GIS-BASED APPROACH IN ESTIMATING CARBON EMISSION ATTRIBUTED BY LAND USE AND LAND COVER DYNAMICS IN BUTUAN CITY, PHILIPPINES

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ABSTRACT: Monitoring land use and land cover (LULC) dynamics is crucial in evaluating and decision-making in addressing the pressing concerns on carbon emission. Butuan City has experienced major land conversion activities ranging from the purpose of settlement driven by urbanization and expansion of agricultural areas to address the increasing demand for food and deforestation. This study used integrated methods in remote sensing, geographic information system (GIS), and Intergovernmental Panel on Climate Change (IPCC) to calculate vegetative carbon and soil organic carbon (SOC) emissions induced by LULC dynamics from 2011-2016 and 2016-2021. Land cover maps for 2011, 2016, and 2021 were generated using the Google Earth Engine with an SVM classifier using tier-based boundary delineation to minimize repetitive misclassifications and maximize the accuracy for each map of at least 93%. From 2011-2016 and 2016-2021, LULC dynamics in Butuan City showed a successive increase in grassland areas (3,910.53 ha equivalent to 784.24% and 721.31 ha equivalent to 16.36%, respectively) and water areas (66.69 ha equivalent to 5.14% and 205.657 ha equivalent to 15.065%, respectively). Other land classes has experienced area reduction during 2011-2016 and area increase in 2016-2017, such as agricultural lands (225.1 ha decrease equivalent to -1.21% 2011-2016 and 2,302.482 ha increase equivalent to 11.165% in 2016-2021), barren lands (200.1 ha decrease equivalent to -64.64% in 2011-2016, and 1,463.28 ha increase equivalent to 1,337.07% increase in 2016-2021), and built-up areas (909.02 ha decrease equivalent to -21.33% in 2011-2016, and 1,660.06 ha increase equivalent to 49.513% in 2016-2021). Forest areas have experienced successive reductions with -6.94% (2,779.075 ha) in 2011-2016 and -8.59% (3,198.656 ha) in 2016-2021. The decline in vegetation carbon stocks or vegetative carbon emissions in Butuan City was approximately 583,567.24 tons of carbon during 2011-2016 and 8,161,161.46 tons of carbon during 2016-2021. SOC emissions from land conversion involving soil activities were approximately 421,318.94 tons and 514,213.95 tons of carbon in 2011-2016 and 2016-2021, respectively. Overall, LULC dynamics have resulted in significant quantities of carbon emission of both vegetative carbon and SOC in Butuan City from 2011-2021.

1. INTRODUCTION

Anthropogenic activities have been linked by the IPCC (Intergovernmental Panel on Climate Change) to be a major contributor to the world’s climate (Houghton et al., 2012). The greenhouse gas emissions due to land use/land cover changes alter the atmosphere balance conditions, which leads to changes in climatic factors such as temperature, precipitation, humidity, sea level, and others (IPCC,2006; DeFries et al., 2002; Houghton, 2002; Leite et al., 2012).

Land conversion activities such as deforestation and land use change are considered significant contributors to introducing more greenhouse gases (GHG) into the atmosphere and are increasing over time (Smith et al., 2014; Tubiello et al., 2014). An estimated 25% of GHG emission is to be accounted to both LULC change and the burning of fossil fuels (Watson et al., 2000). Existing natural characteristics of the planet have mitigated the effects of climate change. Plants and tree ecosystems, specifically forest areas, are considered carbon sinks. These are areas where carbons are deposited on the ground instead in gaseous form, which contributes to the greenhouse effect. The carbon dioxide present in the air were also utilized by plant and trees for photosynthesis instead of being introduced into the atmosphere (Brown et al., 1996). With the increased demands for food, shelter, and basic human needs due to increased population, the forest ecosystem is under the increasing threat of land conversion for mining activities, agricultural transformation, and human settlement (FAO 2010; Houghton, 2012).

The soil structure and physical properties, including soil quality, can be affected by land management (Haghighi et al., 2010). Soil function is also strongly impacted by LULC dynamics. Depleting available carbon from biomass on the earth's surface also accounted for LULC changes by destroying primary forests and land conversions. It was considered the major carbon emission source (Don et al., 2011). The dynamics of CO2 emission are driven by the disturbance and introduction of above-ground and below-ground biomass (Brasil, 2016; Robinson et a, 2013). Several studies have accounted for a strong relationship between CO2 emission and LULC dynamics (Robinson et al., 2013; Zhu et al., 2018; IPC, 2006; DeFries et al., 2002; Houghton, 2002; Leite et al., 2012). These activities involving LULC dynamics are majorly driven by human activities (Houghton, 2002).

LULC comprehensive analysis and spatial distribution provide a better understanding of its dynamics and relate it with the impacts of carbon emission on climate change. With the development of technologies, the increased availability and improved quality of multi-spatial and multi-temporal remote sensing data, and the development of new analytical techniques and processes, it is now possible to monitor LULC dynamics timely and in a cost-effective manner way (Deng et al., 2009). Integration of visualization and geographic analysis functions with general database operation, GIS is widely used in analyzing and processing spatial information in LULC dynamics (Lee, 2018).

2. MATERIALS AND METHODS

The general methodological framework of this study, as shown in Figure 1, involves the creation of land cover maps for 2011, 2016, and 2021, analyzing the Spatio-temporal changes using the land-use and land-cover matrix in the GIS environment. Vegetative carbon emission was calculated based on the carbon density of each land conversion type. At the same time, the soil organic carbon (SOC) was calculated based on the disruptive land conversion activities, which involve vegetation removal and soil activities at a specific location based on the GSOCmap (v1.5.0) of UN-FAO (FAO, 2019). Finally, the total carbon emission is calculated by adding the vegetative carbon emission and the soil organic carbon (SOC) induced both by LULC dynamics

2.1 Study area

The study was conducted in Butuan City, Agusan del Norte, Philippines (8.951549°, 125.527725). It is a highly urbanized area in the Caraga Region, Philippines, with a total area of 817.3 square kilometers.

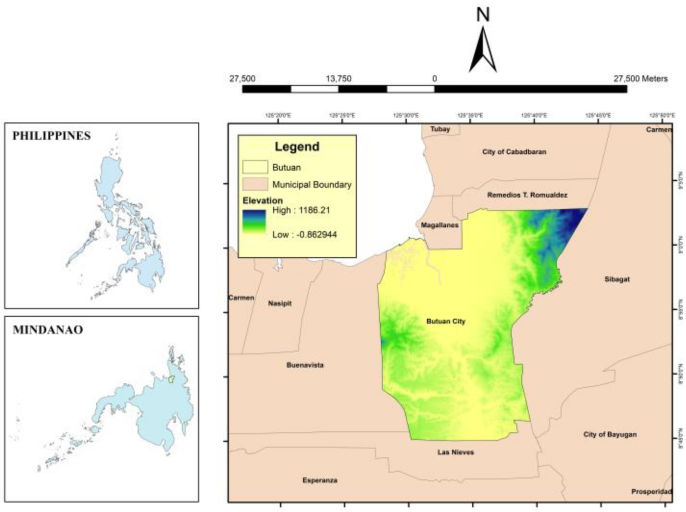


Figure 1. Butuan City, Philippines

2.2 Land Cover Classification

Land cover classifications were based on the UN-FAO 7 major land classifications such as (i) forest, (ii) agricultural areas, (iii) grassland, (iv) built-up, (v) water, (vi) barren, and (vii) wetlands (UN-FAO). The land-cover maps for 2011, 2016, and 2021 with 30-m spatial resolution were generated using the Google Earth Engine using the SVM (support vector machine) classifier. A 2-tier land cover classification process was used in creating the maps, as shown in Figure 2.

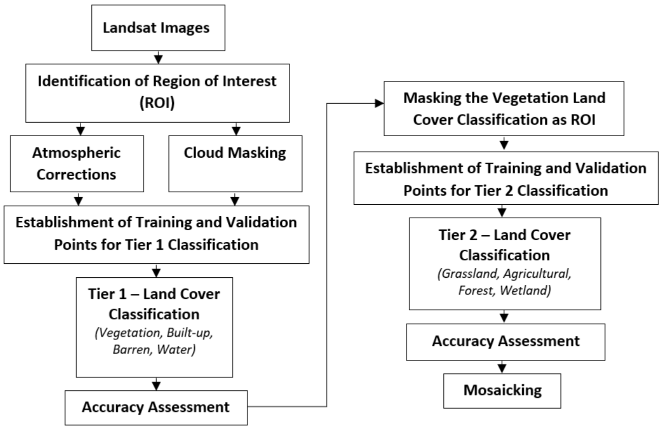


Figure 2. Land Classification Process using Google Earth Engine

2.1 LULC dynamics and transformation matrix

The LULC dynamics for 2011, 2016, and 2021 were calculated using the "from-to-approach" Intersect Tool in ArcGIS to calculate the change in the area and identify specific transformations of each land classification. The transformation matrix was created to specify the land-cover transformations for each land-cover type within the study area. Different transformation matrices for 2011-2016 and 2016-2021 were created to consider the different pacing of land-cover transformation at different time frames.

2.2 Vegetative Carbon Emission

The vegetative carbon emission was calculated using the change in carbon stock for each land use category using the IPCC 2006 values for vegetative carbon density, as shown in Table 1.

Table 1. Carbon density per land-use category (IPCC, 2006)

Land Use Category	Carbon density (t C/ha)	Source of data
Forest	165-260	IPCC default (Houghton et al, 1997)
Wetlands	15	IPCC, 2000
Agricultural land	45.4	Lasco et al, 2003
Grassland	1.24	IPCC 2000
Water	0	Qui et al, 2016
Built-up	0	Qui et al, 2016
Barren (Other land)	0.67	IPCC default (Houghton et al, 1997)

The change in vegetative carbon was the calculated in GIS environment using the equation:

$$\Delta C_{Vegetative} = \sum_{1}^{i}[(D_{AFTERi} - D_{BEFOREi}) \times \Delta Area_i] \quad \text{(Equation 1)}$$

Where $\Delta C_{Vegetative}$ represents the change in vegetative carbon storage (emission) caused by LULC dynamics; D_{AFTERi} represents the biomass carbon density of land type *i* after land conversion; ; $D_{BEFOREi}$ represents the biomass carbon density of land type *i* before land conversion; $\Delta Area_i$ represents the conversion area; and i represents the LULC converted from one type to another.

2.2 Soil Organic Carbon Emission Calculation

Soil organic carbon (SOC) was calculated by overlaying the GSOCMap raster data of UN-FAO with the LULC transformation. The amount of SOC emission was calculated based on the conversion area of each land-use type. The calculation for SOC emission has only focused on disruptive land conversion that involves soil disturbance activities.

These land-cover conversions are the following: forest-agricultural, forest-built up, forest-grassland, forest-barren, forest-water, agricultural-built up, agricultural-barren, agricultural-water, agricultural-grassland, grassland-built up, grassland-barren, grassland-water, barren-built up and barren-water. The SOC change (emission) was calculated using the formula:

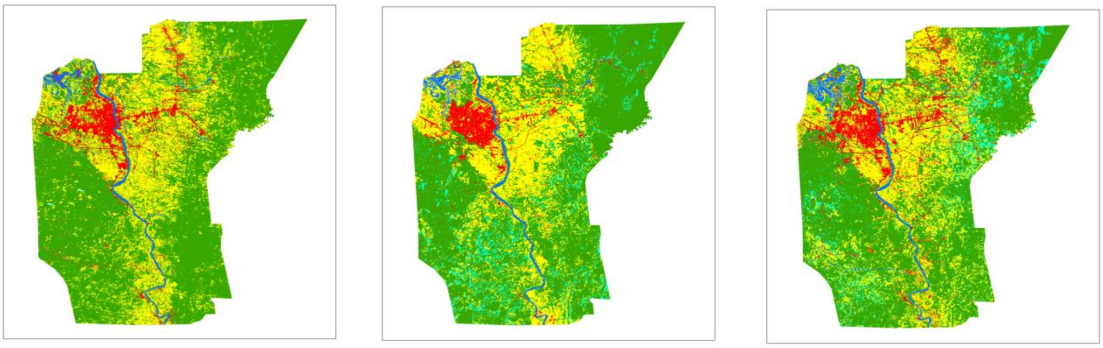
$$\Delta SOC = \sum_i (SOC_{is} \times\times \Delta Area_{is}) \qquad \text{Equation 2}$$

Where ΔSOC is the change of SOC storage; SOC_i is the SOC density per land type i; and $\Delta Area_{is}$ is the change in area per land cover change

3. RESULTS AND DISCUSSION

3.1 Land Cover Classification using Google Earth Engine

LULC maps were generated using a Support Vector Machine (SVM) classifier executed in Google Earth Engine (GEE). The images used for classification were satellite images of Landsat 7 (2011) and Landsat 8 (2016 and 2021), with cloud coverage of less than 10%. Training and validation points are limited to 1600 pixels, with a ratio of 80% for training and 20% for validation. Each of the land-cover maps, as shown in Figure 3, was iterated and retrained until it reached a minimum accuracy of at least 93%. Contextual edits were also carried out to correct some misclassified pixels using Google Earth Images.



2011 **2016** **2021**

Figure 3. LULC Maps of Butuan City (2011, 2016 and 2021)

3.2 LULC Dynamics of Butuan City from 2011-2016 and 2016-2021

Table 2. Changes in Areas and Land-use in Butuan City

	Area (2011) (ha)	Area (2016) (ha)	Percent Change (2011-2016)	Area (2021) (ha)	Percent Change (2016-2021)	Total Change (%) (2011-2021)
Agricultural	18,606.07	18,380.97	-1.21	20,683.45	12.53	11.17
Forest	40,019.27	37,240.20	-6.94	34,041.55	-8.59	-14.94
Barren	309.53	109.44	-64.64	1,572.72	1,337.07	408.09
Built-up	4,261.80	3,352.78	-21.33	5,012.84	49.51	17.62
Grassland	498.64	4,409.17	784.24	5,130.48	16.36	928.90
Water	1,298.44	1,365.13	5.14	1,570.79	15.07	20.97

Table 3. Land conversion matrix for Butuan City (2011-2021)

2011	2021						Total
	Agricultural	Barren	Built-up	Forest	Grassland	Water	
Agricultural	-	672.64	1,320.64	5977.04	1088.86	231.68	9,290.85
Barren	243.21	-	30.76	27.76	1.77	2.53	306.03
Built-up	1,289.47	371.86	-	472.60	70.28	77.90	2,282.11
Forest	7,899.71	459.39	1,194.95	-	3,889.91	189.78	13,633.74
Grassland	202.22	14.58	38.31	209.19	-	17.47	481.77
Water	243.33	22.29	30.84	62.22	15.45	-	374.13
Total	9,877.94	1,540.76	2,615.50	6,748.80	5,066.28	519.35	26,368.63

Butuan City has undergone significant land-use changes from 2011 up to 2021. A total of 26,368.63 hectares have experienced land-cover change, as shown in Table 3. Land conversion to agricultural land, forest, and grassland are the significant changes that occurred between 2011-2021. As shown in Table 2, the largest significant change for 2011-2016 was the 784.24% increase in grassland areas which is equivalent to 3,910.53 hectares and has continued to grow 16.36% in 2021, accounting for the total increase of grassland areas to 928.90% (4,631.84 ha), which is to a rate of 92.9%/yr increase in grassland in Butuan City. The increase in grassland areas was caused by several land conversion activities, such as the 3,889.91 hectares of forest areas converted to grassland and 1,088.86 hectares of agricultural land converted to grassland.

A total of 9,877.94 hectares is observed to have been converted into agricultural areas. The major contributor to this change was the 7,899.71 hectares of forest areas converted to agricultural areas. There might have been a 1.21% decrease in agricultural areas from 2011-2016, but the 12.53% increase from 2016-2021 brought the total increase of 11.165% in agricultural areas, which is equivalent to 2,077.384 hectares, with a rate of 1.12%/year increase which is approximately 207.7 hectares per year expansion of agricultural areas in Butuan City.

A sustained decrease in forest areas was observed with -6.94% from 2011 to 2016 (34,041.55 ha) and -8.59% (3,198.65 ha) from 2016-2021, bringing a total decrease of -14.94% (5,977.72 ha) from 2011-2021, indicating a rate of -1.49%/yr. It is also shown in Table 3 that a total of 13,633.74 hectares of forest areas have undergone land conversion, with 7,899.71 hectares converted to agricultural areas, 3,889.91 hectares converted to grassland, and 1,195.95 hectares converted to built-up areas, with only 6,748.80 hectares subjected to reforestation.

The fluctuation decreased on barren land from -64.64% in 2011-2016 to a 1,337.07% increase in 2016-2021. A total of 1,540.76 hectares was converted to barren land from 2011-2021. The major contributor to this change was the 672.64 hectares of agricultural land that was converted into barren. It can be observed that a total area of 2,615.50 hectares has been converted into built-up areas. The significant contributors to the increase in built-up areas were land conversion from agricultural to built-up (1,320.64 ha) and forest to built-up (1,194.95 ha), which indicate an expansion and encroachment of urbanization within Butuan City. The effect of urbanization is deemed to be inevitable and, with visible effects, as shown in Figure 4. Butuan City showed that the effect of urbanization, and population increase and could cause pressure on the environment.

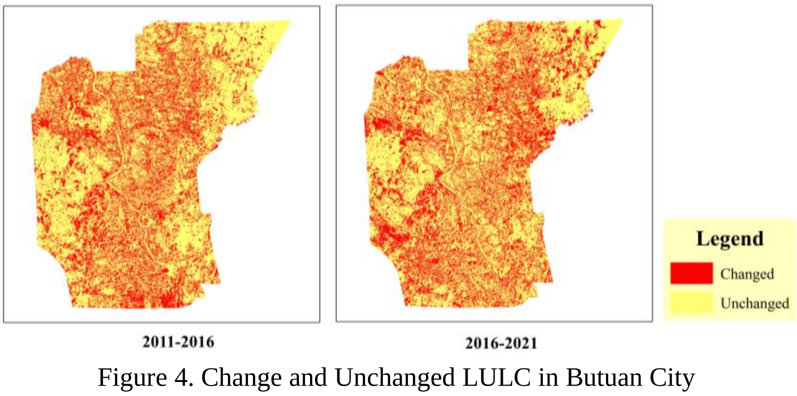


Figure 4. Change and Unchanged LULC in Butuan City

3.3 Vegetative Carbon Emission induced by LULC dynamics

The dynamics of LULC had a direct effect on the carbon stocks of Butuan City. The conversion of areas specifically lands conversion activities, which involved the removal of vegetation or biomass, impacts the amount of carbon being released into the atmosphere either through direct burning (CO2 gases) or aerobic decomposition (methane gas). The movement of carbon stock can indicate if certain activities, such as land conversion, could induce carbon sequestration or carbon emission.

Table 4 and Table 5 shows the different vegetative carbon emissions for every type of land conversion in Butuan City. Positive values indicate carbon emitted, while negative values indicate carbon sequestered. The largest contributing factor in either carbon emission or sequestration were those areas that involved forest conversion. Examples are those Forest to Agricultural areas land conversion in 2011-2016 from Table 4 that shows 1,025,823.381 tons of carbon being emitted, and in 2016-2021 as shown in Table 5 of the same LULC change, it emitted 1,062,562.90 tons of carbon. Vegetative carbon emission for both scenarios (2011-2016 and 2016-2021) shows high amounts of carbon emission. Even with the efforts to mitigate carbon emission through activities such as reforestation, etc., the total vegetative carbon emission of Butuan City from 2011-2021 was still 1.4 million tons of carbon which is equivalent to 140,000 tons of carbon per year.

Table 4. Vegetative Carbon Emission induced by LULC change (2011-2016)

LULC Change	Area Change	Carbon Density (2011)	Carbon Density (2016)	Carbon Emission (tons of C)
Agricultural - Barren	25.252	45.4	0.67	1,129.508
Agricultural - Built-up	761.244	45.4	0	34,560.461
Agricultural - Forest	6713.564	45.4	212	-1,118,479.820
Agricultural - Grassland	988.159	45.4	1.24	43637.086
Agricultural - Water	140.241	45.4	0	6,366.952
Barren - Agricultural	265.057	0.67	45.4	-11,855.992
Barren - Built-up	16.664	0.67	0	11.165
Barren - Forest	23.212	0.67	212	-4,905.391
Barren - Grassland	0.235	0.67	1.24	-0.134
Barren - Water	1.047	0.67	0	0.701
Built-up - Agricultural	1616.808	0	45.4	-73,403.077
Built-up - Barren	17.953	0	0.67	-12.028
Built-up - Forest	625.944	0	212	-132,700.051
Built-up - Grassland	25.088	0	1.24	-31.110
Built-up - Water	65.308	0	0	0.000
Forest - Agricultural	6157.403	212	45.4	1,025,823.381
Forest - Barren	51.700	212	0.67	10,925.739
Forest - Built-up	640.619	212	0	135,811.125
Forest - Grassland	3374.212	212	1.24	711,149.000
Forest - Water	132.349	212	0	28,058.085
Grassland - Agricultural	220.678	1.24	45.4	-9745.126
Grassland - Barren	2.892	1.24	0.67	1.648
Grassland - Built-up	25.610	1.24	0	31.756
Grassland - Forest	206.808	1.24	212	-43,586.930
Grassland - Water	20.654	1.24	0	25.611
Water - Agricultural	204.287	0	45.4	-9,274.638
Water - Barren	10.692	0	0.67	-7.164
Water - Built-up	20.477	0	0	0.000
Water - Forest	46.980	0	212	-9,959.656
Water - Grassland	3.111	0	1.24	-3.858
			TOTAL	**583,567.243**

Table 5. Vegetative Carbon Emission induced by LULC change (2016-2021)

Change	Area Change	Carbon Density (2011)	Carbon Density (2021)	Carbon Emission (tons of C)
Agricultural - Barren	934.18	45.4	0.67	41,785.86
Agricultural - Built-up	2,044.31	45.4	0	92,811.78
Agricultural - Forest	3,844.41	45.4	212	-640,478.39
Agricultural - Grassland	684.37	45.4	1.24	30,221.68
Agricultural - Water	342.48	45.4	0	15,548.65
Barren - Agricultural	37.68	0.67	45.4	-1,685.31
Barren - Built-up	14.65	0.67	0	9.81
Barren - Forest	17.08	0.67	212	-3,608.85
Barren - Grassland	6.90	0.67	1.24	-3.93
Barren - Water	25.79	0.67	0	17.28
Built-up - Agricultural	906.32	0	45.4	-41,147.14
Built-up - Barren	332.18	0	0.67	-222.56
Built-up - Forest	235.05	0	212	-49,829.55
Built-up - Grassland	34.13	0	1.24	-42.32
Forest - Agricultural	6,377.93	212	45.4	1,062,562.90
Forest - Barren	240.10	212	0.67	50,739.38
Forest - Built-up	768.94	212	0	163,015.23
Forest - Grassland	3,785.04	212	1.24	797,734.77
Forest - Water	54.32	212	0	11,515.92
Grassland - Agricultural	668.01	1.24	45.4	-29,499.28
Grassland - Barren	10.73	1.24	0.67	6.12
Grassland - Built-up	38.04	1.24	0	47.17
Grassland - Forest	3,119.06	1.24	212	-657,374.04
Grassland - Water	2.30	1.24	0	2.85
Water - Agricultural	287.61	0	45.4	-13,057.58
Water - Barren	19.66	0	0.67	-13.17
Water - Built-up	21.13	0	0	0.00
Water - Forest	60.80	0	212	-12,889.02
Water - Grassland	5.49	0	1.24	-6.80
			TOTAL	**816,161.46**

Carbon density for forest areas is significantly higher than any other land cover type; this indicates that any land conversion activities that involve forest conversion should be analyzed thoroughly due to the impact that they could have on the environment.

3.4 Soil Organic Carbon induced by LULC dynamics

Land conversion activities do not only emit carbon because of the removal of vegetation through conversion. Land conversion activities also trigger the release of carbon stored in the topsoil, usually at 0-30m depth, called the soil organic carbon. Soil organic carbon varies on the type of land cover and soil type. With the available GSOCmap of the UN-FAO, we could overlay the areas subjected to disruptive land cover conversion to their corresponding soil organic carbon value.

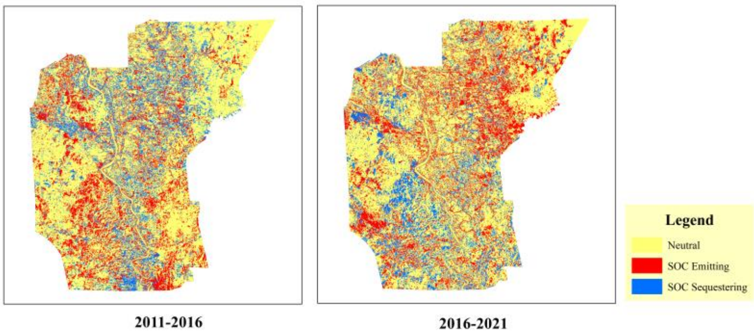


Figure 5. Soil organic carbon emission/sequestration for Butuan City

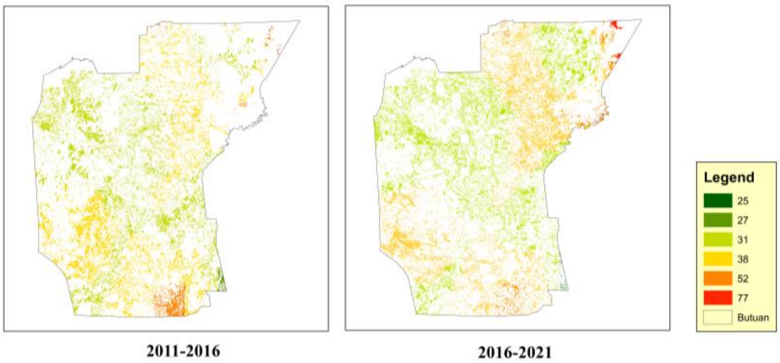


Figure 6. Soil Organic Carbon Map of Butuan City

Table 6. SOC emission per land cover change scenario

SOC (tons/ha)	Area (hectares) (2011-2016)	SOC Emission (tons of C)	Area (hectares) (2016-2021)	SOC Emission (tons of C)
25	0.183	4.565	-	-
27	78.888	2,129.968	27.757	749.428
31	5,979.673	185,369.87	7065.249	219,022.732
38	5,285.855	200,862.472	6758.966	256,840.692
52	617.343	32,101.842	602.702	31,340.502
77	11.042	850.229	81.306	6,260.598
	TOTAL	**421,318.94**		**514,213.95**

After the areas with disruptive land conversion activities were identified, the raster dataset for SOC was then extracted to calculate the total SOC emission from 2011-2016 and 2016-2021. Considering the SOC recharge duration, which is in the standard of ~20 years (IPCC, 2006), only the land cover with unextracted SOC and unchanged land cover from 2011-2016 were utilized to extract the SOC emission for 2016-2021. As shown in Table 6, the SOC emission of Butuan City from 2011-2016 and 2016-2021 are 421,318.94 tons and 14,213.95 tons of carbon, respectively. The results gave a total of 935,535.89 tons of carbon from 2011-2021, equivalent to 93,553.59 tons per year.

3.5 Total Carbon Emission

The total carbon emission induced by LULC dynamics in Butuan City was the sum of the vegetative and SOC emissions from 2011-2021. The total vegetative carbon emission was 1,399.728.7 tons of carbon, while the total SOC emission is 935,535.89 tons of carbon which gives an overall total of 2,335,264.59 tons of carbon, equivalent to 233,526.456 tons per year. The result indicates 0.684 tons of carbon emission per person per year, which is around half of the average (1.22 tons of CO_2 per person per year) CO_2 emission of the Philippines in 2016 (worldometers.info).

4. CONCLUSIONS

LULC dynamics have shown a significant impact in influencing carbon emission between soil and the atmosphere. The spatio-temporal analysis and integration of CO2 emission-induced land conversion activities could help properly evaluate urbanization's impacts on the environment. For a decade (2011-2021), Butuan City has experienced significant LULC changes, which were usually driven by the increasing level of urbanization, adapting of the agricultural zone through expansion to keep up with the increasing demand, and resulting in forest areas being converted to agricultural zones. Land conversion activities have environmental repercussions, specifically the release of carbon into the atmosphere through the removal of biomass (vegetative carbon) and disturbance in soil (SOC), which could result in an increase in greenhouse gas emissions. From the events 2011-2016 and 2016-2021, both the vegetative carbon emission and the soil organic carbon emission have sustained their increase, resulting in the release of more than 2 million tons of carbon in just a decade. Butuan City may not be yet at the limit of its allowable emission, but the behavior of how the amounts of carbon emission have increased through time. Adequate and effective countermeasures should be employed to combat the pressing concerns of global warming and climate change by mitigating carbon emissions through efforts to use efficient land-use planning activities.

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