p–ISSN 2012–3612 | e–ISSN 2782–8824
www.edjournal.cfnr–uplb.org

Ecosystems and Development Journal
Volume 13 | Number 2 | pp. 17–28 | 2023

Assessment of carbon stock of Bustos Watershed, Bulacan, Philippines using Integrated Valuation of Ecosystem Services and Trade-offs (InVEST)

Maria Graciella L. Roque[1*], Jan Joseph V. Dida[2]

[1]*College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*
[2]*Institute of Renewable Natural Resources, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

ABSTRACT. Land use and land cover changes are pivotal factors contributing to global environmental concerns, particularly in forest cover reduction, accretion of greenhouse gas emissions, intensification of climate change, and the overall depletion of natural resources. These challenges are evident in Bustos Watershed in Bulacan, Philippines, where ongoing land conversion underscores the necessity of evaluating carbon storage in the area. Carbon stock (C-stock) assessment is essential in determining the trade-offs associated with transitioning between different land uses. Such assessment, in turn, serves as a foundational criterion for decision-making amid highly competing land uses. Hence, this study assessed the forest C-stock of Bustos Watershed using data from Landsat 5 (2009–2010) and Landsat 8 (2020–2021) satellites. The carbon storage and sequestration model of Integrated Valuation of Ecosystem Services and Trade-offs (InVEST), the generated land cover maps, the available carbon (C) values from different literature, and the C-stock of the watershed area were estimated. The findings reveal that forests remain the dominant cover type within Bustos Watershed in 2010 and 2021. However, a noteworthy decline of 21.6% in forest cover is evident during the intervening period, which may be related to conversions to alternative land cover types, including agriculture (9.38%), grassland or shrubland (10.68%), and built-up areas (0.51%). Consequently, the total C-stock experienced a discernible decrease of 12.58% by 2021, highlighting the substantial impact of land use changes on carbon sequestration within the Bustos Watershed.

Keywords: carbon pool, land cover, remote sensing

Article Information
Received 01 October 2023
Accepted 06 February 2024
Published online 29 April 2024
*Email: mlroque@up.edu.ph

INTRODUCTION

Forest ecosystems in the Philippines can become both a carbon (C) source and a C-sink. From the 1500s to the present, deforestation has added 3.7 Gt C to the atmosphere, 70% of which was emitted during this century (Lasco & Pulhin, 2003). Through rehabilitation activities, such as reforestation and agroforestry, the degraded forest lands in the Philippines' largest degraded areas have been given a high capacity for carbon sequestration (Lasco & Pulhin, 2000). The increasing recognition of forests' capacity to store carbon, important for climate change mitigation, has led to a significant increase in research. These research focuses on the parts and functions of Philippine Forest ecosystems in the context of climate change, particularly about the ecosystems' C-sequestration capacity (Lasco & Pulhin, 2003). Climate change mitigation studies are also being conducted on the impacts of climate change, as a function of increasing population and anthropogenic activities that manifest evidently in Philippine forest ecosystems. The study of Origenes and Lapitan (2021) revealed an increase in studies related to forest biomass in recent years. This surge is attributed to the growing need for fundamental ecosystem data, to develop effective ecological land management strategies and predict forest dynamics and utilization. Biomass calculation has also increased significance in contemporary times, particularly in quantifying C-stock within a forest stand.

One of the tools used to assess the spatial distribution and estimated magnitude of C-stock is Integrated Valuation of Ecosystem Services and Trade-offs (InVEST), which is a set of open-source software models in Geographic Information System (GIS) applications, wherein maps and values can be used to examine the impact of different environmental or multiple ecosystem services (Nelson *et al*., 2009). This model assesses carbon storage in terrestrial habitats using geographical land use and C-density data, integrated by four C-pools: aboveground biomass, belowground biomass, soil organic C, and dead organic matter.

With the expanding accessibility of spatial data and GIS technology, remote sensing methods are now used to develop and generate land use maps for C-stock analysis and modeling. Studies have shown that InVEST is applicable in evaluating the possible impacts of land use changes on various environmental resources, specifically in the Philippines (Liang *et al*., 2017). It also estimates the amount of stored C in the area over time using land use maps and stocks in the C pools. Moreover, the model calculates the net quantity of C stored in a land parcel through time (Sharp *et al*., 2018).

Land use management is crucial to climate change mitigation and adaptation strategies (Labata *et al*., 2012). Despite the increasing global concern and acknowledgment of the importance of C-stock assessment, limited initiatives have been undertaken to evaluate C-stocks at watershed scales across diverse land use and cover scenarios (UNFCCC, 2014; Labata *et al*., 2012). This lack of effort has led to a shortage of quantitative data for specific land covers. It is imperative to recognize the current and evolving C-stock at a watershed level and delineate alternative land uses to enhance productivity and reduce greenhouse gas emissions *in situ*, especially in rehabilitation activities.

In Bulacan, Philippines, land cover change and C-stock assessment using InVEST on a watershed scale has yet to be performed. Thus, this study focused on assessing forest C-stock of Bustos Watershed in Bulacan by estimating the total stored C based on the four (4) previously described C-pools (aboveground and belowground biomass, soil, and dead organic matter). According to Bulacan's Provincial Development and Physical Framework (n.d.), the Bustos Dam Watershed Reservation, situated in the north-northeast region of Bulacan, is subject to protection and rehabilitation. The baseline data from this study will help local government units monitor the status of the watershed, including climate change mitigation towards better decision-making on forest protection against deforestation, other land management strategies, policies, and sustainable development.

This study also aims to determine the extent of different land cover classes in the watershed, which will describe the relationship between land cover change and the total C of the site. However, due to COVID-19 restrictions for on-site data gathering, C pool values were accumulated using different related articles in the country. Validation was done based on the site's changes in land use and land cover (LULC). Other C pool parameters have also not been considered due to model constraints. It is also important to note that the model did not include extensive measurements throughout the soil profile (Petrokofsky *et al*., 2012). Values for C-stock were taken from different literature, which may affect the C values per C pool due to other species and ages in the area. Since the InVEST model is based on C estimations for each land cover type, the findings are only as comprehensive and dependable as the land cover categorization and provided C-pool values. It does not record C that transfers from one pool to another (Sharp *et al*., 2018).

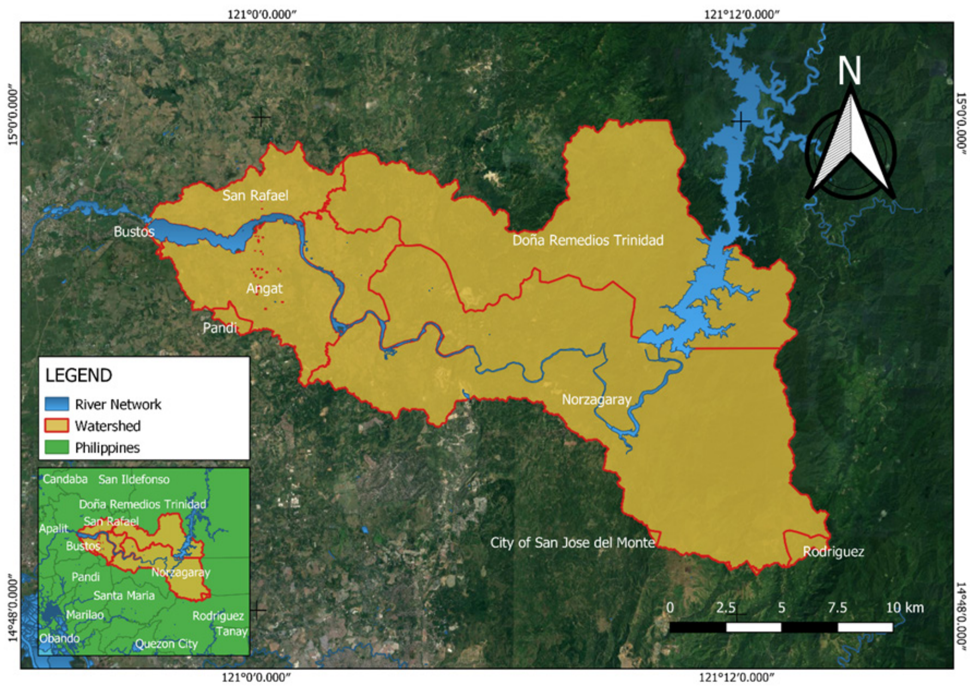

Figure 1. Location map of the Bustos Watershed in Bulacan, Philippines.

METHODOLOGY

Study site

Bustos Watershed, with approximately 31,339.26 ha of total cover area, is located in the eastern part of Bulacan, Philippines (**Figure 1**). It traverses eight municipalities: San Rafael, Bustos, Angat, Pandi, San Jose del Monte, Norzagaray, Doña Remedios Trinidad, and one from Rizal Province, Rodriguez. Bustos Watershed is classified as a medium watershed and is surrounded by Bustos Dam (14°57′N to 120°57′E) and Angat Watershed Forest Reserve (14°54′N to 121°09′E). It is also considered a sub-watershed of the Angat Watershed Forest Reserve. The Angat Reservoir primarily supplies the irrigation water of the Angat-Maasim River Irrigation System (AMRIS) and releases it into Bustos Dam (Tabios & de Leon, 2020). The Bustos Watershed contributes local inflows to Bustos Dam, which makes the watershed part of the AMRIS irrigation water supply chain (Tabios & de Leon, 2020).

Delineation of the watershed

Quantum GIS (QGIS) Software and a Digital Elevation Model (30 ASTER DEM) were used to delineate the boundary of the watershed using a basin tool called Fill Sinks by Wang & Liu (2006). The stream networks of the defined watershed were created using the same DEM data. After generating the boundary, it was converted into a shapefile to build a map depicting the defined watershed and stream networks, each represented by a distinct symbology. The watershed delineation followed the methods conducted by Eisa *et al*. (2022).

Image classification of satellite imagery

Following the methodology of Dida *et al*. (2021), the LANDSAT-5 Thematic Mapper (TM) and LANDSAT-8 Operational Land Imager (OLI) images were generated from Google Earth Engine (GEE) platform with 30 m spatial resolution. The processing in the GEE platform also included the cloud masking process and top-of-atmosphere (ToA) reflectance data.

After acquiring the satellite images, the band combination was set into natural image colors: Bands 3, 2, 1 for Landsat 5, and Bands 4, 3, 2 for Landsat 8. Using the natural image colors of Landsat 5 and 8, the Regions of Interest (ROI) were established by selecting spectral signatures. The ROIs characterized each land cover classification per DENR Memorandum Circular 2005–005, *viz*., forest, agriculture, grass/shrub land, barren land, built-up, and water bodies. Seventy-five (75) ROIs per land cover type were assigned. The ROI polygons were applied in the generated supervised image classification using the band processing of the QGIS SCP plugin. The Maximum Likelihood classification algorithm, including the mean and variance of the signature, was used to approximate the probability of classifying the pixel to its appropriate class.

Accuracy assessment

The accuracy assessment was done using a site-specific methodology using the confusion or error matrix. The error matrix contained all the information from comparing the classified and the reference images' pixels. The accuracy tool under the SCP plugin generated 75 random points for the accuracy assessment. The land cover classes of random points were identified in Google Earth Pro. Subsequently, the error matrix and its parameters were calculated using the post-processing tool in the SCP plugin in QGIS (Mangiameli *et al*., 2018).

Carbon stock estimation

Using InVEST, the C storage and sequestration model calculated how much C is stored in the watershed using the assigned C-pool values for different LULC classes (Sharp *et al*., 2018). Following the formula of Xiang *et al*. (2018), the C density (C_i) of each land cover per pixel was computed by adding the C densities of the four (4) described C-pools (Equation 1).

$$C_i = C_{i(aboveground)} + C_{i(belowground)} + C_{i(soil\ litter)} + C_{i(dead\ matter)} \quad \text{(Eq. 1)}$$

Secondary sources were referred to assign C-pool values (**Table 1**). The Province of Bulacan has most of Region III's surviving closed-canopy forests. As part of the AMRIS, the surrounding areas specifically Angat Watershed, can sustain lowland dipterocarp stands at altitudes ranging from 490 to 920 m and consist of grassland and scrubland areas with secondary bamboo (BirdLife International, 2022). Thus, the aboveground biomass value for forests in Kaliwa Dam, Philippines, of Metropolitan Waterworks and Sewerage System (2019) was used in the C pool. The belowground biomass and soil organic C value for dipterocarp forest stands were based on the values developed by Racelis (2005) for Mount Makiling. The carbon pool values for agriculture and grass- or shrub-land were obtained from the study conducted in Kalahan Forest Reserve, Nueva Vizcaya, by Villamor *et al*. (2010). Lasco *et al*. (2004) estimates for the secondary forest of Mount Makiling were the basis for the values of dead organic matter. Lastly, the C-pool values of water, built-up areas, and barren land were all set to zero following Dida *et al*. (2021).

After determining the C density, the total C storage of each land cover per pixel (C_{total}) was obtained. It is the sum of the product of the total C densities for the LULC type i and the area of LULC type i (A_i), as shown in Equation 2 (Xiang *et al*., 2018):

$$C_{total} = \sum_{i}^{n} C_i \ x \ A_i \quad \text{(Eq. 2)}$$

Table 1. Assigned carbon pool values (tons $ha^{-1}yr^{-1}$) for the different land cover and land use classes.

Code	Class	Above-ground biomass	Below-ground biomass	Soil organic carbon	Dead matter
1	Built up	0	0	0	0
2	Forest	38.03[a]	44.66[d]	10.23[d]	1.94[c]
3	Agriculture	4.11[b]	1.56[b]	43.49[b]	1.94[c]
4	Grass/Shrub	4.15[b]	1.56[b]	39.09[b]	1.94[c]
5	Barren land	0	0	0	0
6	Water	0	0	0	0

[a]*Estimates from Kaliwa Dam, Philippines (Metropolitan Waterworks and Sewerage System, 2019)*
[b]*Estimates from Kalahan Forest Reserve, Nueva Vizcaya (Villamor et al., 2010)*
[c]*Estimates from Mount Makiling Forest Reserve, Laguna (Lasco et al., 2004)*
[d]*Estimates from Mount Makiling Forest Reserve (Racelis, 2005)*

RESULTS AND DISCUSSION

Land cover of Bustos Watershed

The majority of the area was covered by forests, with a total area of 26,431.61 ha (84.34%) in 2010 and 19,661.53 ha (62.73%) in 2021 (**Figure 2**).

In 2010, built-up areas comprised 6.18% of the total area, around 1,938.16 ha **(Table 2)**. The water areas occupied 1,329.49 ha or 4.24% of the total area. Barren land and agricultural lands comprised approximately 2% of the watershed, totaling 892.77 ha and 726.70 ha, respectively. The land cover type with the least area was the grassland or shrubland, with a percentage of 0.07 or 20.52 ha.

Unlike in 2010, agricultural lands increased to 11.70% of the total watershed area, with 3,667.84

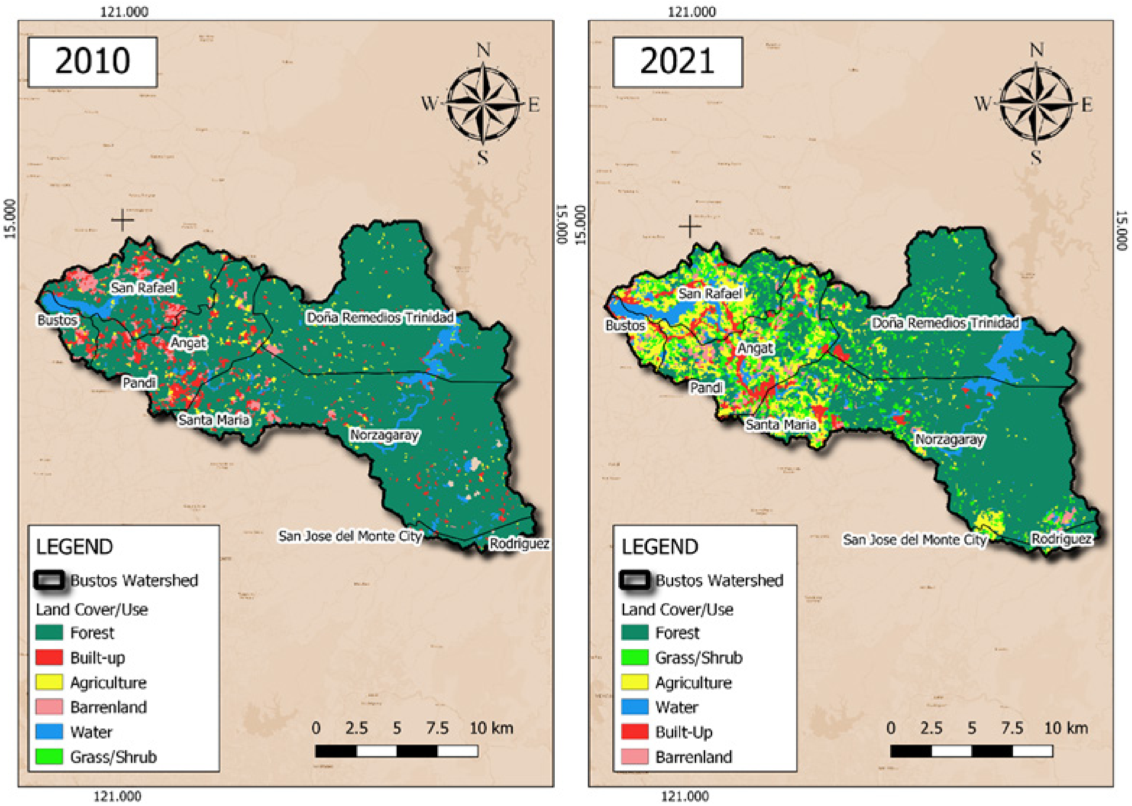

Figure 2. Land cover map of Bustos Watershed in 2010 and 2021.

ha in 2021. Grass or shrublands and built-up areas also sprawled to 3,368.28 ha (10.75%) and 2,098.87 ha (6.70%). About 2,018.68 ha or 6.44% of the watershed were water areas. Barren lands obtained the least total area with 1.67% or 524.05 ha.

In 2010, almost all the towns were dominated by forest cover. The Municipality of Norzagaray held most of the forest areas in Bustos Watershed. However, by 2021, the forest areas in the municipalities of Bustos, San Rafael, Angat, Pandi, Sta. Maria, as well as some parts of Doña Remedios Trinidad and Norzagaray were mostly converted into built-up and agricultural areas. Nonetheless, the municipality of Norzagaray still held the majority of the forest cover in the watershed.

Results show that 11 years after 2010, grass or shrubland areas accumulated the highest increase in percentage, with a 10.68% growth, followed by agricultural land, with a 9.38% increase. Even though forest areas comprised most of the

Table 2. . Land cover area (ha) and land cover changes (%) in Bustos Watershed from 2010 and 2021.

Land cover type	Area of the land cover type for 2010 (ha)	Area of the land cover type for 2021 (ha)	Increase or decrease of the area of the land cover type (%)
Forest	26,431.61 (84.34%)	19,661.53 (62.73%)	–21.60
Grass/Shrub	20.52 (0.07%)	3,368.28 (10.75%)	10.68
Agriculture	726.70 (2.32%)	3,667.84 (11.70%)	9.38
Built-up	1,938.16 (6.18%)	2,098.87 (6.70%)	0.51
Water	1,329.49 (4.24%)	2,018.68 (6.44%)	2.20
Barren land	892.77 (2.85%)	524.05 (1.67%)	–0.33
TOTAL	31,339.25 (100%)	31,339.25 (100%)	

watershed area, it was noticeable that the forest cover had the highest decrease, accumulating a 21.60% loss. In relation to the loss of forest areas, there was also an increase in the percentage of built-up areas, which sprawled to 0.51% more land area. Among the land cover types, grass- or shrubland had the highest gain, accumulating an increase of 3,347.76 ha (**Figure 3**). It was followed by agriculture and water, with a respective total area of 2,941.14 ha and 689.19 ha. Built-up areas also gained 160.71 ha. As other land cover types increased, forest cover greatly decreased, losing a total area of 6,770.08 ha. Barren lands also slightly decreased, as it lost about 368.72 ha.

Forest areas, about 1,046.77 ha, were converted to built-up areas. Results show that urban sprawl, as in built-up land expansion and land urbanization, is evident in Bustos Watershed. The observed issue is also one of the most apparent, irreversible, and abrupt land cover changes. Like in Bustos Watershed, urbanization is also the primary cause of many environmental and socio-economic changes on several scales (Gao & O'Neil, 2020). Since built-up areas are the main site of human-environment interactions, socio-economic dynamics drive the places and processes of new built-up lands. This phenomenon affects various environmental aspects at different temporal and spatial scales, such as freshwater quality and availability, climate extremes, flooding, and ecosystem disruption (Seto *et al.*, 2010). Based on the trends, as the global population increases, the demand for urbanization increases as humans seek accommodation and economic development.

Most forest areas were converted into agricultural lands, accumulating a total area of 3,034.25 ha. The agricultural land area also increased based on the graph provided **(Figure 3)**. As of 2020, the region (Central Luzon) where the Bustos watershed is situated is considered the country's largest plain, with agricultural plains covering over 40% of the region's land area. This is also why Central Luzon produces most of the country's rice and is designated as the "Rice Bowl of the Philippines" or "Rice Granary of the Philippines." It contributes significantly to the Philippine economy, with an 8.98% Gross Domestic Product (GDP). Moreover, as the built-up area increases, the need for commodities and animal agriculture also increases. The agri-food productivity increases to meet the demands of the growing population, which expands the agricultural lands, leading to deforestation (FAO, 2021).

Lastly, there was a possibility that the loss of barren lands accounted for the gain of grass- or shrubland, agriculture, or built-up areas. Specifically, 235.16 ha of barren land was converted into grass or shrubland, while 192.58 ha were converted into built-up areas. Some studies show that barren lands are impossible to convert into agricultural lands due to poor productivity (El-Gammal *et al.*, 2014). However, with proper management practices, it can be converted into an agricultural area. In Pampanga, Philippines, the *Magsasaka Siyentista* Oscar Baluyot's land was successfully turned into a productive agricultural area for sweet tamarind despite being overtaken by *lahar* and desolated for a significant period. With the help of a science- and technology-based project by the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD), strategic interventions such as irrigation during dry seasons, fertilizer application, and pruning of unproductive branches kept Baluyot's land productive (Magpantay & Cabello, 2011). This again shows that the conversion of barren land into croplands is a viable development opportunity, which can reduce the pressure for forest conversion.

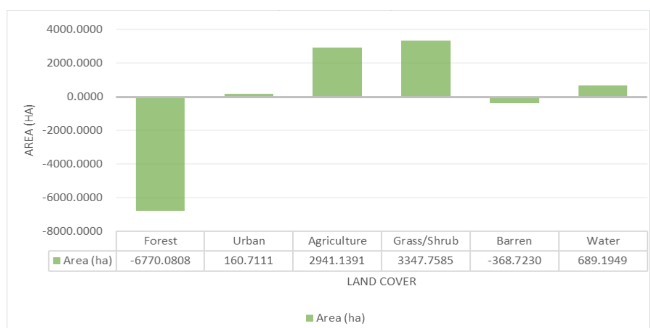

Figure 3. Net change of the land cover in Bustos Watershed from 2010 to 2021.

Accuracy assessment

Land cover accuracy values are presented in **Table 3**. Kappa hat classification was used to assess the measure of the agreement between the reference and the generated map. A kappa coefficient of 0.8 to 1 is considered a good classification. However, a coefficient close to zero (0.4 and below) is a poor classification. A coefficient of 0.41–;0.79 has a moderate to substantial strength of agreement (Rwanga & Ndambuki, 2017). For 2010, 86.78% accuracy with a Kappa hat classification 0.7985 was obtained. On the other hand, the land cover classification 2021 has an accuracy of 91.17%, with a Kappa hat classification of 0.8618. Following the described interpretation, the kappa coefficients for 2010 and 2021 are rated as good classification.

Table 3. Accuracy and Kappa hat classification.

	2010	2021
Overall accuracy	86.7836	91.1653
Kappa hat classification	0.7985	0.8618

Carbon storage

The intensity of the color in **Figure 4** varies depending on the C-stocks, wherein lighter colors contain lower C, while darker colors contain higher C-stocks. In 2010, the estimated C-stock in Bustos Watershed was 2,553.05 kt of C. Eleven years later, the estimated total C-stock of the watershed decreased by 321.23 kt of C (12.58%). The total C-stock accumulated in 2021 is 2,231.82 kt of C. The municipality of Norzagaray has the highest total C-stocks among the municipalities traversed by the watershed for both 2010 and 2021. Consequently, most forest areas and watershed features were mostly located in the Municipality of Norzagaray.

The decrease in the total C-stock can be linked to land cover conversion rates from 2010–2021. The forest is the major carbon sink and source, as it absorbs and stores massive C from the atmosphere. As presented in **Figure 4**, forest areas of the Bustos Watershed had the highest loss due to urbanization and land cultivation, supporting the increasing population and its demands, thereby reducing total C-stocks.

In 2010, belowground biomass accumulated the highest total C with 1,185.20 kt of C (46.42%) (**Figure 5**). It was followed by aboveground biomass, with 1,011.33 kt (39.61%) of C and soil carbon, with 303.64 kt of C (11.90%). Dead litter obtained the least total C, with 52.88 kt (2.07%). In 2021, the highest total C was obtained from belowground biomass, with 893.73 kt of C

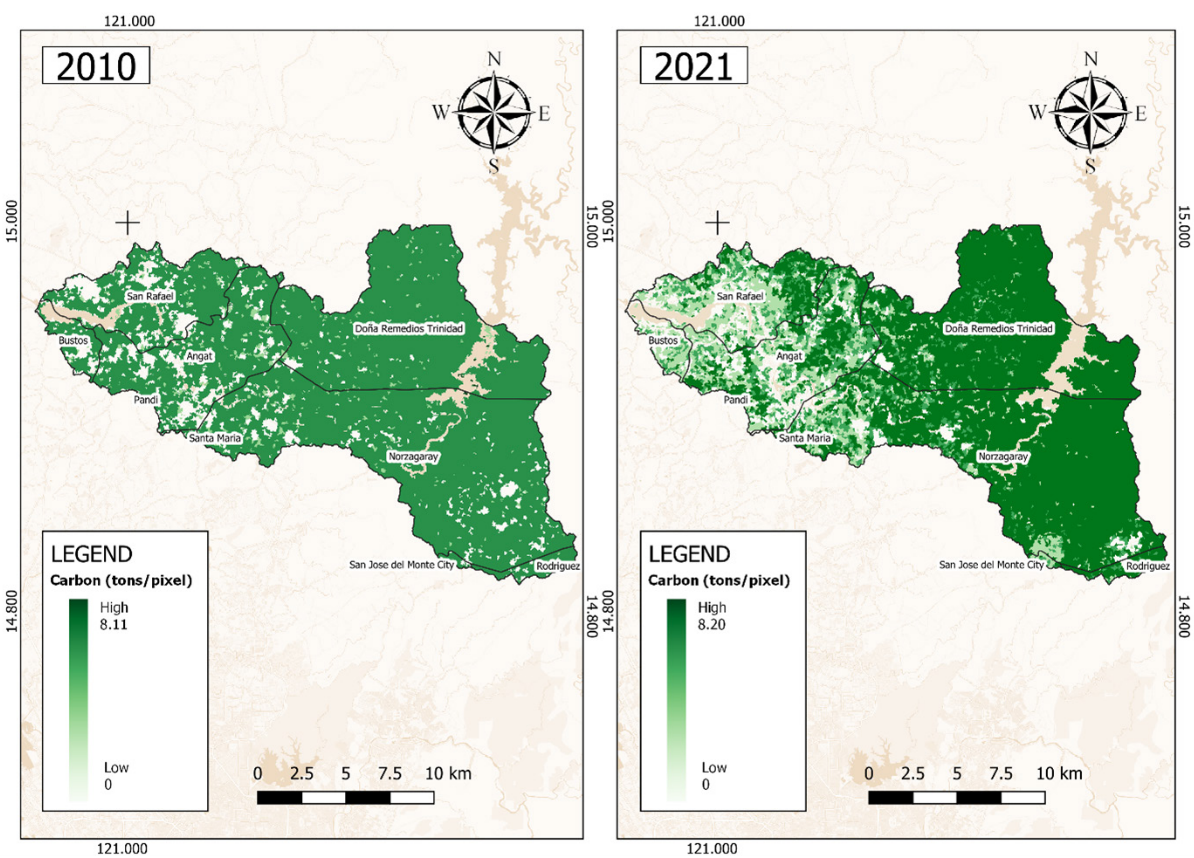

Figure 4. Total carbon content of Bustos Watershed in 2010 and 2021.

(40.04%). Aboveground biomass, soil C, and dead litter contributed less than belowground biomass, with 781.45 kt (35.01%), 504.18 kt (22.59%), and 52.46 kt (2.35%) of C, correspondingly.

Figure 5 further shows that the soil carbon increased while all the other C-pools, namely, aboveground, belowground, and dead litter, decreased. Soil C had increased, accumulating a total C growth of 200.54 kt (**Table 4**). This lone C-pool increase could be attributed to the expansion of agricultural and grass- or shrub-land areas despite the decrease in forest areas. According to FAO (2015), agricultural and grassland soils have the potential to store around 10% of the global soil C, which is roughly 50% more than a forest can store globally.

The forest cover was the most significant contributing factor to the total C of Bustos watershed despite experiencing a major area loss in 2021 (**Figure 6**). In 2010, forest lands accumulated 2,514,942.47 tons of C (98.45%) and 1,874,171.63 tons of C (75.06%), decreasing by 23.39% in 2021. Grass or shrubland acquired a total C of 0.10% or 2,575.82 tons in 2010, which increased by 16.83% to 422,652.07 tons in 2021. Agricultural land comprised 1.45% of the total C in 2010. It also increased by 6.57%, resulting in 200,216.44 tons of C or 16.93%.

The changes in C values of the watershed can be attributed to the land cover conversion over the past 11 years. Despite major forest cover losses from 2010–2021, the forest still held most of the stored C. With this, the reduction in total C-stock can be attributed to a rise in the total area of land cover classes, which acquire low C pool contents, such as built-up areas, barren land, and water. Agricultural and grass or shrub land had an increase in its contribution to the total C-stock, as the land cover area for these types also increased.

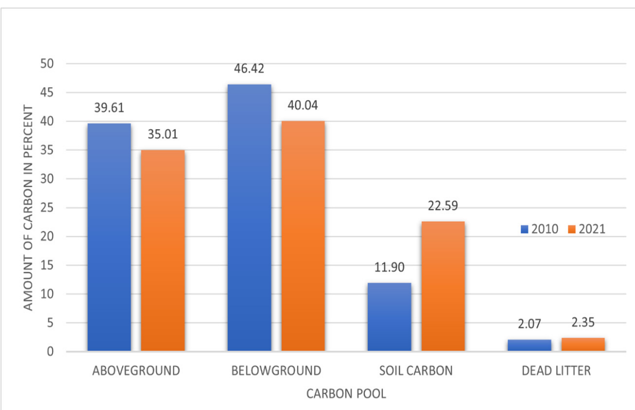

Figure 5. Carbon content per carbon pool of the Bustos Watershed in 2010 and 2021.

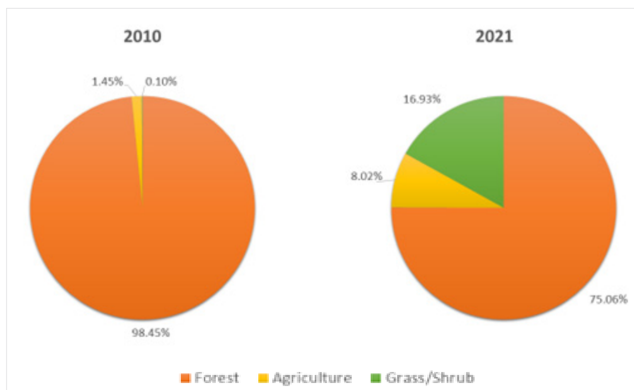

Figure 6. Comparison of the carbon content per land cover in Bustos Watershed in 2010 and 2021.

Table 4. Total carbon content per carbon pool of the Bustos Watershed in 2010 and 2021.

Carbon pool	Total carbon for 2010 (kt)	Total carbon for 2021 (kt)	Increase or decrease of total carbon (kt)
Aboveground biomass	1,011.33	781.45	–229.88
Belowground biomass	1,185.20	893.73	–291.47
Soil carbon	303.64	504.18	200.54
Dead litter	52.88	52.46	–0.42
TOTAL	2,553.05	2,231.82	–321.23

Results suggest that the conversion from forest to agriculture accumulated the greatest change among other land cover types (**Figure 7**). The forest lost a total area of 3,034.26 ha with 155.97 kt of C, which increased the C-stock of the agricultural areas in 2021.

Regarding political jurisdictions, most of the riparian forest cover of San Rafael, Bustos, and Angat municipalities was converted to agricultural land. As in those forest areas near the water bodies, riparian forest lands are the deforestation hotspot in Bustos Watershed.

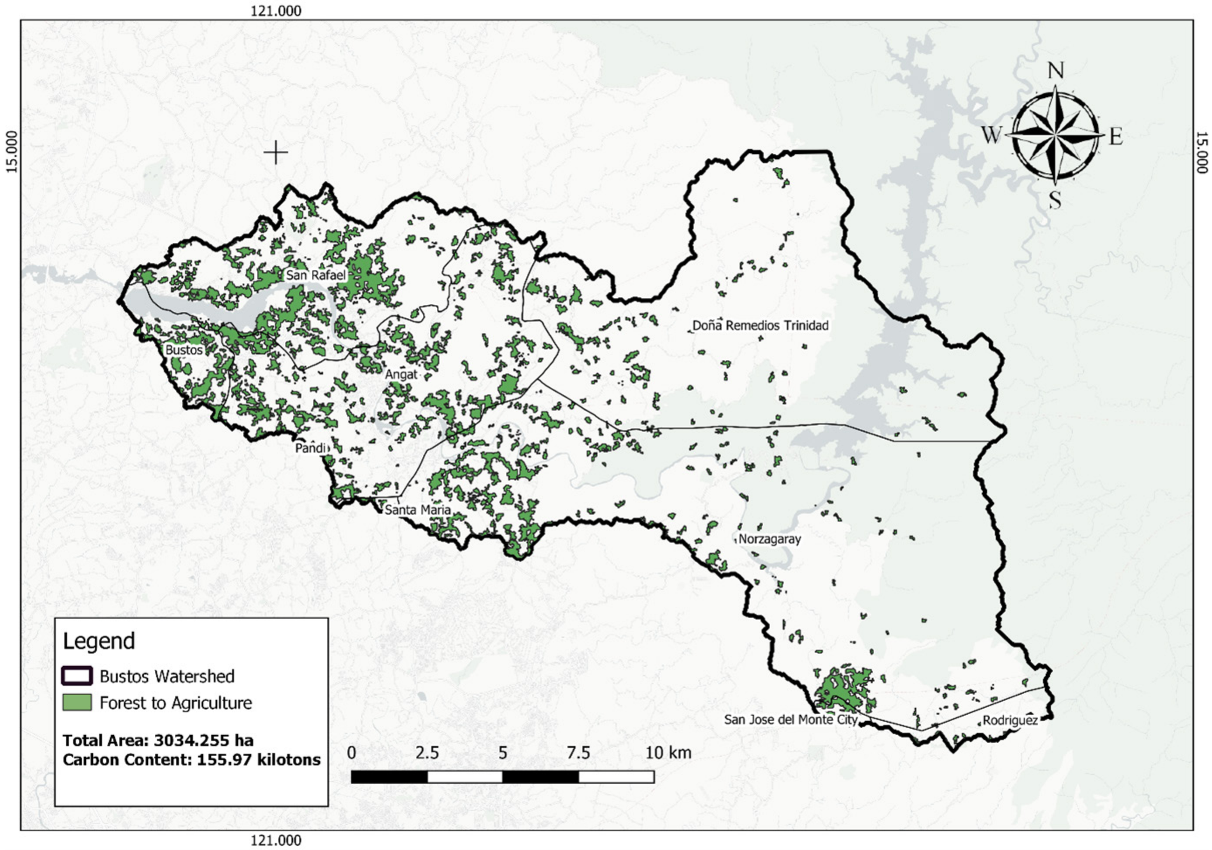

Figure 7. Conversion of forest to agriculture in Bustos Watershed from 2010 to 2021.

As for the soil series, most areas in Kalahan and Bustos Watershed have clay and clay loam soil textures. The soil carbon for the agricultural lands of Kalahan has a higher C pool value than the others. However, land utilization for grazing animals and crop cultivation has grown from negligible to around 30% of the global land mass, primarily at the expense of grasslands and forests. The shift in land use in Bustos Watershed from forest to agricultural areas led to reduced carbon content. There was a massive decrease in carbon when forest areas were converted to agricultural areas because forests can hold more carbon in their biomass than agricultural ecosystems (Escobar & Hogan, 2020).

The second most prevalent conversion is from forest areas to grass or shrublands. The converted land cover has a total area of 2,594.46 ha, around 129.94 kt of C. The forests of the Municipalities of Angat and San Rafael have the largest extent of conversion to grass- or shrub-land (**Figure 8**). The western forest part of the Municipality of Norzagaray was also converted into a grass- or shrub-land area.

The C-stocks in Bustos Watershed decreased when forest areas, which held most of the stored carbon, were converted to grasslands. This land conversion also led to soil C loss by soil organic matter oxidation aided by tillage. It was estimated that converting natural forests to other land cover generated roughly one-third of the total net C dioxide emissions to the atmosphere (Yellajosula *et al*., 2020).

CONCLUSIONS AND RECOMMENDATIONS

Forests are major sinks and sources of carbon (C) because they can both store and release massive amounts of C into the atmosphere. On the other hand, the ability of ecosystems to deliver, maintain, and control essential activities and services, including carbon storage, is being compromised amid massive watersheds and land

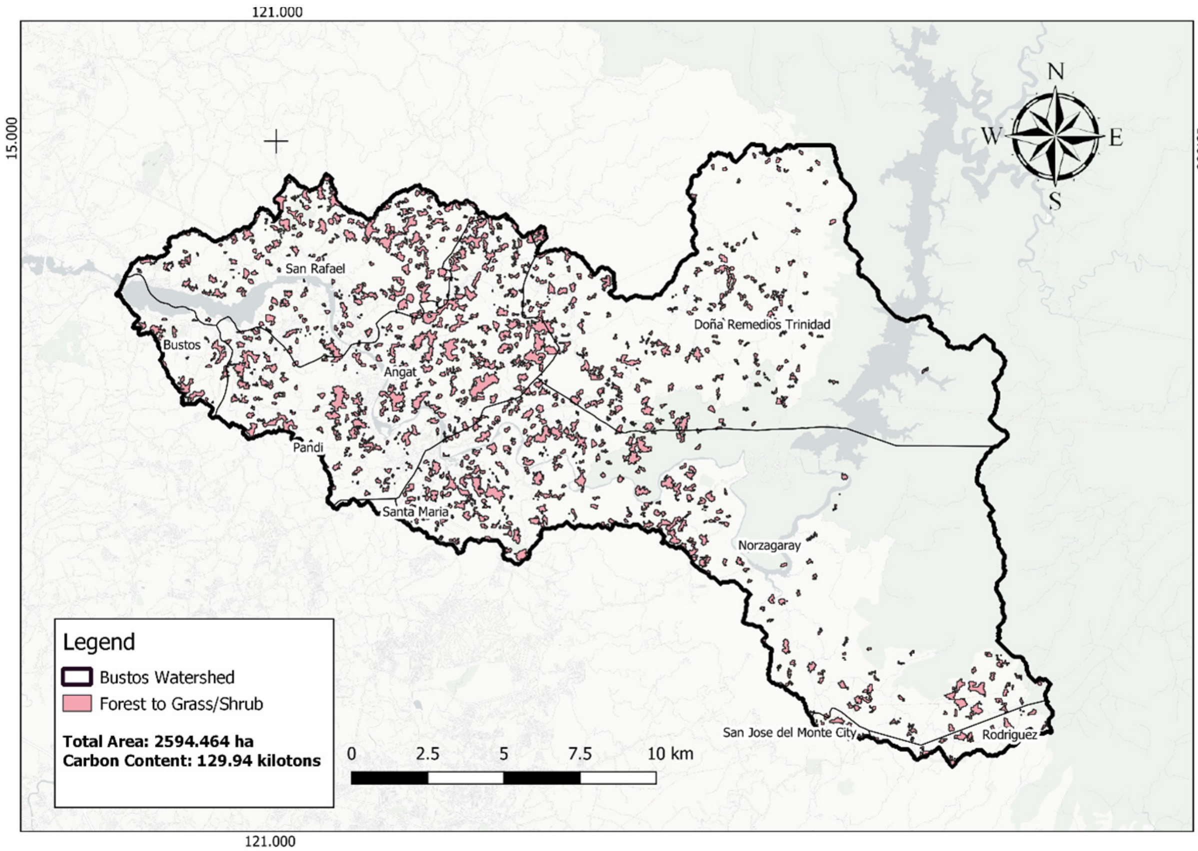

Figure 8. Conversion of forest to grass- or shrub-land in Bustos Watershed from 2010 to 2021.

degradation. This study assessed the C-stock of the Bustos Watershed in Bulacan, Philippines, using a C modeler in QGIS and InVEST. Results reveal that most of the watershed is covered by forest, comprising 84.34% in 2010 and 62.73% in 2021. The results for Bustos Watershed further highlighted that forest land conversion experienced the most prevalent loss, while grass- or shrub-land areas exhibited the major gain, followed by agriculture, water, and built-up areas.

Most of the forests in Bustos Watershed, particularly those along water bodies, were converted into agriculture and grass- or shrub-land. Most forest areas in the municipality of Bustos were converted to agricultural areas, while the largest portions of the forest areas of Angat and San Rafael were turned to grassland or shrubland.

Overall, total C-stocks decreased in 2021 due to land conversion, whereby land cover types with higher C values were converted to land cover types with zero to low C values. Specifically, soil carbon increased, while aboveground biomass, belowground biomass, and dead litter decreased. This is particularly attributed to land cover conversion from forests to agricultural and grass- or shrub-land areas. Despite major forest loss in Bustos Watershed, its forest lands still hold the largest C-stocks in the watershed. Findings reveal that the land cover conversion significantly affects C storage at the watershed scale. The reduction in the total C-stock can be related to the increase in the areas of other land cover classes with low C-pool values. Inversely, the increase in the total C-stock can be ascribed to the rise in the total area of land cover classes with high C-pool values.

Future researchers are encouraged to collect primary data on biomass densities and field validation of the land cover types in Bustos Watershed to improve accuracy. Furthermore, studies on other portions of the Angat Watershed Forest Reserve or the entire Angat Watershed are recommended.

Most importantly, the study's results can significantly contribute to the local government units of the municipality or province by monitoring the status of the watershed, identifying the deforestation hotspots, and providing potential climate change mitigation.

LITERATURE CITED

BirdLife International. (2022). *Important Bird Areas Factsheet: Angat Watershed*. Retrieved on 29 November 2023 from: <http://datazone.birdlife.org/site/factsheet/angat-watershed-ibaphilippines/refs>.

DENR [Department of Environment and Natural Resources] Memorandum Order 2005-05. (2005). *Adopting Forestry Definitions Concerning Forest Cover/Land Use*. Retrieved on November, 23, 2023 from: https://forestry.denr.gov.ph/images/policies/2005/dmc/dmc2005-005.pdf.

Dida, J. J. V., Tiburan Jr, C. L., Tsutsumida, N., & Saizen, I. (2021). Carbon stock estimation of selected watershed in Laguna, Philippines using InVEST. *Philippine Journal of Science, 150*(2), 501–513.

Eisa, B. M. A. M., Saeed, A. M., Dafalla, M. S., & Omer, A. M. A. Y. (2022). Delineation of Wadi Haseeb Watershed from digital elevation model using HEC-Geo-HMS in ArcGIS, East Nile, Sudan. *East African Scholars Journal of Agriculture and Life Sciences, 5*(10). DOI: :10.36349/easjals.2022.v05i10.001.

El-Gammal, M., Ali, R. R., & Eissa, R. (2014). Land use assessment of barren areas in Damietta Governorate, Egypt using remote sensing. *Egyptian Journal of Basic and Applied Sciences, 1*(3), 151–160.

Escobar, S. & Hogan, V. (2020) Why Does Agriculture Threaten and Decrease The Global Carbon Balance and Stock. *Humans for Abundance*. Retrieved on 15 November 2023 from: <https://www.humansforabundance.com/post/why-does-agriculture-threaten and-decrease-the-global-carbon-balance-and-stock>.

FAO [Food and Agriculture Organization of the United Nations]. (2021). COP26: Agricultural expansion drives almost 90 percent of global deforestation. Retrieved on 11 October 2023 from: <https://www.fao.org/newsroom/detail/cop26-agricultural-expansion-drives almost-90-percent-of-global-deforestation/en>.

FAO [Food and Agriculture Organization of the United Nations] (2015). FAOSTAT database. Retrieved on 11 October 2023 from: <http://faostat3.fao.org/home/E.>

Gao, J. & O'Neil, B. C. (2020). Mapping global urban land for the 21st century with data-driven simulations and shared socioeconomic pathways. *Nature Communications, 11*.

Labata, M. M., Aranico, E. C., Tabaranza, A. E., Patricio, J. P. & Amparado, R. F. (2012). Carbon stock assessment of three selected agroforestry systems in Bukidnon, Philippines. *Advances in Environmental Sciences, 4*(1), 5–11.

Lasco, R. D., Guillermo, L. 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.

Lasco, R. D. & Pulhin, F. B. (2000). Forest land use change in the Philippines and climate change mitigation. *Mitigation and Adaptation for Strategies for Global Change, 5*, 81–97.

Lasco, R. D. & Pulhin, F. B. (2003). Philippine forest ecosystems and climate change: carbon stocks. *Annals of Tropical Research, 25*(2), 37–51.

Liang, Y., Liu, L., & Huang, J. (2017). Integrating the SD-CLUE-S and InVEST models into assessment of oasis carbon storage in Northwestern China. *Ecological Modelling, 345*, 30–40.

Magpantay, D. Z. & Cabello, D. (2011). Once a barren land, this farm is now teeming with tamarind. *Philippine Star*. Retrieved on 20 November 2023 from: <https://www.philstar.com/business/agriculture/2011/01/09/646046/once-barren-land-farm-now-teeming-tamarind>.

Mangiameli, M., Mussumeci, G., & Candiano, A. (2018). A Low-Cost Methodology for Multi-Spectral Image Classification. *International Conference on Computational Science and Its Applications* – ICCSA 2018, *10964*, 263–280.

Metropolitan Waterworks and Sewerage System [MWSS]. (2019). New centennial water source – Kaliwa dam project: Environmental impact statement. Retrieved on 11 October 2023 from <https://www.brimonitor.org/case-studies/the-new-centennial-water-source-kaliwa-dam-project-ncws-kdp/>.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D. R., Chan, K., Daily, G., Goldstein, J. & Kareiva, P. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment, 7*(1), 4–11.

Origenes, M. G. & Lapitan, R. L. (2021). Carbon stock assessment through above-ground biomass of trees at different forest composition in Mt. Malindawag, Lubilan, Naawan, Misamis Oriental, Philippines. *International Journal of Forestry, Ecology, and Environment, 3*(1), 100–113.

Petrokofsky, G., Kanamaru, H., Achard, F., Goetz, S. J., Joosten, H., Holmgren, P., Lehtonen, A., Menton, M., Pullin, A., & Wattenbach, M. (2012). Comparison of methods for measuring and assessing carbon stocks and carbon stock changes in terrestrial carbon pools. How do the accuracy and precision of current methods compare? A systematic review protocol. *Environmental Evidence, 1*(6), 1–21.

Provincial Office of Bulacan. (n.d.). Provincial Development and Physical Framework Plan 2010–2030. p. 22.

Racelis, E. L. (2005). Carbon stock assessment of large leaf mahogany (*Swietenia macrophylla* King.) and dipterocarps plantation in the Mt. Makiling Forest Reserve. College of Forestry and Natural Resources. University of the Philippines Los Baños.

Rwanga, S. S. & Ndambuki, J. M. (2017). Accuracy assessment of land use/land cover classification using remote sensing and GIS. *International Journal of Geosciences, 8*, 611–622.

Seto, K. C., Sanchez-Rodriguez, R., & Fragkias, M. (2010). The New geography of contemporary urbanization and the environment. *Annual Review of Environment and Resources, 35*, 167–194.

Sharp, R., Tallis, H. T., Ricketts, T., Guerry, A. D., Wood, S. A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C. K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M. Mandle, L., Hamel, P., Vogl, A. L., Rogers, L., Bierbower, W., Denu, D., & Douglass, J. (2018). *InVEST 3.5.0 User'sGguide*. The Natural Capital Project, Standford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

Tabios III, G. Q. & de Leon, T. Z. (2020). Assessing the Philippine irrigation development program. *Philippine Institute of Development Studies*, 1–6.

Tabios III, G. Q. & De Leon, T. (2020). Assessing the resurgent irrigation development program of the Philippines: Water resources component (No. 2020–11). PIDS Discussion Paper Series.

UNFCC [United Nations Framework Convention on Climate Change]. (2014). *Handbook on measurement, reporting, and verification for developing country parties*. United Nations Framework Convention on Climate Change, Bonn, Germany.

Villamor, G. B., Pampolina, N., Forcadilla, R., Bugtong, N., Alano, J., Rice, D., Omas, T., Castillo, R., & Pulan, D. (2010). Rapid carbon stock appraisal: Kalahan, Nueva Vizcaya, Philippines. *World Agroforestry Centre Southeast Asia Program*, 1–45.

Wang, L. & H. Liu. (2006). An efficient method for identifying and filling surface depressions in digital elevation models for hydrologic analysis and modelling. *International Journal of Geographical Information Science, 20*(2), 193–213.

Xiang, H., Jia, M., Wang, Z., Li, L., Mao, D., Zhang, D., Cui, G., & Zhu, W. (2018). Impacts of land cover changes on ecosystem carbon stocks over the transboundary of Tumen river basin in Northeast Asia. *Chinese Geographical Science, 28*(6), 973–985.

Yellajosula, G., Cihacek, L., Faller, T., & Schauer, C. (2020). Soil carbon change due to land conversion to grassland in a semi-arid environment. *Soil System, 4*(3), 43. doi: 10.3390/soilsystems4030043.