PAN
POLSKA AKADEMIA NAUK

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

ITP-PIB

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2023.145346
2023, No. 57 (IV–VI): 159–166

Impact of land use and land cover changes on carbon stock in Aceh Besar District, Aceh, Indonesia

Ashfa Achmad[1)] ✉, Ichwana Ramli[2)], Nizamuddin Nizamuddin[3)]

[1)] Universitas Syiah Kuala, Architecture and Planning Department, Jl. Tgk. Syech Abdurrauf No. 7, 23111, Banda Aceh, Indonesia

[2)] Universitas Syiah Kuala, Agricultural Engineering, Banda Aceh, Indonesia

[3)] Universitas Syiah Kuala, Mathematics Department, Banda Aceh, Indonesia

RECEIVED 23.09.2022 ACCEPTED 31.01.2023 AVAILABLE ONLINE 02.06.2023

Abstract: The international community affirms the critical role of forests in climate change mitigation, which includes reducing emissions from degradation and deforestation, carbon stock conservation, sustainable forest management, and increasing carbon stocks in developing countries. It relates to land use and land cover changes. This study aims to review land use and land cover changes (LULC) in two decades, namely 2000–2010 and 2010–2020, and the impact on carbon stocks. Landsat satellite imagery in 2000, 2010, and 2020 are classified into six categories: built-up area, cropland, forest, water body, bareland, and grassland. This classification uses supervised classification. The accuracy kappa coefficient values obtained for the LULC 2000, LULC 2010, and LULC 2020 maps were 89.61%, 83.90%, and 87.10%, respectively. The most dominant systematic LULC change processes were forest degradation in 2000–2020; the transition of forest to cropland (349.20 ha), forest to bareland (171.19 ha), and forest to built-up area (661.68 ha). Loss of using the forest for other uses was followed by a decrease in carbon stock. There was a high decrease in carbon stock in the forest category (11,000 Mg C·y^{-1}). The results showed a significant change in land use and cover. The decline in the area occurred in the forest category, which decreased from year to year. Meanwhile, the built-up area increases every year. Carbon stocks also decrease from year to year, especially forests as the most significant carbon store, decreasing in the area.

Keywords: Aceh Besar District, carbon stock, forest, land use and land cover, landscape

INTRODUCTION

Forest ecosystems are essential in providing carbon (C), which is estimated to be 80% above ground and 40% below ground (Nakakaawa, Vedeld and Aune, 2011). The international community affirms the critical role of forests in climate change mitigation. It applies the concept of reducing emissions from deforestation and forest degradation (REDD), which includes reducing emissions from degradation and deforestation, carbon stocks conservation, sustainable forest management, and increasing carbon stocks in developing countries (Mendoza-Ponce *et al.*, 2018).

The potential of Aceh Province to provide carbon is quite significant. The province had a forest area of 3,929,420 ha in 2012 or 68.50% of the total area of Aceh Province. With such a forest area, the carbon produced is also relatively high (Sanusi, Mujibussalim and Fikri, 2013). For this reason, an appropriate REDD strategy is necessary to maintain this carbon stock, considering the decreasing forest area in Aceh. In 2018, the forest area in Aceh was around 3,004,352 ha, but by the end of 2019, it had decreased to 2,989,212 ha. Based on SK.580/MENLHK/SETJEN/SET.1/12/2018 the area of forest and marine conservation in Aceh Province is around 3,550,390.23 ha. Irrational land use leads to severe land degradation and decreases the potential for long-term carbon storage (Mendoza-Ponce *et al.*, 2018). Several previous studies have shown that a decrease in carbon stocks and the value of ecosystem services can occur due to temporal changes in the regional landscape in the form of land use and land cover (LULC) (Nakakaawa, Vedeld and Aune, 2011; Vedeld and Aune, 2011; Fidayanti, 2016; Rizki, Bintoro and Hilmanto, 2016; Barri *et al.*, 2018; Estoque *et al.*, 2018; Shen *et al.*, 2018), from natural causes, human activities, and environmental policies (Cai and Peng, 2021).

The amount of carbon stock in each land use category may vary, depending on the density and diversity of plants. Biomass measurements on various land use changes in the site combined with satellite imagery technology will provide an estimate of carbon stocks and estimate emissions from LULC changes (Kolis *et al.*, 2017; Azizalrahman and Hasyimi, 2018). Remote sensing (RS) technology is an important data source in many regional and environmental planning studies. Aside from being a monitoring tool, it can also classify LULC, identify the impact of changes that occur, and create models to produce best-fit scenarios for sustainable planning (Mushore *et al.*, 2017; Song and Deng, 2017; Achmad *et al.*, 2019). LULC maps derived from these RS data can provide important information and assist in monitoring change patterns, including composition and spatial configuration. Changes in forest area based on RS will be used to identify the value of ecosystem services and the number of carbon stocks (Mendoza-González *et al.*, 2012; Rizki, Bintoro and Hilmanto, 2016). Understanding LULC is key to enforcing a sustainable, friendly and compliant environment (Chouari, 2022).

This research produces information on the dynamics of changes in the regional landscape and carbon stocks in Aceh Besar 2000–2020. The main result is to discover the pattern of changes in LULC and the impact on carbon stocks.

MATERIALS AND METHODS

STUDY LOCATION

The regional boundaries are delegated based on the boundaries of Aceh Besar District, namely in the north bordering the Malacca Strait, in the south bordering Aceh Jaya District, in the west, it is adjacent to Pidie District, and in the east, it is bordered by Samudra Indonesia, with an area of 2,969.00 km^2 covering 23 sub-districts and 604 villages. More details can be seen in Figure 1. Aceh Besar District is located close to the equator, so this area is classified as having a tropical climate. In 2020, the average air temperature ranged from 26.42 to 28.26°C.

STUDY METHODS

To determine the pattern of changes in the landscape of the region from 2000 to 2020, the Landsat 2000, 2010, and 2020 satellite imagery (EarthExplorer, no date) are classified into six land use and land cover (LULC) categories namely: 1) forest, 2) grassland, 3) agricultural land, 4) waterbody, 5) built-up land, and 6) bareland, using ArcGIS®10.1. Classification is carried out on a supervised-maximum likelihood basis. LULC maps were tested for accuracy using reference points with the following equation (Congalton, 1991; Foody 2001):

$$OA = \frac{\sum_{k=1}^{q} n_{kk}}{N} 100\% \tag{1}$$

$$K = \frac{N \sum_{k=1}^{q} n_{kk} - \sum_{k=1}^{q} n_{k+} \cdot n_{+k}}{N^2 - \sum_{k=1}^{q} n_{k+} \cdot n_{+k}} \tag{2}$$

where: OA = overall accuracy, K = kappa coefficient, q = number of rows in matrix, N = total number of observations, n_{kk} = the number of observation in row k and column k, n_{k+} and n_{+k} = marginal totals of row k and column k respectively.

The carbon stock used for forest land cover (including degraded forest) is the average forest carbon stock data. For plantation and agricultural land cover with regular planting and harvesting cycles, time-averaged C stock data is used (Hairiah *et al.*, 2011; Agus *et al.*, 2013).

Reference data on carbon stocks in above-ground biomass used in the National Action Plan for Reducing Greenhouse Gas Emissions can be seen in Table 1. For the sub-national level (provincial and district), it is encouraged to develop local emission factors with a higher accuracy level and reflect the province's state or district. A higher tier is also indispensable in result-based carbon trading (result-based payment).

In calculating emissions, there are two approaches, namely (1) changes in carbon stocks (stock difference) and (2) calculating increases and decreases in carbon stocks (gain and loss). The method of changing carbon stocks (stock difference) is a method by estimating the difference in carbon stocks over an interval, for example, one cycle of plantation plants (Pk) or plantation forests (Ht). This method was also used by Hairiah *et al.* (2011), and Agus *et al.* (2013). The area whose use does not change in a certain period is assumed to be non-emitting (zero emissions), and the area that changes cover emits carbon, the amount of carbon contained by the initial land cover minus the carbon stock of subsequent land cover.

RESULTS AND DISCUSSION

LAND USE AND LAND COVER CHANGES

The accuracy kappa coefficient values obtained for the land use and land cover (LULC) 2000, LULC 2010, and LULC 2020 maps were 89.61, 83.90, and 87.10%, respectively, as seen in Figure 2. Figure 2 shows that the land cover is divided into six classes: bareland, built-up area, cropland, forest, grassland and water body. In Figure 3, it can be seen that the most significant land cover area from 2000 to 2010 was the forest. In 2000 the forest area reached 182,638.89 ha, and in 2010 the area increased to 184,006.71 ha. The second largest land cover is cropland. In 2000 cropland had an area of 52,747.20 ha, and in 2010 it had an additional area of 55,383.12 ha. Then there were grasslands in 2000 with an area of 28,423.62 ha and in 2010 with an area of 29,274.30 ha. The built-up area was 10,206.36 ha in 2000 and 11,559.78 ha in 2010. While the waterbody is a land cover with the smallest area, namely in 2000, it had an area of 3,280.77 ha and in 2010 only slightly increased to 3,586.05 ha.

From 2010 to 2020 (Fig. 3), forests were the most extensive of the six land cover classifications. In 2020 forest area decreased from 184,006.71 to 183,354.57 ha. Cropland from 2010 to 2020 also decreased from 55,383.12 ha to 54,128.70 ha. Bareland also experienced a decrease in the area, in 2010, it had an area of 13,298.31, and in 2020, it was reduced to 12,861.45 ha. Meanwhile, the built-up area from 2010 to 2020 has increased from 11,559.78 ha to 15,038.01 ha.

From the results of the analysis, it was found that there were many changes in land from 2000 to 2010. However, the land changes were insignificant; only some land cover was significantly changed. From the analysis results, a lot of land area decreased from

Fig. 1. Study area – Aceh Besar District, Aceh Province, Indonesia; source: own elaboration based on Nations Online Project (2022), Portal Tataruang (2022) and EarthExplorer (2022)

2000 to 2020. The most significant decrease in land area from 2000 to 2010 was bareland, with a decrease of 6,949.98 ha. Meanwhile, the most significant change in the land area that increased from 2000 to 2020 is the built-up area, with an area of 4,831.65 ha.

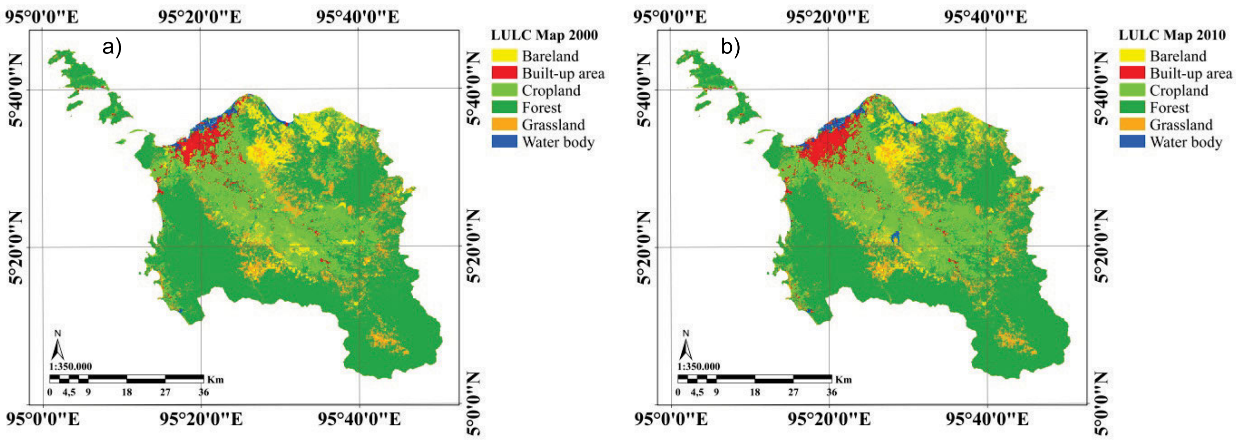
From 2000 to 2010, bareland experienced a decrease in land area. The change from bareland to cropland is the largest area, 2,823.03 ha (Tab. 2). Bareland also turned into a forest with an area of 1,912.14 ha and grassland with an area of 1,613.97 ha. Bareland land conversion into waterbody has the slightest land change, only 55.26 ha. From 2000 to 2010, cropland also changed into a built-up area of 1,036.17 ha. Meanwhile, forests also have land cover changes, but they are insignificant.

Based on Table 3, there are land changes from 2010 to 2020. This is indicated by a decrease in the bareland area from 13,298.31 ha to 12,861.45 ha. Changes in the land, from bareland, changed to a built-up area with an area of 697.95 ha, cropland – of 21.78 ha and forest – of 2.79 ha. Cropland experienced the most significant land change to a built-up area with an area of 1,811.07 ha. Forest also experienced a land change into a bareland with an area of 155.52 ha and a built-up area of 499.41 ha.

Table 1. Recommended above-ground emission factors (carbon stocks) for inventorying emissions from land use change on a national scale

Land cover	C ($Mg \cdot ha^{-1}$)	Source
Secondary forest	169	World Agroforestry Centre (2011) for the high-density secondary forest; Rahayu *et al.* (2005); IPCC (2006) for tropical Asia; Saatchi *et al.* (2011); World Agroforestry Centre (2011) for the low-density forest, Harja *et al.* (2011) with consecutive values of 250, 203, 180, 158, 150 and 74 $Mg \cdot ha^{-1}$
Plantation forest	64	World Agroforestry Centre (2011) mineral soil 70 $Mg \cdot ha^{-1}$, peat soil 60 $Mg \cdot ha^{-1}$
Shrubs	30	IPCC (2006); Istomo *et al.* (2006); Jepsen (2006); World Agroforestry Centre (2011) consecutive 35, 30, 20 and 27 $Mg \cdot ha^{-1}$
Grassland	4	Rahayu *et al.* (2005)
Waterbody	0	assumption
Cropland	30	Rahayu *et al.* (2005) (agroforestry)
Build-up area	4	World Agroforestry Centre (2011)
Non-build-up area	2.5	assumption

Source: PPN/Bappenas (2014).



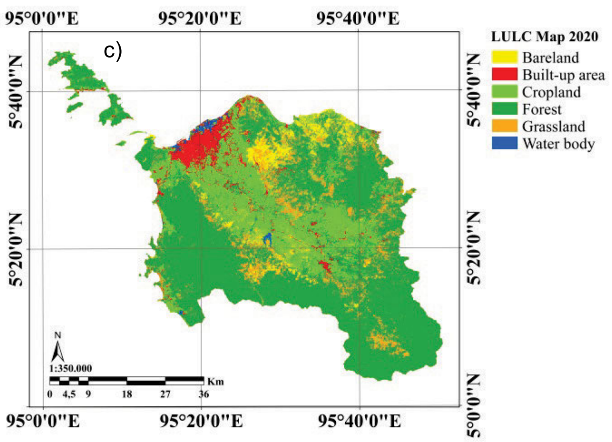


Fig. 2. Land use and land cover (LULC) maps of the years: a) 2000, b) 2010, c) 2020; source: own study

Meanwhile, the built-up area from 2010 to 2020 continues to expand. Many croplands, bareland, and less productive forests are converted into built-up areas that can meet the increasing needs of the population every year (Nakakaawa, Vedeld and Aune, 2011; Agus *et al.*, 2013; Kolis *et al.*, 2017).

Table 4 shows the land change matrix from 2000 to 2020. Significant land changes occurred in bareland, which experienced the largest decrease in the area – 6,949.98 ha. Bareland has changed land into several land covers, namely cropland, with the most significant addition of 2,801.97 ha, built-up area, forest, grassland, and waterbody. The change of land from bareland to cropland occurs due to the large number of bareland clearings that are considered less productive into cropland that is used for productive agricultural land so that it can support food security and the economy of the surrounding community (Li *et al.*, 2016; Nguyen *et al.*, 2017).

The built-up area has a tremendous change in area addition, reaching 4,831.65 ha. It is indicated by many bareland, forest,

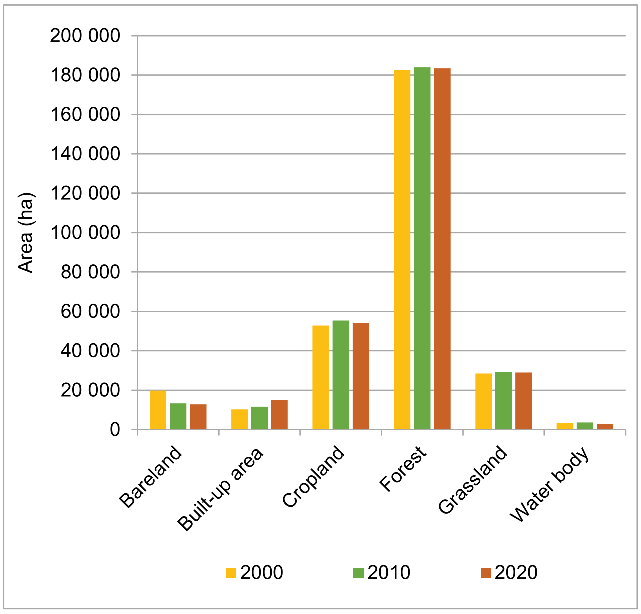


Fig. 3. Land use and land cover (LULC) changes in 2000, 2010 and 2020; source: own study

Changes in land cover that occurred from 2000 to 2020 are indeed undeniable. With the increasing population growth rate and economic growth that occurs every year, it is urgently necessary to meet the needs of space to meet various needs and development (Herath, Halwatura and Jayasinghe, 2018; Doan, Kusaka and Nguyen, 2019). So the need for productive land to meet human needs will continue to increase. However, this land change must also continue to be considered so as not to harm the surrounding environment and must continue to follow the policies and spatial plans that have been set. Therefore, all land changes must have good planning to be able to maintain and preserve the environment and prevent various uncontrolled land changes so that land changes that occur can follow the spatial plan and are sustainable (Ambrey *et al.*, 2017; Xie *et al.*, 2017).

THE CHANGES IN CARBON STOCKS

The results of the calculation of carbon stocks are presented in Table 5. Based on carbon calculations (using Tab. 1), in 2000, with bareland area of 19,811.43 ha, the carbon stock was 49,528.58 Mg. With a built-up area of 10,206.36 ha, the carbon stock is 40,825.44 Mg. With a cropland area of 52,747.2 ha, the carbon stock is 1,582,416.00 Mg. With a forest area of 182,638.89 ha, the carbon stock is 30,865,972.41 Mg. In grassland with an area of 28,423.62 ha, the carbon stock is 113,694.48 Mg,

Table 2. Land use and land cover (LULC) changes matrix 2010 against 2000

LULC category in 2000	LULC category in 2010						
	bareland	built-up area	cropland	forest	grassland	water body	grand total
Bareland	13,277.43	129.60	2,823.03	1,912.14	1,613.97	55.26	19,811.43
Built-up area	–	10,206.36	–	–	–	–	10,206.36
Cropland	–	1,036.17	51,505.56	0.99	–	204.48	52,747.20
Forest	20.88	163.80	349.20	182,093.58	–	11.43	182,638.89
Grassland	–	11.52	705.33	–	27,660.33	46.44	28,423.62
Water body	–	12.33	–	–	–	3,268.44	3,280.77
Grand total	13,298.31	11,559.78	55,383.12	184,006.71	29,274.30	3,586.05	297,108.27

Source: own study.

Table 3. Land use and land cover (LULC) changes matrix 2020 against 2010

LULC category in 2010	LULC category in 2020						
	bareland	built-up area	cropland	forest	grassland	water body	grand total
Bareland	12,575.79	697.95	21.78	2.79	–	–	13,298.31
Built-up area	–	11,559.78	–	–	–	–	11,559.78
Cropland	4.50	1,811.07	53,559.81	–	7.74	–	55,383.12
Forest	155.52	499.41	–	183,351.78	–	–	184,006.71
Grassland	100.98	153.18	–	–	29,020,14	–	29,274.30
Water body	24.66	316.62	547.11	–	–	2,697.66	3,586.05
Grand total	12,861.45	15,038.01	54,128.70	183,354.57	29,027.88	2,697.66	297,108.27

Source: own study.

cropland, grassland and waterbody being converted into built-up areas. From the results of the analysis, it can be seen that the built-up area continues to increase every year. It is due to a large number of land conversions of bareland, cropland, forest and grasslands for built-up areas with increasing demand.

Table 4. Land use and land cover (LULC) changes matrix 2020 against 2000

LULC category in 2000	LULC category in 2020						
	bareland	built-up area	cropland	forest	grassland	water body	grand total
Bareland	12,560.22	872.37	2,801.97	1,908.09	1613.52	55.26	19,811.43
Built-up area	–	10,206.36	–	–	–	–	10,206.36
Cropland	4.50	2,799.36	49,730.13	0.99	7.74	204.48	52,747.20
Forest	171.19	661.68	349.20	181,445.49	–	11.43	182,638.89
Grassland	100.98	169.29	700.29	–	27,406.62	46.44	28,423.62
Water body	24.66	328.95	547.11	–	–	2,380.05	3,280.77
Grand total	12,861.45	15,038.01	54,128.70	183,354.57	29,027.88	2,697.66	297,108.27

Source: own study.

Table 5. Carbon stock in each land use and land cover (LULC) category

LULC category	Carbon stock (Mg)		
	2000	2010	2020
Bareland	49,528.58	33,245.78	32,153.63
Built-up area	40,825.44	46,239.12	60,152.04
Cropland	1,582,416.00	1,661,493.60	1,623,861.00
Forest	30,865,972.41	31,097,133.99	30,986,922.33
Grassland	113,694.48	117,097.20	116,111.52
Water body	0.00	0.00	0.00

Source: own study.

while the waterbody with an area of 3,280.77 ha does not produce carbon stock. In 2010 and 2020, there were changes in the area, which impacted the carbon reserves of each land cover. The following Table 5 shows the carbon stock for each land cover.

In Table 6 can be seen that bareland has decreased in the area so that the carbon stock in bareland land cover decreased by 16,282.80 Mg in 2000–2010 and experienced another decrease by 1,092.15 Mg in 2010–2020. The built-up area land cover increased by 5,413.68 Mg in 2000–2010 and experienced another increase by 13,912.92 Mg in 2010–2020. In cropland, land cover increased by 79,077.60 Mg in 2000–2010 and decreased by 37,632.60 Mg in 2010–2020. Forest land cover increased by 231,161.58 Mg in 2000–2010 and decreased by 110,211.66 Mg in 2010–2020. Grassland land cover increased by 3,402.72 Mg in 2000–2010 and decreased by 985.68 Mg in 2010–2020. For more details on carbon stock changes for each land use and land cover category that occurred from 2000 to 2020, it can be seen in Figure 4.

Table 6. Changes in carbon stock in each land use and land cover (LULC) category

LULC category	Change in carbon stock ($Mg \cdot ha^{-1}$)	
	2000–2010	2010–2020
Bareland	–16,282.80	–1,092.15
Built-up area	5,413.68	13,912.92
Cropland	79,077.60	–37,632.60
Forest	231,161.58	–110,211.66
Grassland	3,402.72	–985.68
Water body	0.00	0.00

Source: own study

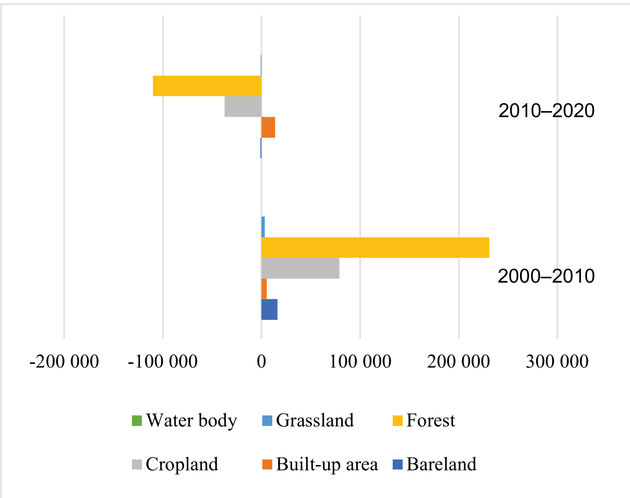


Fig. 4. Differences in changes in carbon stock; source: own study

CONCLUSIONS

This paper provides a detailed analysis of the dynamics of each land use and land cover (LULC) category change in Aceh Besar District over two decades, namely 2000–2010 and 2010–2020. This study yields valuable information on patterns and drivers of LULC changes and on changes in carbon stocks. This information, on the one hand, provides the basis for a more comprehensive study of alternative mitigations related to the LULC change process. These results are critical in advancing our knowledge of the complex LULC change process and the carbon cycle. The most dominant systematic LULC change processes were forest degradation in 2000–2020; the transition of forest to cropland (349.20 ha), forest to bareland (171.19 ha), and forest to built-up area (661.68 ha). The loss of the forest occurs in the central part of the district, where the forest has been converted to scrub and grassland mainly due to overuse for subsistence grazing and commercial firewood. Loss of using the forest for other uses was followed by a decrease in carbon stock. There was also a high carbon stock decrease in the forest category (11,000 Mg $C \cdot y^{-1}$). Future investigations may provide us with a topic to discuss how adding other relevant factors will alter the model's predictions compared to empirical observations. Future efforts may consider incorporating more complex dynamic biomass growth models for different land uses. The upcoming activity is creating a relevant spatial planning scenario so that forests are still conserved as protected areas, and carbon stocks are maintained.

ACKNOWLEDGEMENTS

We thank Universitas Syiah Kuala and the Ministry of Education, Culture, Research, and Technology, Republic of Indonesia for supporting this research.

FUNDING

This research was funded by the Ministry of Education, Culture, Research, and Technology, Republic of Indonesia, Contract No. 32/UN11.2.1/PT.01.03/DPRM/2022.

REFERENCES

Achmad, A. *et al.* (2019) "Land use and cover changes and their implications on local climate in Sabang City, Weh Island, Indonesia," *Journal of Urban Planning and Development*, 145(4). Available at: https://doi.org/10.1061/(asce)up.1943-5444.0000536.

Agus, F. *et al.* (2013) "Historical CO_2 emissions from land use and land use change from the oil palm industry in Indonesia, Malaysia and Papua New Guinea," in *Reports from the Technical Panels of the 2nd Greenhouse Gas Working Group of the Roundtable on Sustainable Palm Oil*. RSPO, pp. 65–88. Available at: https://www.tropenbos.org/resources/publications/historical+co2+emissions+from+land+use+and+land+use+change+from+the+oil+palm+industry+in+indonesia,+malaysia+and+papua+new+guinea (Accessed: April 21, 2022).

Ambrey, C.L. *et al.* (2017) "Cultivating climate justice: Green infrastructure and suburban disadvantage in Australia," *Applied Geography*, 89, pp. 52–60. Available at: https://doi.org/10.1016/j.apgeog.2017.10.002.

Azizalrahman, H. and Hasyimi, V. (2018) "Dataset normalization for low carbon cities in a multi-criteria evaluation model," *Data in Brief*, 18, pp. 1111–1116. Available at: https://doi.org/10.1016/j.dib.2018.03.130.

Barri, M.F. *et al.* (2018) *Deforestasi Tanpa Henti: Potret Deforestasi di Sumatera Utara, Kalimantan Timur, dan Maluku Utara [Endless deforestation: A portrait of deforestation in North Sumatra, East Kalimantan and North Maluku]*. Edited by A. Ruwindrijarto and C. Purba. Bogor: Forest Watch Indonesia. Available at: https://fwi.or.id/wp-content/uploads/2018/03/deforestasi_tanpa_henti_2013-2016_lowress.pdf (Accessed: June 10, 2022).

Cai, W. and Peng, W. (2021) "Exploring spatiotemporal variation of carbon storage driven by land use policy in the Yangtze River delta region," *Land*, 10(11), 1120. Available at: https://doi.org/10.3390/land10111120.

Chouari, W. (2022) "Land Use/Land Cover change detection in the wetlands. A case study: Al-Aba Oasis, west of Ras Tanura, Kingdom of Saudi Arabia," *Journal of Water and Land Development*, 53, pp. 229–237. Available at: https://doi.org/10.24425/jwld.2022.140802.

Congalton, R.G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, 37(1), 35–46. Available at: https://doi.org/10.1016/0034-4257(91)90048-B.

Doan, V.D., Kusaka, H. and Nguyen, T.Q. (2019) "Roles of past, present, and future land use and anthropogenic heat release changes on urban heat island effects in Hanoi, Vietnam: Numerical experiments with a regional climate model," *Sustainable Cities and Society*, 47, 101479. Available at: https://doi.org/10.1016/j.scs.2019.101479.

EarthExplorer (no date). USGS. Available at: https://earthexplorer.usgs.gov/ (Accessed: June 24, 2022).

Estoque, R.C. *et al.* (2018) "Changes in the landscape pattern of the La Mesa Watershed – The last ecological frontier of Metro Manila, Philippines," *Forest Ecology and Management*, 430, pp. 280–290. Available at: https://doi.org/10.1016/j.foreco.2018.08.023.

Fidayanti, N. (2016) "Analisis serapan karbondioksida berdasarkan tutupan lahan di kota Palangka Raya [Analysis of carbon dioxide absorption based on land cover in the city of Palangka Raya]," *Jurnal Matematika, Saint, Dan Teknologi*, 17(2), pp. 77–85. Available at: https://jurnal.ut.ac.id/index.php/jmst/article/view/197 (Accessed: March 10, 2023).

Foody, G.M. (2002). "Status of land cover classification accuracy assessment," *Remote Sensing of Environment*, 80(1), 185–201. Available at: https://doi.org/10.1016/S0034-4257(01)00295-4.

Hairiah, K. *et al.* (2011) *Measuring carbon stocks across land use systems: A manual*. Bogor: World Agroforestry Centre.

Herath, H.M.P.I.K., Halwatura, R. and Jayasinghe, G.Y. (2018) "Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy," *Urban Forestry & Urban Greening*, 29, pp. 212–222. Available at: https://doi.org/10.1016/j.ufug.2017.11.013.

Kolis, K. *et al.* (2017) "Forest land consolidation and its effect on climate," *Land Use Policy*, 61, pp. 536–542. Available at: https://doi.org/10.1016/j.landusepol.2016.12.004.

Li, X. *et al.* (2016) "Spatial and temporal patterns of wetland cover changes in East Kolkata Wetlands, India from 1972 to 2011," *International Journal of Applied Geospatial Research*, 7(2), pp. 1–13. Available at: https://doi.org/10.4018/ijagr.2016040101.

Mendoza-González, G. *et al.* (2012) "Land use change and its effects on the value of ecosystem services along the coast of the Gulf of

Mexico," *Ecological Economics*, 82, pp. 23–32. Available at: https://doi.org/10.1016/j.ecolecon.2012.07.018.

Mendoza-Ponce, A. *et al.* (2018) "Identifying effects of land use cover changes and climate change on terrestrial ecosystems and carbon stocks in Mexico," *Global Environmental Change*, 53, pp. 12–23. Available at: https://doi.org/10.1016/j.gloenvcha.2018.08.004.

Mushore, T.D. *et al.* (2017) "Linking major shifts in land surface temperatures to long term land use and land cover changes: A case of Harare, Zimbabwe," *Urban Climate*, 20, pp. 120–134. Available at: https://doi.org/10.1016/j.uclim.2017.04.005.

Nakakaawa, C.A., Vedeld, P.O. and Aune, J.B. (2011) "Spatial and temporal land use and carbon stock changes in Uganda: Implications for a future REDD strategy," *Mitigation and Adaptation Strategies for Global Change*, 16, pp. 25–62. Available at: https://doi.org/10.1007/s11027-010-9251-0.

Nations Online Project (no date) *Map of Southeast Asia*. Available at: https://www.nationsonline.org/oneworld/map_of_southeast_asia.htm (Accessed: July 15, 2022).

Nguyen, H.H. *et al.* (2017) "Land-use change and socio-ecological drivers of wetland conversion in Ha Tien Plain, Mekong Delta, Vietnam," *Land Use Policy*, 64, pp. 101–113. Available at: https://doi.org/10.1016/j.landusepol.2017.02.019.

Portal Tata Ruang (2022) *Gambar Peta Aceh Lengkap dengan Nama Kabupaten dan Kota [Complete map of Aceh with regency and city name]*. Available at: https://www.tataruang.id/2022/05/17/gambar-peta-aceh-lengkap-dengan-nama-kabupaten-dan-kota/ (Accessed: July 20, 2022).

PPN/Bappenas (2014) *Penghitungan Baseline Emisi dan Serapan Gas Rumah Kaca Sektor Berbasis Lahan [Technical guidelines for calculation of baseline greenhouse gas emissions and absorption in the land-based sector]*. Jakarta: Badan Perencanaan Pembangunan Nasional Republik Indonesia.

Rizki, G.M., Bintoro, A. and Hilmanto, R. (2016) "Perbandingan emisi karbon dengan karbon tersimpan di Hutan Rakyat Desa Buana Sakti Kecamatan Batanghari Kabupaten Lampung Timur [Comparison of carbon emissions with carbon stored in the Community Forest of Buana Sakti Village, Batanghari District, East Lampung Regency]," *Jurnal Sylva Lestari*, 4(1), pp. 89–96. Available at: https://doi.org/10.23960/jsl1489-96.

Sanusi, Mujibussalim and Fikri (2013) "Perdagangan karbon Hutan Aceh: Analisis hukum pada tahapan perencanaan [Aceh's Forest carbon trading: Legal analysis at the planning stage]," *Kanun Jurnal Ilmu Hukum*, 59, pp. 41–63. Available at: http://e-repository.unsyiah.ac.id/kanun/article/download/6159/5061 (Accessed: July 8, 2022).

Shen, L. *et al.* (2018) "What drives the carbon emission in the Chinese cities? – A case of pilot low carbon city of Beijing," *Journal of Cleaner Production*, 174, pp. 343–354. Available at: https://doi.org/10.1016/j.jclepro.2017.10.333.

SK.580/MENLHK/SETJEN/SET.1/12/2018 Tentang perubahan ketiga atas keputusan menteri kehutanan No. SK.865/MENHUT-II/2014 Tanggal 29 September 2014 tentang Kawasan Hutan dan Konservasi Perairan Provinsi Aceh [SK.580/MENLHK/SETJEN/SET.1/12/2018 Regarding the third amendment to the decision of the Minister of Forestry No. SK.865/MENHUT-II/2014 dated September 29, 2014 concerning Forest Areas and Marine Conservation of Aceh Province]. Jakarta: Kementrian Lingkungan Hidup dan Kehutanan, Republik Indonesia.

Song, W. and Deng, X. (2017) "Land-use/land-cover change and ecosystem service provision in China," *Science of the Total Environment*, 576, pp. 705–719. Available at: https://doi.org/10.1016/j.scitotenv.2016.07.078.

Xie, G. *et al.* (2017) "Dynamic changes in the value of China's ecosystem services," *Ecosystem Services*, 26, pp. 146–154. Available at: https://doi.org/10.1016/j.ecoser.2017.06.010.