). There are also studies related to specific carbon storage component variables such as aboveground biomass of secondary forests by Magcale-Macandog et al. (2006) and soil carbon (e.g., Gevaña et al. 2008 and Gevaña and Pampolina 2009). However, considering that one of the major factors affecting terrestrial carbon is land use dynamics (Fitts et al. 2021), local studies that provide a holistic perspective of the impact of land use and land cover changes as a whole on carbon storage (i.e., Reyes and Ludevese 2015) have been limited. Recently, though, due to developments in remote sensing technologies and the increasing availability of satellite data, mapping carbon storage and sequestration that provide site-specific information has been gaining momentum (e.g., He et al. 2016; Almarines 2017; Li et al. 2018; Sarathchandra et al. 2021; Lahiji et al. 2020; Dida et al. 2021; Aitali, 2022). InVEST is one of the software developed to map, quantify, and assess the carbon stock in a landscape. It comprises a set of free, open-source software models developed by the Natural Capital Project of Stanford University to map and value the goods and services from nature that support and enhance human life (Sharp et al. 2020). The model has many advantages, such as its applicability globally, flexibility in scale, and ability to provide both biophysical and economic outputs (Aitali 2022). Among the suite of models in InVEST, the InVEST Carbon Storage and Sequestration model (InVEST-CSS), which quantifies carbon sequestered in an area, is the most extensively used model (Li et al. 2018). This approach is viewed as a more efficient means of examining the influence of changes in land use on carbon storage over time (Nie et al. 2020). Given the importance of carbon storage in climate regulation, among other related ecosystem services, this study aims to understand the relationship between land use and land cover change and the carbon stock of Baroro Watershed and Pagsanjan-Lumban Watershed using the model.

The intertwined relationship between land use and land cover and carbon storage and sequestration is evident. It is clear from the findings that the carbon stock trend follows the forest cover trend, revealing the very high influence of forested areas on the carbon stock of the watersheds. The observation that annual crops have higher carbon stock capacity than brushland is perhaps due to the latter's association with post-extraction secondary forests or logged-over forests (Lasco et al. 2001). This pseudo-transition zone, which can also include grasslands and open/barren areas, has the potential to store more carbon if appropriate management or conversion is applied. A study by Li et al. (2022) mentioned that converting unused land with low carbon density to cropland facilitates the formation of carbon sinks, thus increasing the overall carbon storage in Heilongjiang Province, Northeast China. However, compared to forest areas, carbon storage is still relatively low in agricultural areas, parallel to the study results in the Lahijan catchment, Iran (Lahiji et al. 2020). In Baroro Watershed, Encisa-Garcia et al. (2020) projected that forest cover will continuously decrease due to cropland and settlement expansion. Consequently, carbon storage is anticipated to decrease in the future as well. In contrast, intensive agriculture is already being practiced in 52% of the Pagsanjan-Lumban Watershed, raising concern not only about its carbon emission but also soil erosion (Varca 2012), as indicated by observable changes in its water quality and other biophysical features (Cruz et al. 2012).

In terms of built areas, its continuous expansion at the expense of vegetated areas, particularly of forest lands, is expected to contribute to the decline of the watersheds' carbon stock, similar to the findings of Dida et al. (2021). Sealing the soil surface due to increased built areas is a known hotspot for carbon stock losses (Tao et al. 2014). With an annual growth rate of 1.14% (Baroro Watershed) and 1.09% (Pagsanjan-Lumban Watershed), computed based on the PSA 2015 to 2020 population census, this development is anticipated to continue especially with the government's commitment to sustain and increase the previous administration's "Build, Build, Build" program along with the newly introduced "Build Better More" infrastructure program of the new Philippine administration ('Build-Better-More' Infra Program to Further Propel PH Economy—NEDA). The enforcement of the United Nations Framework Convention on Climate Change (UNFCCC), which mandates reporting on the changes in carbon storage capacity within areas with vegetation (Sarathchandra et al. 2021), highlights the global significance and relevance of quantifying the potential of various land uses for carbon storage and sequestration (Zhiyanski et al. 2016).

Estimated Value of Carbon Sequestered in Pagsanjan-Lumban and Baroro Watersheds

The present value of carbon sequestration associated with the land cover changes from 2000 to 2020 using the social cost of carbon (Rennert and Kingdon 2019) was estimated. The study used two social costs of carbon: US$ 75 per ton and US$ 5 per ton. Using the InVEST model results, both watersheds experienced a loss in carbon sequestration from 2000 to 2020, with 28,389.94 Mg C and 117,447.37 Mg C for the Pagsanjan-

Lumban and Baroro Watersheds, respectively (Table 7). Despite the negative total quantity of carbon sequestration in the Pagsanjan-Lumban Watershed, the economic value when the five-year interval values were combined was positive, ranging from PhP 64,386,938 to PhP 965,804,077 at US$5 and US$75 per ton of carbon, respectively. In the Baroro Watershed, however, the total estimated value of carbon sequestration due to land cover changes was negative, ranging from PhP 65,709,788 to PhP 985,646,826 at US$5 and US$75 per ton of carbon, respectively. These findings suggest that the Pagsanjan-Lumban Watershed is a carbon sink, while the Baroro Watershed is a net carbon emitter from 2000 to 2020. This further implies that PLW has made a positive economic contribution to avoiding climate change. The total economic value of carbon sequestration per land cover in the two watersheds is illustrated in Figures 8 and 9.

Table 7: Estimated value of carbon sequestration due to land use and land cover changes from 2000-2020 in the Pagsanjan-Lumban Watershed and Baroro Watershed

Year	Carbon Sequestered	Global SCC (USD per ton CO_2)		Global SCC (PhP per ton CO_2)	
		2.50%	7%	2.50%	7%
		$75	$5	$1 = PhP 50.865 (BSP, Aug 1, 2019)	
Pagsanjan-Lumban Watershed					
2005	176,179	48,493,265	3,232,884	2,466,609,914	164,440,661
2010	- 41,112	- 7,026,360	- 468,424	-357,395,806	- 23,826,387
2015	-291,057	-30,887,212	- 2,059,147	-1,571,078,058	-104,738,537
2020	127,600	8,407,904	560,527	427,668,027	28,511,202
Total	**-28,390**	**18,987,596**	**1,265,840**	**965,804,077**	**64,386,938**
Baroro Watershed					
2005	- 30,572	-8,414,938.92	-560,996	-428,025,868	- 28,535,058
2010	-50,790	- 8,680,433.25	-578,696	-441,530,237	-29,435,349
2015	2,372	251,760.98	16,784	12,805,822	853,722
2020	-38,458	-2,534,091.08	-168,939	-128,896,543	-8,593,103
Total	**- 117,447**	**-19,377,702.26**	**- 1,291,847**	**- 985,646,826**	**-65,709,788**

Figure 8: Net present value (PhP) of carbon sequestered in Baroro Watershed using a 2.5% (top) and a 7% discount rate (below)

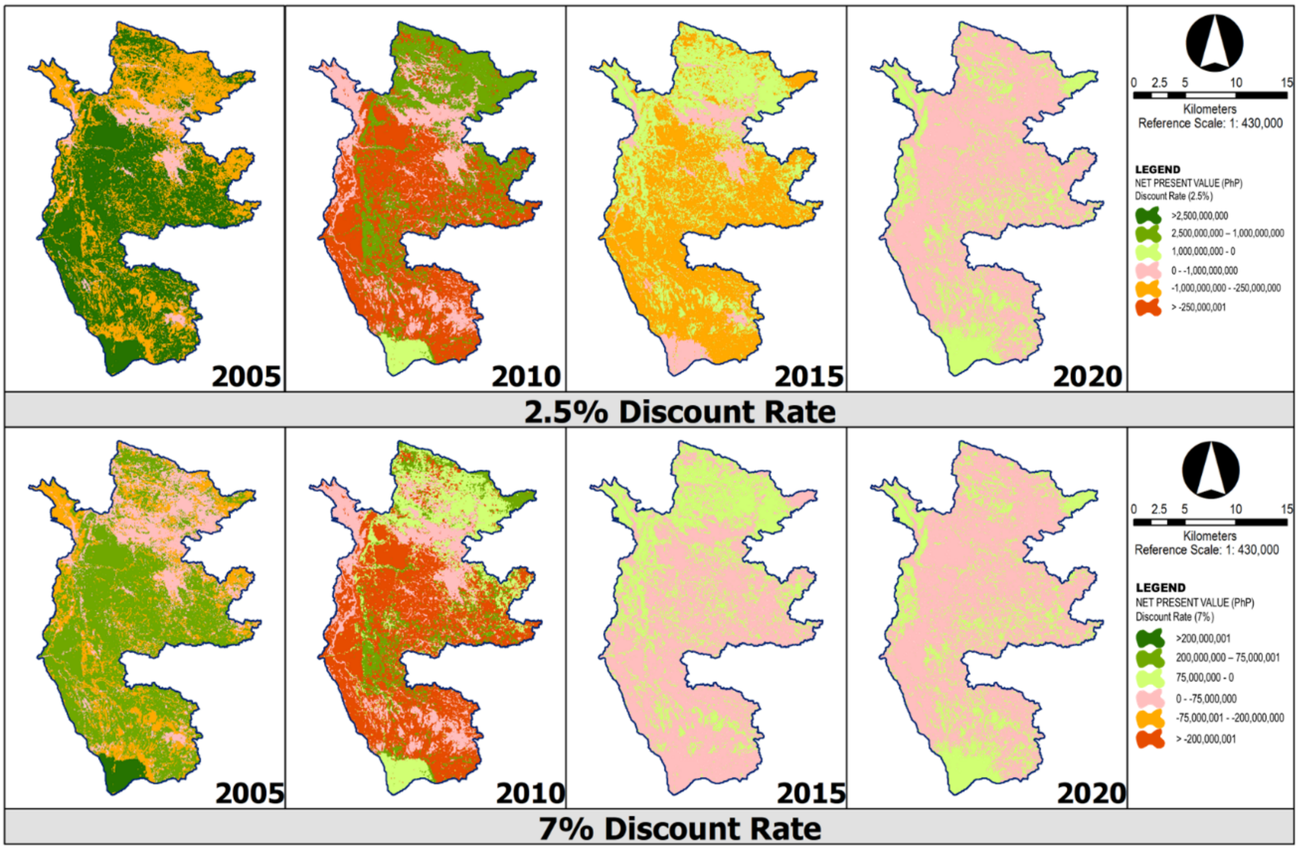

Figure 9: Net present value (PhP) of carbon sequestered in the Pagsanjan-Lumban Watershed using a 2.5% (top) and a 7% discount rate (below)

Measures to Enhance the Role of the Two Watersheds in Climate Change Mitigation

The role of Baroro and Pagsanjan-Lumban Watersheds in mitigating climate change can be enhanced through any or a combination of the following strategies: (1) protection of their existing forests, (2) conversion of existing shrublands and grasslands into forest tree plantations, and (3) integration of woody perennials in the area devoted to annuals.

The Baroro watershed has no closed forest and has a very small area of open forest (330.57 ha). If the open forest is protected, it will, in time, become a closed forest and contain more carbon than the current land use. In addition, if the shrubland covering 12311.91 ha and grasslands with an area of 40.86 ha are planted with trees, substantial amounts of carbon will be sequestered. Moreover, carbon will also increase if woody perennials are integrated into 10% of the area of annual crops. Using these new areas, the Baroro Watershed is estimated to contain 3.27 MtC, an increase of 61% from its current carbon stocks.

Similarly, PLW's carbon stocks can be increased if the closed and open forests are protected. Carbon contained in the closed and open forests will increase over time. Open forests will later become closed forests, increasing the total area covered by the closed forests and storing more carbon compared to its current land use. Shrubland, which covers 8,598.06 ha when planted with trees, will contain more carbon. In addition, when 10% of the area planted with annual crops is integrated with woody perennials, the area will hold more carbon than pure annual crops. In sum, PLW's carbon will increase from 2.01 MtC to 3.27 MtC or an increase of 40.5%.

CONCLUSION

The impacts of land use and land cover change in the carbon storage and sequestration of the Pagsanjan-Lumban Watershed and Baroro Watershed in the Philippines from two-decade observations (2000-2020) were quantified, valued, and mapped. The significant decrease in forest cover in both watersheds was primarily due to conversion to other uses, such as built-up areas and croplands, consequently reducing its huge storage capacity and, hence, adding to its total estimated cost of carbon or diminishing its total estimated benefits. With the findings that the capacity of the watershed to store carbon largely depends on its management, it is vital to develop site-specific strategies through appropriate management measures and interventions to either increase or at least recover its former carbon stock potential. The generated maps of land use and land cover, carbon stock, and NPV of carbon sequestered can be an effective input for spatial planning and decision-making in the study sites.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

FB Pulhin conceptualized the paper, reviewed relevant literature, and assessed the impact of land cover changes on the amount of carbon stored in the Pagsanjan-Lumban Watershed and Baroro Watershed, and wrote a substantial part of the paper. AT Magpantay gathered relevant literature and data, helped in the analysis of the land cover changes in the two watersheds, ran the InVEST model, and contributed to the writing of the paper. NR Almarinez generated the land cover maps using Google Earth engine and analyzed the changes through time. CD Predo estimated the economic value of carbon sequestration and wrote the economic section of the paper. JM Pulhin contributed to the conceptualization, analysis, comments, and review of the paper on top of his role as the Project Leader ITMoB.

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