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Land Cover Changes in Peat Hydrological Unit at East Tanjung Jabung Timur Regency, Jambi Province

(Perubahan Penutupan Lahan di Kawasan Kesatuan Hidrologi Gambut di Kabupaten Tanjung Jabung Timur, Provinsi Jambi)

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Abstract

In Jambi Province, Indonesia, land cover in Tanjung Jabung Timur Regency has experienced substantial transformation over the past two decades. These changes are closely linked to increasing land use pressures, government development policies, and broader environmental challenges such as climate change, biodiversity loss, and peatland degradation. This study aims to analyze the dynamics of land cover change between 2000 and 2022 within the Peat Hydrological Unit (PHU) area of Tanjung Jabung Timur by employing a remote sensing-based approach using cloud computing technology. Landsat 5, 8, and 9 images were classified using the Support Vector Machine (SVM) algorithm on the Google Earth Engine (GEE) platform. The classification incorporated 10 spectral indices to enhance accuracy. The results showed that the SVM classifier achieved a high level of performance, with an Overall Accuracy (OA) of 92.5% and a Kappa coefficient of 88.94. The analysis revealed that the most extensive land cover change occurred in peat swamp forest areas, which were predominantly converted into plantations, contributing to 28.97% of the total PHU area. The findings emphasize the critical role of policy interventions in driving land cover change and highlight the urgent need for sustainable land management strategies to protect peatland ecosystems in the region.

Keywords: *Government policies, land cover classification, peat*

Abstrak

Perubahan tutupan lahan di Kabupaten Tanjung Jabung Timur, Jambi, Indonesia telah mengalami transformasi substansial selama dua dekade terakhir. Perubahan ini terkait erat dengan meningkatnya tekanan penggunaan lahan, kebijakan pembangunan pemerintah, dan tantangan lingkungan yang lebih luas seperti perubahan iklim, hilangnya keanekaragaman hayati, dan degradasi lahan gambut. Penelitian ini bertujuan untuk menganalisis dinamika perubahan tutupan lahan antara tahun 2000 dan 2022 pada wilayah Kesatuan Hidrologi Gambut (KHG) Tanjung Jabung Timur dengan menggunakan pendekatan berbasis penginderaan jauh menggunakan teknologi cloud computing. Klasifikasi pada Citra Landsat 5, 8, dan 9 dilakukan dengan menggunakan algoritma Support Vector Machine (SVM) pada platform Google Earth Engine (GEE). Klasifikasi tersebut menggabungkan 10 indeks spektral untuk meningkatkan akurasi. Hasil penelitian menunjukkan bahwa pengklasifikasi SVM mencapai tingkat kinerja yang tinggi, dengan Akurasi Keseluruhan (OA) sebesar 92,5% dan koefisien Kappa sebesar 88,94. Analisis menunjukkan bahwa perubahan tutupan lahan yang paling luas terjadi di kawasan hutan rawa gambut, yang sebagian besar telah dikonversi menjadi perkebunan, yaitu sebesar 28,97% dari total luas KHG. Temuan studi ini menekankan peran penting intervensi kebijakan dalam mendorong perubahan tutupan lahan dan menyoroti kebutuhan mendesak akan strategi pengelolaan lahan berkelanjutan untuk melindungi ekosistem lahan gambut di wilayah tersebut.

Kata kunci: Kebijakan pemerintah, klasifikasi penutupan lahan, gambut

1. Introduction

Around 30% of the world's tropical peatlands are in Indonesia. Indonesia's peatland area in 2020 was estimated at 13.43 million hectares (Indonesian Center for Agricultural Land Resources Research, 2020), with the majority distributed across Sumatra (43% of the country's total peatland area) and Kalimantan (32%), followed by Papua with the next largest share (25%) (Anda et al., 2021).

Land mapping and data collection are needed to observe peat forests' actual and efficient condition (Shobirin & Ritonga, 2016). Remote sensing technology is one of the methods to rapidly identify land cover changes (Darmawan et al., 2018). Google Earth Engine (GEE) is a web-based platform based on cloud computing that can be accessed online. It can run GIS processes in created scripts and produce analysis according to the desired search (Dewantoro et al., 2021). This technology makes it possible to analyze location data temporarily through image capture. Images widely used are Landsat 5, 8, and 9. GEE provides access to all Landsat images, which can be used for various applications, including monitoring land cover with reasonably good resolution.

East Tanjung Jabung Regency is a regency located in the province of Jambi, which was split off from West Tanjung Jabung Regency in 2000. According to data from the Jambi Provincial Forestry Office (2020), the total area of peatlands in Jambi Province reaches 736,227.2 hectares, with the most significant area being in East Tanjung Jabung Regency, covering 311,992.10 hectares. This area has a history related to peat and swamp forest issues similar to other regions in Indonesia with similar ecosystems. Along with the passage of time and economic pressures, there have been changes in land use patterns. The increasing demand for land for large-scale agriculture, plantations, and industries has led to the conversion of peatlands into agricultural or plantation areas, including oil palm plantations.

Significant changes in land cover area dynamics require spatially based distribution data analysis at a more detailed scale. Moreover, mapping involving the GEE platform is still relatively limited, particularly in Indonesia. Therefore, research on land cover mapping in peatland areas is crucial to obtain accurate data on land cover changes using the latest cloud computing-based methods through the Google Earth Engine platform and accuracy assessments based on Support Vector Machine (SVM) values. This research provides an in-depth understanding regarding the application of such a platform.

2. Methodology

The area used as the focus of study in this research is PHU in East Tanjung Jabung Regency, Jambi Province, which is geographically located between 0°53' - 1°41' South Latitude dan 103°23 - 104°31 East Longitude. The ground checks carried out purposively in PHU East Tanjung Jabung Regency, Jambi Province. Data processing and interpretation are conducted at the Forest Fire Laboratory, Department of Silviculture, Faculty of Forestry and Environment, IPB University.

Tools and materials detect changes in land cover dynamics in the peat hydrological unit area. The materials used are Landsat 5, 8, and 9 satellite image data from the GEE catalog. The shp file of PHU East Jabung Regency obtained from the regional environmental service, Regency boundary data, and Provincial boundary data sourced from the Ina-Geoportal. This research involves eleven indices divided into three types: vegetation, water, and building indices (Table 2).

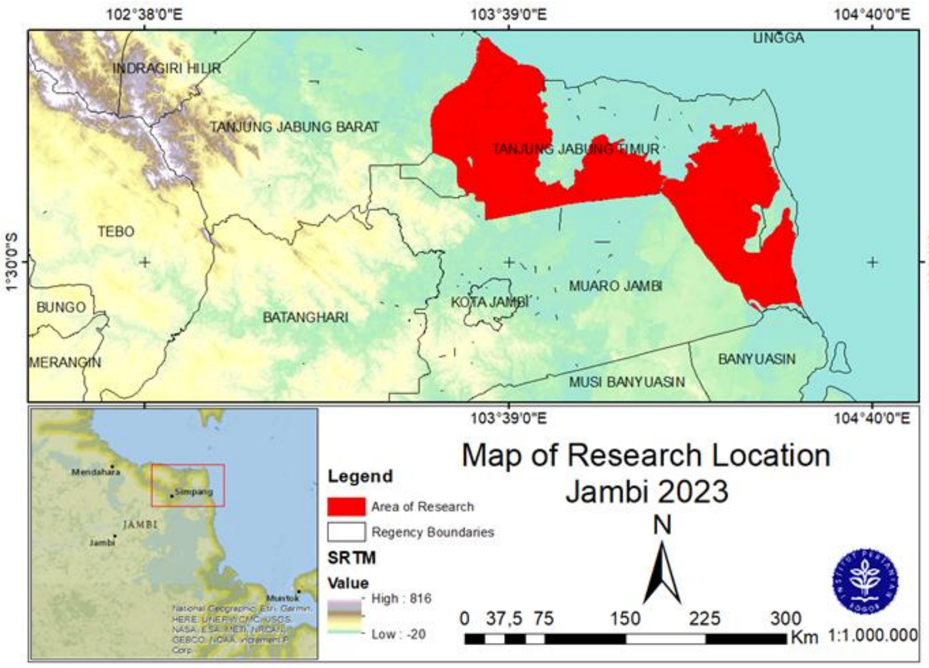

Fig. (*Gambar*) 1. Research location (*Lokasi penelitian*)

Table (*Tabel*) 1. List of indices used (*Daftar indeks yang digunakan*)

No	Method (*Metode*)	Formula *(Rumus)*	Reference (*Pustaka*)
1	Normalized Difference Vegetation Index (NDVI)	NDVI = (NIR - Red) / (NIR + Red)	(Huang et al., 2021)
2	Normalized difference water index (NDWI)	NDWI = (Green - NIR) / (Green + NIR)	(Guo et al., 2017)
3	Normalized Difference Built-up Index (NDBI)	NDBI = (SWIR - NIR) / (SWIR + NIR)	(Li & Chen, 2018)
4	Enhanced Vegetation Index (EVI)	EVI = (NIR - Red) / ((NIR + 6) * (Red - 7.5) * (Blue + 1))) * 2.5	(Villamuelas et al., 2016)
5	Soil-Adjusted Vegetation Index (SAVI)	SAVI = ((NIR - Red) / (NIR + Red +0.5)) * (1.0+0.5)	(Zen et al., 2021)
6	Green Normalized Difference Vegetation (GNDVI)	GNDVI = (NIR - GREEN) / (NIR + GREEN)	(Mangewa et al., 2022)
7	Atmospherically Resistant Vegetation Index (ARVI)	ARVI = (NIR - (Red - (1 * (Red - Blue)))) / (NIR + (Red - (1 * (Red - Blue))))	(Somvanshi & Kumari 2020)
8	Specific Leaf Area Vegetation Indeks (SLAVI)	SLAVI = (NIR) / (Red + SWIR)	(Morcillo-Pallarés et al., 2019)
9	Index-Based Built-Up Area Index (IBI)	IBI = (((SWIR / (SWIR * NIR)) * 2) - ((NIR / (NIR + Red)) + (Green/(Green + SWIR))))	(Kaimaris 2016)
10	Augmented Normalized Difference Water Index (ANDWI)	ANDWI = (Blue + Green + Red - NIR - SWIR1 - SWIR2) / (Blue + Green + Red + NIR + SWIR1 + SWIR2)	(Rad et al., 2021)

The land classification results from GEE will be imported into ArcGIS and processed to obtain the land area per classification using features such as "extract by attribute" and "extract by mask," then re-imported into Excel to obtain the area. This study used two accuracy analysis methods, namely Overall Accuracy (OA) and Kappa Statistics (KS) (Cohen, 1968). This accuracy analysis involves validation data obtained randomly using high-resolution image data in Google Earth Pro software. This validation data is separate from the training data in the classification process. This considers the intervention of validation data in the classification process. The accuracy analysis formula involved is presented below.

$$\text{Kappa Statistic} = \frac{N\sum_{i=1}^{\gamma} X_{ii} - \sum_{i=1}^{\gamma} X_{i+}X_{+1}}{N\sum_{i=1}^{\gamma} X_{i+}X_{+1}} \quad (1)$$

$$\text{User's Accuracy} = \frac{X_{ii}}{X_{+i}} \times 100\% \quad (2)$$

$$\text{Producer's Accuracy} = \frac{X_{ii}}{X_{i}} \times 100\% \quad (3)$$

$$\text{Overall Accuracy} = \frac{\sum_{i=1}^{\gamma} X_{ii}}{N} \quad (4)$$

Table (*Tabel*) 2. Interpretation of kappa values (*Interpretasi nilai kappa*) (Cohen, 1968)

Kappa value (*Nilai kappa*)	Information (*Informasi*)
< 0.00	Poor (*Rendah*)
0.00-0.20	Slight (*Sedikit*)
0.21-0.40	Fair (*Adil*)
0.41-0.60	Moderate (*Sedang*)
0.61-0.80	Substantial (*Besar*)
0.81-1.00	Almost perfect (*Hampir sempurna*)

3. Result and Discussion

3.1. Result

The calculation of land cover area using machine learning with the Support Vector Machine (SVM) algorithm shows dynamic land cover changes occurring annually. The selection of four time intervals is based on a historical approach to fire events, supported by the occurrence of El Niño. Additionally, the selection of five land cover classes is adjusted to the field conditions in Tanjung Jabung Timur (Table 3).

Table (*Tabel*) 3. Land classification area based on ML processing (*Klasifikasi luas lahan menggunakan Machine Learning*)

Time/ *Waktu* (Year/*Tahun*)	Land classification (*Klasifikasi lahan*)	Wide (ha) (*Luas* (*ha*))
2000	Plantation	93,682.89
	Peat bog	95,603.04
	Peat swamp forest	116,885.80
	Water body	742.05
	Bare land	7,039.53
	Settlement	467.55
2010	Plantation	111,353.30
	Peat bog	106,929.40
	Peat swamp forest	85,727.43
	Water body	926.91
	Bare land	8,672.31
	Settlement	811.53
2016	Plantation	87,765.93
	Peat bog	50,745.24

Table (*Tabel*) 3. Continued (*Lanjutan*)

Time/*Waktu* (*Year*/*Tahun*)	Land classification (*Klasifikasi lahan*)	Wide/*Luas* (ha)
	Peat swamp forest	110,729.30
	Bare land	63,299.79
	Settlement	1,880.55
2022	Plantation	163,481.7
	Peat bog	51,209.64
	Peat swamp forest	84,296.16
	Water body	1,699.56
	Bare land	11,259.99
	Settlement	2,473.83

Table 3 shows that plantation areas have increased over the past two decades, with a decline in forest and settlement areas. Meanwhile, Bare land has fluctuated with unpredictable increases and decreases. Figure 2 shows that in the year 2000, PHU East Tanjung Jabung's land cover was predominantly forested (green color).

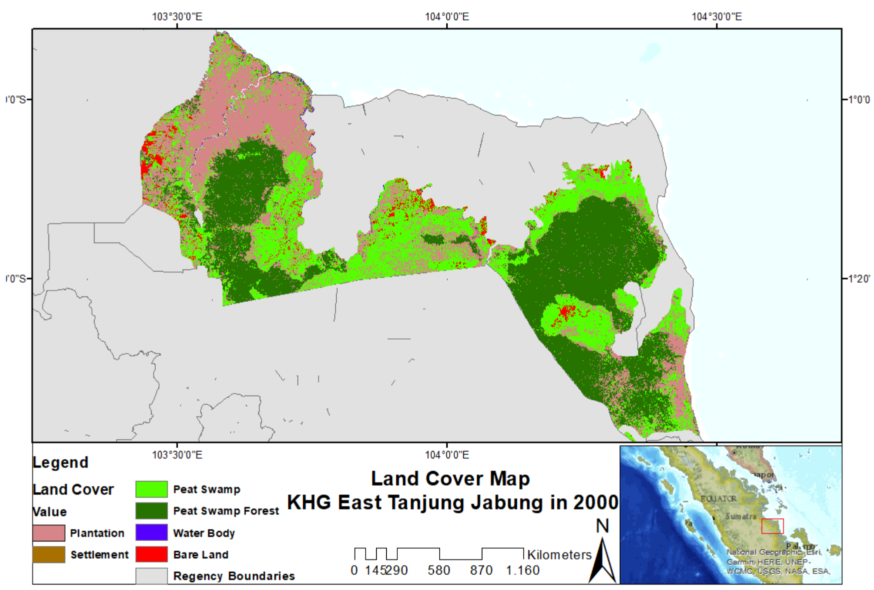

Fig. (*Gambar*) 2. Land cover of PHU East Tanjung Jabung on 2000 (*Penutupan lahan KHG Tanjung Jabung Tiimur tahun 2000*)

Figure 2 shows that in the year 2000, PHU East Tanjung Jabung's land cover was predominantly forested (green color). Peat swamp forests (dark green) were widely distributed, particularly in the central and eastern parts, while peat swamp areas (light green) were also present in significant portions of the region.

Although forest cover was still dominant, early signs of land conversion were evident. The emergence of plantation areas (light red) and patches of bare land (red) indicates initial land clearing activities. Water bodies (blue) remained visible, representing natural aquatic features within the landscape.

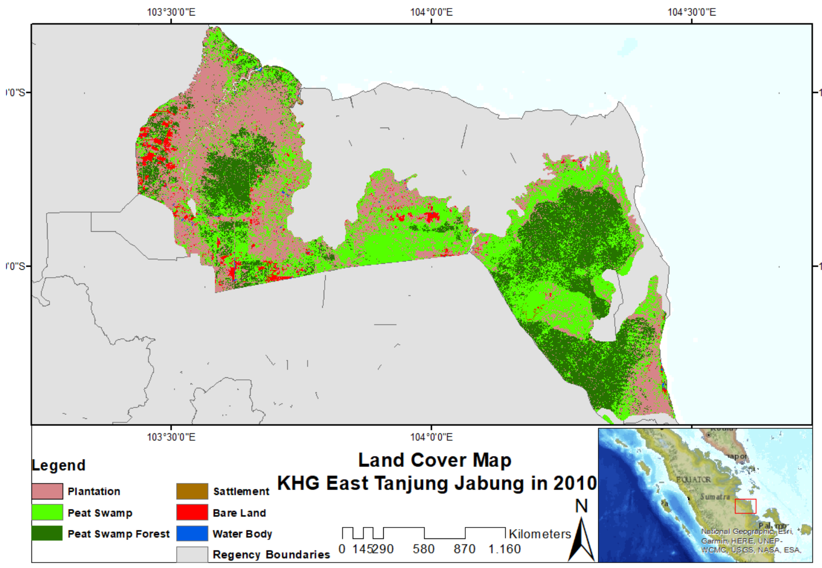

Fig. (*Gambar*) 3. Land cover of PHU East Tanjung Jabung on 2010 (*Penutupan lahan KHG Tanjung Jabung Tiimur tahun 2010*)

Figure 3 shows that compared to the 2000 land cover map, the 2010 land cover map of PHU East Tanjung Jabung shows significant changes. The extent of peat swamp forest (dark green) has noticeably decreased, particularly in the central and western regions. Plantation areas (light red) have expanded considerably, replacing previously forested areas. Additionally, bare land (red) has increased, indicating more intensive land-clearing activities than the previous decade.

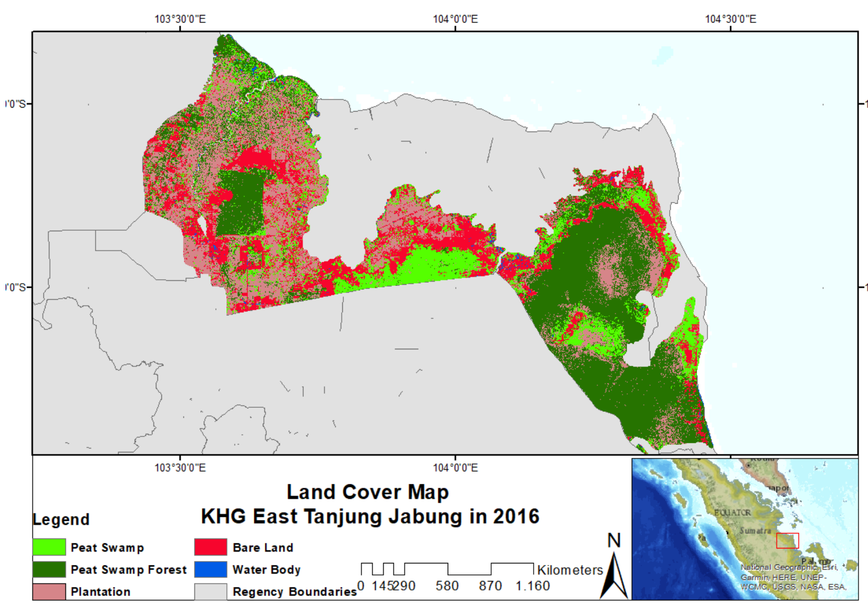

Fig. (*Gambar*) 4. Land cover of PHU East Tanjung Jabung PHU on 2016 (*Penutupan lahan KHG Tanjung Jabung Tiimur tahun 2016*)

Compared to 2010, the 2016 land cover map of PHU East Tanjung Jabung shows a significant expansion of plantation areas (light red), replacing a substantial portion of peat swamp forests (dark green) (Figure 4). Bare land (red) has also increased, particularly in the central and northern regions, indicating intensified land conversion and accelerated deforestation over the past six years.

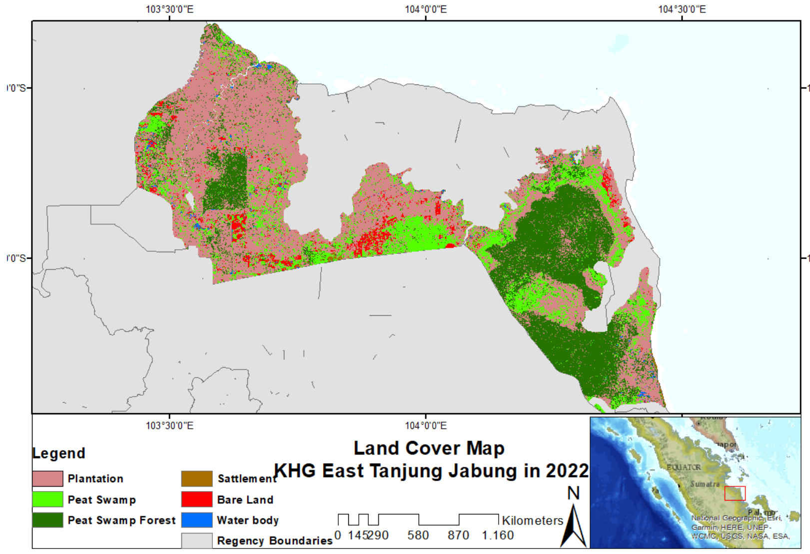

Fig. (Gambar) 5. Land cover of PHU East Tanjung Jabung on 2022 (Penutupan lahan KHG Tanjung Jabung Tiimur tahun 2022)

Figure 5 shows that compared to 2016, the 2022 land cover map of PHU East Tanjung Jabung shows a further expansion of plantation areas (light red), with previously identified bare land (red) transitioning into plantations. The increase in plantation cover has reduced peat swamp forest (dark green), particularly in the central and northern regions of the area.

Fig. (*Gambar*) 6. Changes in land cover from (a) bare land on 2000, to (b) plantations on 2010 (*Perubahan tutupan lahan dari (a) lahan terbuka tahun 2000, menjadi (b) perkebunan tahun 2010*)

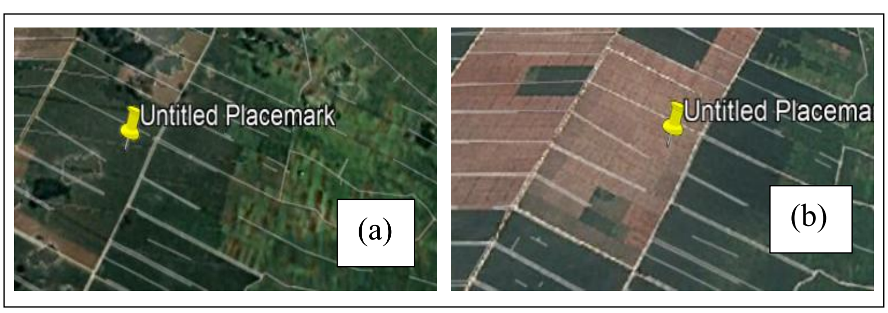

Fig. (*Gambar*) 7. Changes in land cover from (a) plantations on 2010, to (b) bare land on 2016 (*Perubahan tutupan lahan dari (a) Perkebunan tahun 2010, menjadi (b) lahan terbuka tahun 2016*)

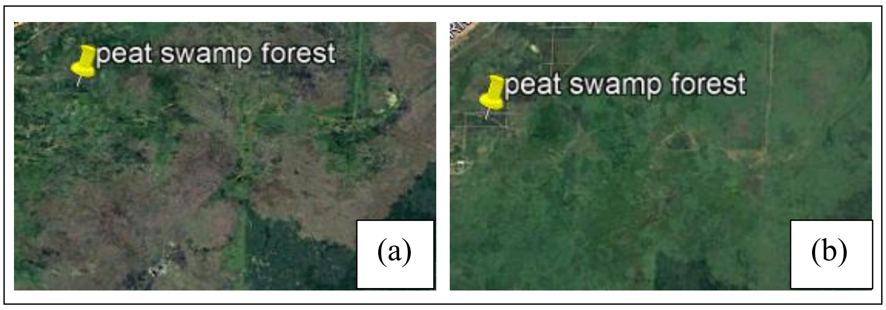

Fig. (*Gambar*) 8. Changes in land cover from (a) peat swamp forests on 2015, to (b) plantations on 2022 (*Perubahan tutupan lahan dari (a) hutan rawa gambut tahun 2015, menjadi (b) perkebunan tahun 2022*)

Figures 6, 7, and 8 clearly illustrate several examples of land cover class changes, which become more evident when further analyzed using Maxar Technologies imagery available in Google Earth Pro. These changes include the transition from bare land to plantations and from forests to plantations over the observation period from 2000 to 2022.

3.2. Discussion

3.2.1. Land cover on 2000

The Peatland ecosystem has undergone significant changes over time to accommodate other land uses, resulting in the degradation of much of the peatland. Intact peatlands in Indonesia remain only 6%, while 13.4-14.9 million hectares (87-97%) are considered degraded (Yuwati et al., 2021). Indonesia's leading causes of peatland degradation are deforestation, conversion into industrial timber estates, and conversion into oil palm plantations (Wicaksono & Zainal, 2022).

Land cover change can be interpreted as damage, degradation, or improvement, depending on the perspective of those who gain or lose from the transition process (Villamor, 2015). Land cover change can occur over different periods and scales in shape and size (Rakhmonov et al., 2021). Changes in land cover can occur according to land utilization and are supported by the necessary needs. Image interpretation for 2000, 2010, 2016, and 2022 shows various land cover changes using Landsat imagery in East Tanjung Jabung Regency, Jambi. The interpretation results indicate several land cover classes, including peat swamp, peat swamp forest, plantations, settlements, water bodies, and bare land (Figure 2).

The land cover in PHU East Tanjung Jabung Regency, Jambi Province, is dominated by plantations with a total area of 93,682.89 hectares. According to Arviansyah et al. (2021), the most rapid decline in land area occurred in rice fields that were converted into plantations. This may be attributed to economic, socio-cultural, environmental, technical, and government policy factors. Several interconnected factors influence the transformation of rice fields into oil palm plantations in this area. Economic factors are the primary driver of land use change from rice fields.

However, it is revealed that government policies also play a significant role as triggers. Initially, the eastern coastal areas of Jambi Province were designated as transmigration sites, and hundreds of thousands of hectares of new rice fields were established. During the Pelita (Five-Year Development) period, this policy successfully made East Tanjung Jabung Regency as one of the leading rice producers. However, the productivity of rice fields in this regency gradually decreased, currently being the lowest among all regencies/cities in Jambi Province, at around 3,6 tons per hectare (BPS Jambi Province, 2015). According to Daulay et al., (2016), inconsistency in development policies is evident from the period 1960 to 2000, where the initial focus was on developing the East Tanjung Jabung area as a center for rice farming, but later shifted to become an area for oil palm plantation development, leading to changes in the function of rice fields.

Various interconnected factors influence the conversion of rice fields into oil palm plantations in this area. Although economic factors appear to be the primary driver of land use change, upon closer examination, government policies also play a significant role as triggers for these changes. The influence of leadership changes in the government of Jambi Province and East Tanjung Jabung Regency on development policies is very noticeable. In the early 2000s, after the appointment of a new Governor in Jambi, a program was launched to develop one million hectares of oil palm plantations. The selection of oil palm cultivation is partly due to the perception of its high economic value, which encourages farmers to choose oil palm farming and manage their crops correctly, as the plant is also considered suitable for cultivation on peat soil with relatively low density or shallow depth (Prakosa et al., 2023).

3.2.2. Land cover on 2010

In 2010, plantations occupied 111,353.3 hectares (Figure 2, Table 3), an increase of 17,760.41 hectares compared to 2000. This increase can occur not only due to economic factors but also due to the significant impact of policy factors. The One Million Hectare Oil Palm Land Program faced strong resistance from environmental organizations; however, the government banned palm oil plantation development on forest land and adopted a more selective approach in granting permits for new oil palm plantation companies.

The efforts to open plantations from 2000 to 2010 resulted in a significant change of land cover from bare land in 2000 to plantations in 2010 (Fig. 3, Table 3). The increase in plantations this year is around 17,670.4 hectares. Meanwhile, bare land was increased by 1,632.78 hectares. On the other hand, the peat swamp forest experienced a substantial decline of around 31,158.36 hectares. Therefore, the increase in land cover from plantations and bare land originally came from the conversion of peat swamp forests. From 2010 to 2016, plantations and peat swamp forests experienced a reasonably high decline of 23,587.38 and 56,184.12 hectares, respectively, while bare land experienced an increase of 5,4627.5 hectares. This is thought to be due to the occurrence of forest and land fires in the years, which caused a significant change in land cover. From 2016 to 2022, plantations increased by 75,715.7 hectares, and peat swamp forest decreased by 26,433.18 hectares and bare land by 52,039.8 hectares. These changes may be due to the opening of such large plantation areas.

3.2.3. Land cover on 2016

Forest area declines occur annually, accompanied by increased plantations and settlements. Reducing natural vegetation makes peatlands vulnerable to subsidence if the peat forest is opened. The construction of ineffective canals in plantation areas can cause a decrease in the peat water table (Manurung et al., 2023). The increase in hotspot points occurred in 2019, with a total of 1,636 hotspots in East Tanjung Jabung Regency, caused by fire incidents that affected an area of 5,151.02 hectares (Saharjo & Effendi, 2023). The highest increase in bare land occurred this year, possibly due to harvesting or clearing land in plantation areas. However, the impact of the oil palm development program has already been significant, with oil palm land expansion reaching 593,000 hectares in 2013, with approximately 107,288 hectares in East Tanjung Jabung Regency (BPS Jambi Province, 2015).

3.2.4. Land cover on 2022

Land cover in PHU East Tanjung Jabung constantly changes periodically. A fast increase can be seen in the plantation area, especially in the oil palm plantation. The granting of business permits to companies to convert areas into oil palm plantations has resulted in 23 companies operating in 2023, with an area of plantations of more than 1,000 hectares. Several other companies also manage large forest areas into oil palm plantations, in addition to communities who manage them individually.

Peat swamp and peat swamp forest areas decreased from 95,603.04 hectares in 2000 to 51,209.64 hectares in 2022 for peat swamps and from 11,688.58 hectares in 2000 to 84,296.16 hectares in 2022 for peat swamp forests. Residential land area has increased significantly from year to year. This can happen due to the increase in population in East Tanjung Jabung Regency, which is causing an increase in the need for land use for residential purposes. According to data from the Central Agency of Statistics (BPS), the population of East Tanjung Jabung Regency in 2017 was 222,384, with an increase of 200,000 people yearly.

The results from the SVM algorithm show that peat swamp forests increased from 2010 to 2016 by 25,001.87 hectares, followed by a decrease in peat bogs by 56,184.16 hectares. Meanwhile, the area of plantations continued to increase, reaching 75,715.77 hectares from 2016 to 2022. This may have occurred due to changes or loss of vegetation on the ground. In 2010, the government's program to convert peat forests into plantations caused a significant loss of peat swamp forests. However, peat swamp forests increased in 2016, possibly due to the succession of abandoned land in 2010. Land cover changes can affect the hydrolysis process within an area (Sunandar, 2016).

The area of plantations increased rapidly in 2022 due to changes from forests and bare land to plantations. The Support Vector Machine (SVM) algorithm demonstrated good performance with an Overall Accuracy (OA) of 92.5% and a Kappa coefficient of 88.94. The OA value of 92.5% indicates that 92.5% of the mapped area was correctly classified. This value was obtained by comparing the correctly classified pixels to the total number of sample pixels used for validation. The Support Vector Machine (SVM) algorithm can be used to classify imagery into land use and land cover (LULC) classes, namely bare land, built-up areas, forests, vegetation, and water bodies (Kebede et al., 2022). The Kappa coefficient of 88.94 reflects a high level of agreement between the classification results and the reference data, even after accounting for potential agreement by chance. This performance demonstrates that the SVM algorithm is effective for land cover classification in the study area.

4. Conclusions and Recommendation

4.1. Conclusions

East Tanjung Jabung Regency experienced dynamic land use changes from 2000 to 2022. The land cover that experienced the most changes was the peat swamp and peat swamp forest, which were converted into plantations and settlements, totaling 1,722,780.11 hectares. The most significant change in land cover classification from 2000 to 2023 was the increase in the area of oil palm plantations, which may result from the government's regulation of the extension of oil palm plantations in the province.

4.2. Recommendation

Based on the results of this study, it is recommended that the government strengthen peatland protection policies, increase public awareness, and implement land restoration programs. In addition, it is important to carry out strict monitoring of land conversion, involve local communities, and build collaboration between related parties to support sustainable agricultural practices.

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