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The impact of land use and land cover changes on ecosystem service value in Aceh Besar Regency, Aceh, Indonesia

Ashfa Achmad*[1,a], Ichwana Ramli[2,b], Nizamuddin Nizamuddin[3,c], Arief Gunawan[1], Siti Zahrina Fakhrana[1]

[1]Universitas Syiah Kuala, Architecture and Planning Department, Banda Aceh, Indonesia
[2]Universitas Syiah Kuala, Agricultural Engineering Department, Banda Aceh, Indonesia
[3]Universitas Syiah Kuala, Mathematics Department, Banda Aceh, Indonesia
*E-mail: ashfa.achmad@usk.ac.id
[a]https://orcid.org/0000-0001-9343-4980, [b]https://orcid.org/0000-0003-3169-8328, [c]https://orcid.org/0000-0003-2932-8651

Abstract. Land use and land cover (LULC) have a significant impact on changes in the value of ecosystem services. Therefore, this study investigated the relationship between ecosystem service value (ESV) and LULC in Aceh Besar Regency by calculating nine ESV variables, namely gas regulation (GR), water supply (WS), soil formation (SF), waste treatment (WT), biodiversity protection (BP), food production (FP), raw materials (RM), recreation (RC), and culture (CT) on each type of land cover in Aceh Besar Regency in three years: 2000, 2010 and 2020. The results showed that both decades saw in all three years, there was a decrease in the value of the forest ecosystem in Aceh Besar Regency due to the addition of activities and population needs, resulting in the conversion of forest land into built-up areas. This indicates that there is a relationship between land use and land cover change and human activities that have the potential to negatively affect the value of ecosystem services.

Key words:
ecosystem service value,
land use and land cover,
transformation,
Aceh Besar Regency

Introduction

Ecosystem services (ES), which include the supply of resources, control of biological processes and the cultural and aesthetic experiences provided by ecosystems, are the priceless advantages that humans derive from nature. The study of ecosystem services is crucial because it enables us to comprehend the complex interactions between people and nature. The term "ecosystem services" refers to the wide range of advantages that ecosystems offer to people, such as the supply of resources, control of natural processes, stimulation of the senses, support for human health and livelihoods, and experiences of culture and beauty (Sandifer et al. 2015; Song and Deng 2017; Zhang et al. 2017; Crouzat et al. 2022).

Studying ecosystem services promotes sustainable development and gives crucial information for accomplishing sustainable development objectives. Numerous products and services that are essential for human existence and economic growth are provided by ecosystems, such as food, water and lumber. Ecosystem services' significant contribution to the world's economies have been calculated in terms of economic worth (Costanza et al. 1997; Costanza and Kubiszewski 2012). Policymakers and resource managers may make well-informed decisions that prioritize the natural resources' sustainable use while preserving their long-term availability by comprehending the function and value of ecosystem services. Several possible benefits of exposure to natural surroundings are improved mental health, stress reduction and general well-being (Hartig et al. 2014). Ecosystem services will help us comprehend how nature improves human health, happiness and quality of life, and will also help us with design strategies to maximize these benefits for individuals and communities.

We can better understand the function of ecosystems in regulating the climate and develop plans for their preservation and restoration by researching these functions. To increase the efficacy and resilience of climate change mitigation and adaptation methods, there is a need to incorporate ecosystem-based approaches (Costanza et al. 1997).

Previous research on ecosystem services has shed important light on how environment and human well-being are interdependent. If conservation initiatives, sustainable development strategies and policymaking at various scales are to be effective, it is crucial to comprehend the provisioning, regulating, cultural and health-related services provided by ecosystems. We may work toward a more balanced and harmonious relationship with our environment and ensure that benefits continue to be provided for both present and future generations by appreciating the importance of ecosystems and the services they provide.

The availability of these services is decreased when natural habitats are converted to agricultural or urban areas. For instance, agricultural deforestation can result in worse soil, poorer water quality and biodiversity loss, all of which have an adverse effect on food production and water supply. There is a need for sustainable land management strategies that balance resource extraction with ecosystem preservation by demonstrating the trade-offs between land conversion for agriculture and the possible loss of other ecosystem services (Foley et al. 2005).

Deforestation and reforestation are two examples of changes in plant cover that might interfere with these regulatory functions, increasing greenhouse gas emissions, lowering water quality and increasing susceptibility to natural catastrophes. In order to prevent climate change and foster resilience, the effects of land use change on the global carbon cycle must be understood and the importance of taking these regulatory functions into account in land management choices must be emphasized (Vitousek et al. 1997).

The provisioning, regulating, cultural and sustaining functions of ecosystems are impacted by changes in LULC, which have a considerable impact on the value of ecosystem services. For the purpose of advancing sustainable resource management, protecting biodiversity and guiding policy choices, it is essential to comprehend these consequences. We may work towards a more balanced and harmonious approach to land management, guaranteeing the continuous availability of benefits from nature for current and future generations by acknowledging the interdependence between land use changes and ecosystem service value.

Materials and methods

The LULC transformation uses the findings from previous research (Achmad et al. 2023). The study location is shown in Figure 1. In this section, only the calculation of ESV and its relationship with LULC transformation are presented. Ecosystem service variables are 1) gas regulation (GR); 2) water supply (WS); 3) soil formation (SF); 4) waste treatment (WT); 5) biodiversity protection (BP); 6) food production (FP); 7) raw materials (RM); 8) recreation (RC); and 9) culture (CT) (Costanza et al. 1997; Estoque and Murayama 2012):

$$\mathrm{ESV}=\sum(A_i \times VC_i)$$

where:
ESV: ecosystem series value
A_i: the area of the i^{th} land ecosystem (ha)
VC_i: ecosystem services value per unit area of the ith land ecosystem

Results and discussion

Land cover change and population growth in Aceh Besar

The global ecosystem services are being reduced as a result of human-induced challenges such as population growth, urbanization and agricultural development, which is causing LULC transitions to

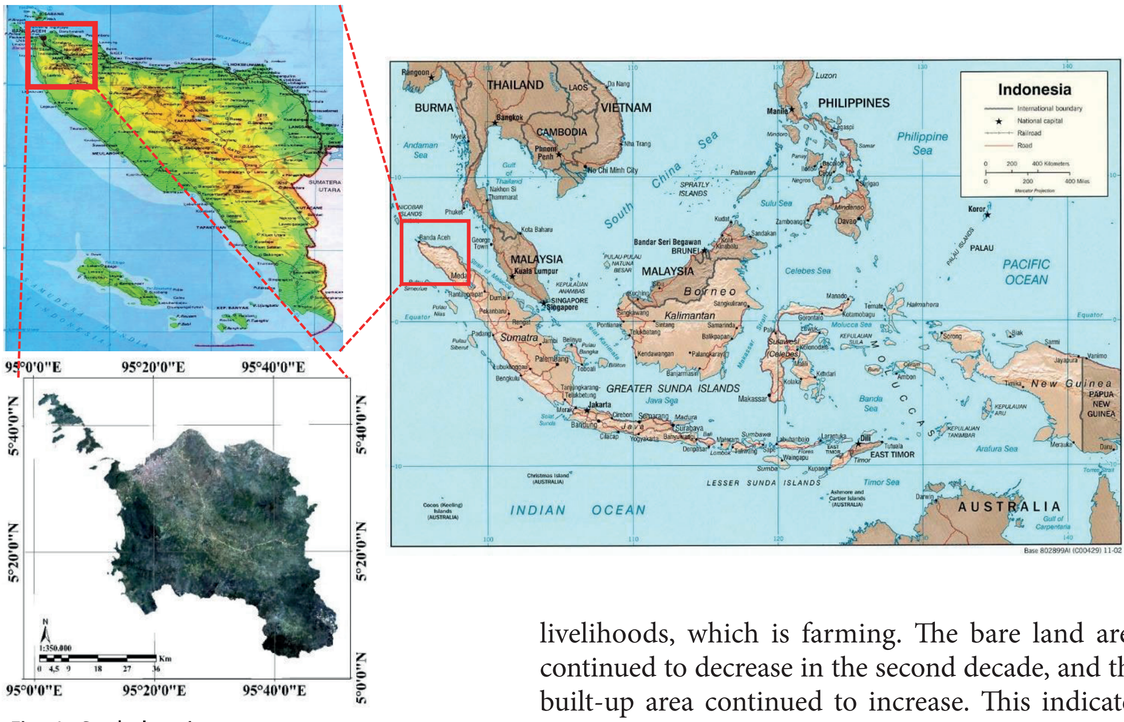

Fig. 1. Study location
Source: Achmad et al. 2023

proceed quickly (Song et al. 2015). The existence of reliable information on LULC changes is essential for land management and planning (Fan et al. 2019). Figure 2 describes land cover changes in Aceh Besar Regency for each decade from 2000 to 2020. In this research, there are six land covers that are observed for changes, namely bare land, built-up area, cropland, forest, grassland and water body. Information on the extent of these land covers was retrieved from previous research (Achmad et al. 2023).

Population and GDRP have a considerable influence on the dynamics of land cover area changes. Table 1 shows the population in Aceh Besar for the years 2000, 2010 and 2020, where there was an increase in population of 116,778. If data on population and land cover change are linked, there is some interesting information that could be taken away.

By the year 2010, there had been a significant increase in both population and built-up area. The addition of 112,156 persons affects the development in Aceh Besar. Construction to meet basic human needs might have happened while converting bare land to built-up areas. At the same time, there was an increase in cropland of 2,807 ha. This is in accordance with one of Aceh Besar's main livelihoods, which is farming. The bare land area continued to decrease in the second decade, and the built-up area continued to increase. This indicates that population growth affects the conversion of bare land to built-up areas for living and activities, as well as to land with specific purposes to support livelihoods, such as cropland. The expansion of agricultural land for food production was the main driver of ESV changes in the area (Muche et al. 2023).

Dynamic changes happened to the area of the forest. In 2010, there was a decrease of 220 ha forest in conjunction with the population growth.

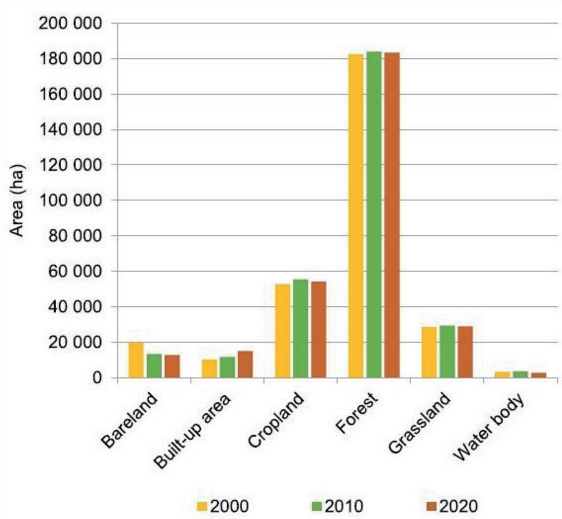

Fig. 2. Land Use and Land Cover Change (LULC) in 2000, 2010 and 2020
Source: Achmad et al. 2023

Table 1. Population of Aceh Besar Regency in 2000, 2010 and 2020

Year	Total Population
2000	288,757
2010	400,913
2020	405,535

Source: BPS Aceh Besar (2000, 2010, 2020)

This may have been due to the conversion of forest land into area to support population needs or deforestation. The reduction continued to happen in the next decade, with a further reduction of 600 ha of forest land compared to the previous decade. This phenomenon should be addressed before it becomes harmful to the environment.

The most notable factor contributing to ecosystem deterioration in many locations is the conversion of natural areas into farms and urban areas (Elias et al. 2019). Thus, creating and enforcing suitable land use rules that balance the demands of agricultural and settlement land is crucial to achieving stable regional sustainability (Muche et al. 2023).

ESV calculation

There are nine ecosystem services used in this study for each land use category. The values for each service were retrieved from the work of Costanza et al. (1997). Some academics have utilized Costanza's global ecosystem services assessment model to focus on a particular region, species, community or ecosystem (Holmlund and Hammer 1999; Rönnbäck 1999). The values in Table 2 are used to indicate each ecosystem service for each land cover type. The multiplication tables are provided in Tables 4–6.

ESV is calculated using the equation:

$$ESV = \Sigma(Ak\ x\ VCk)$$

where:
ESV = total ecosystem service value
Ak = area (ha)
VCk = Value Coefficient (Table 2)
k = land cover type

The exchange rate used is USD 1 = IDR 15,522 (2023 currency rates). The following table shows the calculation of ESV in rupiah for each type of land cover in Aceh Besar Regency with time series 2000, 2010 and 2020. The total ESV values (Tables 4 to 6) generated in the three tables have been multiplied by the exchange rate in Table 3. data.

The comparison between ESV results in 2000 and 2010 shows the escalating results in three land use cover categories, which are cropland, grass land and water body. However, on the other side, forest experienced a decrease in ESV value due to the downsizing of its area. This phenomenon continued to happen for the next decade. Cropland, on the other hand, increased by 4,771 ha, due to the increase in farming activities among people in Aceh Besar.

Table 2. Equivalent value

Equivalent Value	Land Use Categories						
	Bare land	Built-up area	Cropland	Forest	Grassland	Water body	Non built-up area
Food Production	-	-	1	0.80	1.24	0.76	-
Raw Materials	-	-	0	2.56	0	0	-
Gas Regulation	-	-	0	0	0.13	0	-
Climate Regulation	-	-	0	2.65	0	0	-
Hydrological Regulation	-	-	0	0.09	0.06	0.14	-
Waste Treatment	-	-	0	1.61	1.61	12.31	-
Soil Formation and Conservation	-	-	0	8.65	0.56	0	-
Biodiversity Maintenance	-	-	0.7	0.33	0.89	0	-
Providing Aesthetic Value	-	-	0	1.26	0.04	4.26	-
Total	**-**	**-**	**1.7**	**17.95**	**4.53**	**17.47**	**-**

Source: BPS Aceh Besar (2000, 2010, 2020)

Table 3. ESV rate conversion

Land Cover Type	Equivalent to Biomes/ Ecosystems	ESV Coefficient (US$/ha/year)	ESV Coefficient (Rp/ha/year)
Agricultural land	Cropland	92	1,428,024
Water body	Wetland	14.785	229,492
Forest and Vegetation	Tropical Forest	2.007	31,152,654
Built-up land	Urban	0	0
Open land	Desert	0	0

Source: Rahman and Szabó 2021; Widayani et al. 2023

This trend then decreased in the next decade, when the land for crop area decreased. Despite increases in the production of food, timber and housing, human-dominated land-uses (such as urbanization and agricultural demands) had a detrimental impact on the provision of ecosystem services (Assefa et al. 2021)

The importance of forest ecosystems as a primary source of raw materials means that changes in this area have a direct impact on the value of raw materials. There was a rise in PDCM (magnitude of population density change) accompanied by a drop in the volume of changes in the raw material value per unit area. The number of changes in the value of raw materials per unit area will be lessened, though, as urban growth and expansion take the place of farms and woods as the PDCM increases above a specific threshold (Fei et al. 2015).

Human activity has a significant impact on the value of ecosystem services (Keller et al. 2015; Msofe et al. 2019). Irrational human actions will reduce the benefits that ecosystems provide or even undermine the ecological foundation that sustains human society's ability to grow sustainably, if people fail to recognize or value ecosystem services (Soy-Massoni et al. 2016; Kertész et al. 2019).

The maintenance of many ecosystem services was negatively impacted by land reclamation and other human actions that drastically altered the structure of ecosystems (Kubiszewski et al. 2013). The value of ecosystem services per unit area may therefore decrease in the absence of rigorous land management and planning for rural development. The value of regulating climate change, conserving water and providing entertainment and culture per unit area decreased at a slower rate as population density change (PDCM) increased (Fei et al. 2018).

Decreases in ecosystem services brought on by LULC changes may have an effect on the region's actual and prospective resistance to factors brought on by human activity, as well as the livelihoods of those who depend on the land (Muche et al. 2023). LULC changes have negative impacts on ecosystem services (Estoque and Murayama 2012; Achmad et al. 2020). However, biodiversity resources that uphold the stability of ecological communities can enhance ecosystem functions (Li et al. 2017). Rapid land conversion resulting from changes in LULC will cause a decrease in ESV (Admasu et al. 2023).

Conclusion

The study of LULC changes in Aceh Besar Regancy, Aceh, Indonesia, highlights the complex relationship between human activities and ecosystem services. The findings emphasize the importance of sustainable land management practices to protect the valuable benefits provided by nature. Urban development and other human activities can alter land use and have a significant impact on ecosystem services. The research shows that the value of ecosystem services in Aceh Besar Regancy decreased from 2000 to 2020, largely due to changes in LULC. While these changes have negative effects on ecosystem services, they can be mitigated through careful planning and management.

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Table 4. ESV calculation in 2000

LUC Categories	Area (Ha)	Ecosystem Services										TOTAL ESV VALUE (IDR ha 10^6)
		FP	RW	GR	CR	HR	WT	SFC	BM	PAV	TOTAL ESV	
Bare land	19,811	-	-	-	-	-	-	-	-	-	-	-
Built-up area	10,206	-	-	-	-	-	-	-	-	-	-	-
Cropland	52,747	52,747	0	0	0	0	0	0	36,923	0	89,670	128,051
Forest	182,639	146,111	467,556	0	483,994	16,438	294,049	1,579,828	60,271	230,125	3,278,371	102,130
Grassland	28,423	35,245	0	3,695	0	1,705	45,762	15,917	25,297	1,137	128,758	4,011,159
Water body	3,281	2,493	0	0	0	459	40,387	0	0	13,976	57,317	13,154
Non built-up area	-	-	-	-	-	-	-	-	-	-	-	-

Table 5. ESV calculation in 2010

LUC Categories	Area (Ha)	Ecosystem Services										TOTAL ESV VALUE (IDR ha 10^6)
		FP	RW	GR	CR	HR	WT	SFC	BM	PAV	TOTAL ESV	
Bare land	14,860	-	-	-	-	-	-	-	-	-	-	-
Built-up area	11,560	-	-	-	-	-	-	-	-	-	-	-
Cropland	55,554	55,554	0	0	0	0	0	0	38,888	0	94,442	134,865
Forest	182,420	145,936	466,994	0	483,412	16,418	293,695	1,577,930	60,198	229,849	3,274,431	102,007
Grassland	29,274	36,299	0	3,806	0	1,756	47,131	16,393	26,054	1,171	132,610	4,131,158
Water body	3,441	2,615	0	0	0	482	42,363	0	0	14,660	60,120	13,797
Non built-up area	-	-	-	-	-	-	-	-	-	-	-	-

Table 6. ESV Calculation in 2020

LUC Categories	Area (Ha)	Ecosystem Services										TOTAL ESV VALUE (IDR ha 10^6)
		FP	RW	GR	CR	HR	WT	SFC	BM	PAV	TOTAL ESV	
Bare land	13,408	-	-	-	-	-	-	-	-	-	-	-
Built-up area	14,721	-	-	-	-	-	-	-	-	-	-	-
Cropland	54,711	54,711	0	0	0	0	0	0	38,298	54,711	147,721	210,949
Forest	181,798	145,438	465,403	0	481,765	16,362	292,695	1,572,552	18,055	229,065	3,221,334	100,353
Grassland	28,919	35,859	0	3,759	0	1,735	46,559	16,195	161,800	1,157	267,065	8,319,781
Water body	3,550	2,698	0	0	0	497	43,703	1,988	0	15,124	64,011	14,690
Non built-up area	-	-	-	-	-	-	-	-	-	-	-	-

Disclosure statement

No potential conflict of interest was reported by the authors.

Author contributions

Study design: AA, IR, NN; data collection: AA, AG, ZF; statistical analysis: IR, AG; result interpretation: AA, IR, NN; manuscript preparation: AA, IR, ZF; literature review: AA, AG, ZF.

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