Proceedings of Forum for University Scholars in Interdisciplinary Opportunities and Networking
Graduate School, Universitas Terbuka
https://conference.ut.ac.id/index.php/fusion

Forest Cover Analysis Using Time Series Change Method in Aceh Region

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Abstract
The forests of Aceh constitute a critical ecological buffer and serve as the last refuge for endangered species such as tigers, elephants, rhinoceroses, and orangutans. However, forest cover in Aceh has experienced significant decline over the past decade, with the province losing hundreds of thousands of hectares since 2015. This degradation is driven by illegal encroachment, forest conversion into plantations, illegal logging, mining, and infrastructure expansion, further aggravated by inadequate supervision, weak law enforcement, and conflicting interests in natural resource management. This study aims to analyze forest cover dynamics in Aceh from 2015 to 2021 using a time series change method. Key variables include forest cover area, reforestation data, deforestation data, reforestation ratio, and deforestation ratio. Data analysis was conducted using Powersim Studio Version 10.0. The results indicate that, without policy intervention, Aceh's forests will become ecologically unstable within the next 100 years, posing high risks of both natural and humanitarian disasters. To address this, the study recommends policy interventions focusing on increasing the reforestation ratio under a moderate scenario. Additionally, community engagement in tree planting and stricter law enforcement against illegal logging are suggested as complementary strategies to ensure sustainable forest conservation.

Keywords:
Aceh Forests; Forest Cover; Deforestation; Reforestation; Time Series; Forest Policy.

1. Introduction

The Province of Aceh is one of the regions in Indonesia that possesses the largest and most biodiverse tropical forest areas. Aceh's forest landscape forms an integral part of the Leuser Ecosystem, which plays a vital role in maintaining regional ecological balance and serves as the last remaining habitat for critically endangered species such as the Sumatran tiger (*Panthera tigris sumatrae*), Sumatran rhinoceros (*Dicerorhinus sumatrensis*), Sumatran elephant (*Elephas maximus sumatranus*), and Sumatran orangutan (*Pongo abelii*).

However, over the past decade, the condition of forest cover in Aceh shows an increasingly worrying trend. According to data from the Central Bureau of Statistics (Badan Pusat Statistik), the province has lost hundreds of thousands of hectares of forested land since 2015. The regions experiencing the highest rates of deforestation include South Aceh, East Aceh, and the city of Subulussalam, as well as conservation areas such as the Rawa Singkil Wildlife Reserve and Gunung Leuser National Park.

This phenomenon is driven by multiple factors, including illegal encroachment, forest conversion for plantations, illegal logging, mining and infrastructure expansion. The lack of adequate supervision, weak law enforcement, and conflicting interests in natural resource management have further exacerbated forest degradation. As a result, in addition to the decline in environmental quality and the loss of wildlife habitats, communities living near forest areas have become increasingly vulnerable to natural disasters such as floods, landslides, and droughts.

The decline in forest cover has not only had local impacts, but also threatens Indonesia's broader commitments to climate change mitigation, particularly in reducing greenhouse gas emissions from the forestry sector. Therefore, analyzing the dynamics of forest cover change in Aceh is crucial in formulating effective and sustainable forest protection policies.

2. Method

The time series change method is a data analysis approach used to examine and model the changes of a variable over a sequence of time. Time series data are arranged at specific intervals, such as annually. The variables analyzed include forest cover area, reforestation data, deforestation data, reforestation ratio, and deforestation ratio. The secondary data sources analyzed were obtained from the Central Bureau of Statistics (Badan Pusat Statistik), the Aceh Environmental and Forestry Agency (Dinas Lingkungan Hidup dan Kehutanan Aceh), and the non-governmental organization HAkA Foundation, concerning forestry issues in Aceh for the period 2015–2021.

The data were analyzed using Powersim Studio software, version 10.0. This software enables the simulation of "what-if" scenarios to assess the impact of one variable on others over a specific time frame. By examining the interrelationships among variables, the author can draw conclusions regarding whether reforestation activities contribute to a reduction in the rate of deforestation, thereby enabling targeted interventions on the relevant variables.

According to the Food and Agriculture Organization (FAO, 2020), there is no single global standard for the ideal percentage of forest cover, as it is determined by ecological, geographical, and social conditions. However, for tropical countries with high biodiversity such as Indonesia, maintaining forest cover above 40% of the total land area is considered essential for ensuring ecological stability. Based on data from the Central Bureau of Statistics, the total land area of Aceh Province is 5,677,081 hectares. Forest cover in Aceh, according to reference data from 2015, was 3,050,316 hectares, or approximately 53.75% of the province's total land area. Therefore, the forest cover condition in 2015 was still considered to fall within the ideal category.

Model Validation

In environmental modeling, model validation is a critical process to ensure that the constructed model accurately and reliably represents real-world systems. Validation is carried out by comparing the model outputs against empirical data or logical expectations based on established theory. In general, model validation can be conducted through three main approaches: theoretical validation, visual validation, and statistical validation. Theoretical validation involves comparing the model's structure, variables, and the relationships between variables with well-established theories in the scientific literature.

For instance, literature affirms that deforestation reduces forest cover, which aligns with ecological and environmental policy theories. Hansen et al. (2013) define deforestation as the permanent loss of forest cover due to human activities such as agriculture, plantations, mining, and infrastructure development. A model is considered theoretically valid if it employs logical cause-and-effect relationships and all variables and assumptions are supported by scientific references. Visual validation is performed by visually comparing the model output with real-world data, for example through graphs, maps, or time-series plots. A valid visual indicator is when the model curve follows the trend of actual data, and the spatial patterns of the model resemble empirical patterns. Statistical validation refers to the quantitative assessment of how well the model fits actual data, using specific statistical indicators.

This method aims to evaluate the accuracy, precision, and significance of the model's outputs and provides an objective measure of model reliability. The statistical test employed in this study is AME (Absolute Mean Error). A low AME value indicates a low level of error. The model used in this study operates at a real-world scale, in which certain variables cannot be controlled by the researcher. An AME value below 30% is still considered to fall within the valid range.

Tabel 1. Validation Model

Years	Forest Cover Area of Aceh (Ha) Reference Data	Forest Cover Area of Aceh (Ha) Simulation Data	Reforestation (Ha) Reference Data	Reforestation (Ha) Simulation Data	Deforestation (Ha) Reference Data	Deforestation (Ha) Simulation Data
2015	3.050.316	3.050.316	785	784	21.056	21.056
2016	3.036.323	3.030.044	785	779	21.060	20.916
2017	3.018.505	3.009.906	785	774	17.820	20.777
2018	3.003.481	2.989.902	785	768	15.071	20.639
2019	2.988.342	2.970.031	785	763	15.140	20.502
2020	2.973.670	2.950.292	785	758	14.756	20.366
2021	2.964.657	2.930.685	785	753	9.028	20.641

Absolute Means Error (AME)	
Forest Cover Area	0,49 %
Reforestation	2,11 %
Deforestation	26,82 %

Among the three variables mentioned above, after comparing the reference data with the simulation results, all showed valid values, i.e., below 30%. The AME (Absolute Mean Error) value for forest cover in Aceh was 0.49%, for reforestation 2.11%, and for deforestation 26.82%.

3. Results and Discussion

3.1 Results

Based on the validated model, the author conducted a simulation to project the condition of Aceh's forest cover 100 years into the future, or in the year 2115. If the deforestation ratio is not intervened, the forest cover in Aceh will no longer be within the ideal range. According to the simulation data, by the 2060s, Aceh's forest cover is projected to decrease to only 39.63%, or 2,250,367 hectares. Given that the ideal forest cover is defined as at least 40% of the total land area, the minimum required forest cover in Aceh Province would be 2,270,832 hectares. Based on the simulation table, by the year 2115, Aceh's remaining forest cover is estimated to decline further to just 1,551,701 hectares. Such a level of forest cover would undoubtedly threaten the sustainability of biodiversity within Aceh's forests.

Therefore, functional intervention in the reforestation ratio is necessary to ensure the long-term preservation of forest ecosystems in Aceh Province. In the model structure, two constants are defined: the reforestation ratio and the deforestation ratio. Initially, the author input values based on the Business As Usual (BAU) scenario, derived from processed reference data. Three simulation scenarios were developed—pessimistic, moderate, and optimistic—which are presented in Table 2. The control year for increasing the reforestation ratio is set in the 2060s, as by that time, Aceh's forest cover is projected to fall below 40%, or 2,250,367 hectares, as shown in Table 3.

Tabel 2. Functional Intervention on Model Parameters

Scenario	Reforestation Ratio	Deforestation Ratio
0 (BAU)	0,0257	0,6903
1 (Pesimistic)	0,1918	0,6903
2 (Moderate)	0,3579	0,6903
3 (Optimistic)	0,6903	0,6903

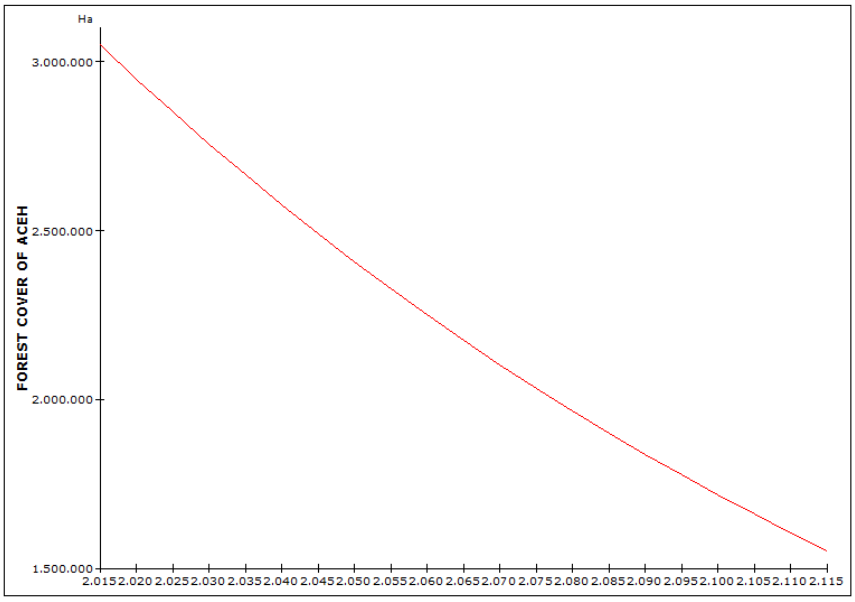
Tabel 3. Result of Bussines As Usual (BAU) Simulation Data

Year	Forest Cover of Aceh (Ha)	Reforestation (Ha)	Deforestation (Ha)
2015	3.050.316	784	21.056
2020	2.948.954	758	20.357
2025	2.850.960	733	19.680
2030	2.756.223	708	19.026
2035	2.664.634	685	18.394
2040	2.576.088	662	17.783
2045	2.490.484	640	17.192
2050	2.407.726	619	16.621
2055	2.327.717	598	16.068
2060	2.250.367	578	15.534
2065	2.175.587	559	15.018
2070	2.103.292	541	14.519
2075	2.033.400	523	14.037
2080	1.965.830	505	13.570
2085	1.900.506	488	13.119
2090	1.837.352	472	12.683
2095	1.776.297	457	12.262
2100	1.717.270	441	11.854
2105	1.660.205	427	11.460
2110	1.605.037	412	11.080
2115	1.551.701	399	10.711

3.2 Discussion

The reference data processing graph (Figure 1) displays a decay pattern, indicating that the rate of deforestation is higher than the rate of reforestation. Without functional intervention, there is a concern that Aceh's forest cover will rapidly decline, potentially leading to environmental and humanitarian disasters.

Figure 1. BAU Scenario Simulation Graph



The following Table 4 is a table of scenario simulation results for pessimistic, moderate, and optimistic options.

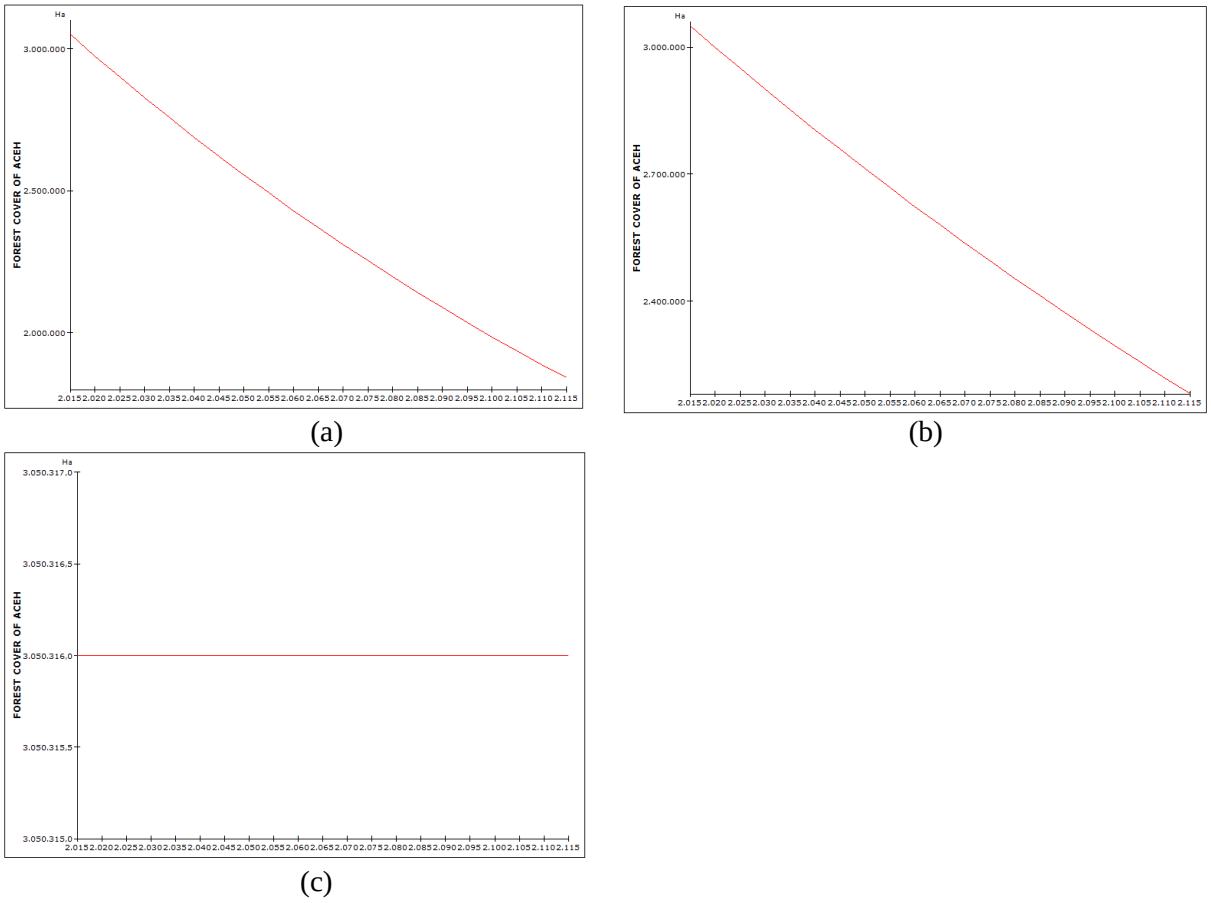
Tabel 4. Result of Pessimistic,Moderate, and Optimistic Simulation Data

Year	Forest Cover of Aceh (Ha)	Refore station (Ha)	Defore station (Ha)	Forest Cover of Aceh (Ha)	Refore station (Ha)	Defore station (Ha)	Forest Cover of Aceh (Ha)	Refore station (Ha)	Defore station (Ha)
2015	3.050.316	5.851	21.056	3.050.316	10.917	21.056	3.050.316	21.056	21.056
2020	2.974.287	5.705	20.532	2.999.620	10.736	20.706	3.050.316	21.056	21.056
2025	2.900.153	5.562	20.020	2.949.766	10.559	20.365	3.050.316	21.056	21.056
2030	2.827.866	5.424	19.521	2.900.741	10.382	20.024	3.050.316	21.056	21.056
2035	2.757.382	5.289	19.034	2.852.531	10.211	19.694	3.050.316	21.056	21.056
2040	2.688.654	5.157	18.560	2.805.122	10.040	19.364	3.050.316	21.056	21.056
2045	2.621.639	5.028	18.097	2.758.500	9.874	19.045	3.050.316	21.056	21.056
2050	2.556.295	4.903	17.646	2.712.654	9.709	18.725	3.050.316	21.056	21.056
2055	2.492.579	4.781	17.206	2.667.370	9.549	18.417	3.050.316	21.056	21.056
2060	2.430.452	4.662	16.777	2.623.235	9.389	18.108	3.050.316	21.056	21.056
2065	2.369.873	4.545	16.359	2.579.637	9.234	17.810	3.050.316	21.056	21.056
2070	2.310.804	4.432	15.951	2.536.763	9.079	17.511	3.050.316	21.056	21.056
2075	2.253.207	4.322	15.554	2.494.602	8.929	17.223	3.050.316	21.056	21.056
2080	2.197.046	4.214	15.166	2.453.142	8.780	16.934	3.050.316	21.056	21.056
2085	2.142.284	4.109	14.788	2.412.371	8.635	16.655	3.050.316	21.056	21.056
2090	2.088.888	4.006	14.420	2.372.277	8.490	16.376	3.050.316	21.056	21.056
2095	2.036.822	3.907	14.060	2.332.850	8.350	16.106	3.050.316	21.056	21.056
2100	1.986.055	3.809	13.710	2.294.078	8.211	15.836	3.050.316	21.056	21.056
2105	1.936.552	3.714	13.368	2.255.950	8.075	15.575	3.050.316	21.056	21.056
2110	1.888.284	3.622	13.035	2.218.456	7.940	15.314	3.050.316	21.056	21.056
2115	1.841.208	3.531	12.710	2.181.586	7.808	15.059	3.050.316	21.056	21.056

In the pessimistic scenario, the functional intervention applied to the reforestation ratio is 0.1918. This results in a deceleration of forest cover loss in Aceh, allowing the ideal forest cover condition to be maintained until approximately the year 2075. This represents a 15-year delay from the baseline

condition prior to any intervention in the reforestation ratio function. In the moderate scenario, the functional intervention applied to the reforestation ratio is 0.3579. A similar effect occurs as in the pessimistic scenario, in which the rate of forest cover reduction in Aceh slows down. As a result, the ideal forest cover condition can be extended until approximately the year 2105, indicating a 55-year delay from the initial condition before reforestation function intervention. Lastly, in the optimistic scenario, the reforestation and deforestation ratios are equal, resulting in Aceh's forest cover in 2115 remaining at the same level as in 2015. This implies that forest cover can be sustainably maintained over time. For a clearer illustration, see Figure 2: Simulation Graphs for the Pessimistic, Moderate, and Optimistic Scenarios.

Figure 2. Simulation Graph for (a) Pessimistic, (b) Moderate, and (c) Optimistic Scenario



Forest cover is a key indicator in assessing the ecological condition of a region and is used as a critical parameter in landscape dynamics models (FAO, 2020). In environmental models, deforestation functions as an input variable that leads to the decline of forest ecosystem stocks and serves as a trigger for ecological degradation. Research by Austin et al. (2019) indicates that deforestation has a strong negative correlation with forest cover in spatial regression models. Moreover, deforestation is a dominant factor in modeling the risk of ecological disasters such as floods and landslides. Reforestation can help restore the ecological function of the land, but it requires a considerable amount of time for vegetation to grow and form a stable forest structure (Chazdon, 2008).

According to several sources, the cost of reforestation ranges between IDR 14–17 million per hectare, although there is no standardized unit cost for reforestation activities. Costs vary depending on factors such as the type of reforestation site, the species of trees being planted, and other contextual variables. Therefore, the author recommends the moderate scenario as a viable option, taking into account the budgetary constraints of relevant stakeholders. Another viable approach is to engage local communities in tree planting efforts, in line with the statement by Laestadius et al. (2015), which asserts that reforestation success rates are higher when implemented through a landscape-based approach and

with community participation. In addition, law enforcement efforts against illegal logging should be continuously strengthened to serve as a deterrent for offenders.

4. Conclusion

Based on the analysis of Aceh's forest cover using the time series change method, the author draws the following conclusions: the model behavior reflects a decay pattern, indicating that Aceh's forest cover will continue to decline if no action is taken by the Aceh Government, local communities, institutions, or other responsible stakeholders involved in forest conservation; the time series data confirms the validity of the dataset; the simulation results show that by the 2060s, the forest cover in Aceh will fall below the ideal threshold of 40% of total land area. Therefore, the author recommends implementing functional intervention under the moderate scenario, taking into account the available budget from relevant stakeholders. Other recommended strategies include involving local communities in tree planting efforts and strengthening law enforcement against illegal logging activities.

5. References

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