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RESEARCH ARTICLE

Deforestation Characteristics between 2006 and 2020 over Tropical Forest in Central Kalimantan, Indonesia

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Abstract Deforestation is reported to possess a vast and detrimental impact on the environment, economy, and social aspects of the community. In this context, the phenomenon should be assessed and analyzed to inform the decision-maker overseeing issued policy and development strategies. Therefore, this research aimed to characterize deforestation in Central Kalimantan between 2006 – 2020 using land cover map issued by the Indonesian Ministry of Environment and Forestry. Changes in natural forest cover were calculated and analyzed using the Remote Sensing and Geographical Information System (GIS) to determine trend, location, and land cover replacement of deforestation, reforestation, and degradation in Central Kalimantan Province, Indonesia. A series of Landsat images from 2000 to 2020 was used with a spatial resolution (30 m) and frequent revisit cycles. Additionally, the levels of forest loss, restoration, and degradation were accurately mapped by analyzing spectral bands and vegetation indices, providing valuable information for conservation efforts and other land-based policies. The results showed that Central Kalimantan lost 1.5 million ha of natural forest with a rate of deforestation of 117,000 ha/year from 2006 to 2020. Deforestation showed a decreasing trend and fluctuation in secondary swamps and dry forests located in the southern part of the island. This research could be used as a base to determine the target location for rehabilitation strategy to prevent further deforestation.

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1. Introduction

The tropics are experiencing fast economic growth due to great strain on natural resources, such as forests. In this context, pressures on land have massive effects on ecosystem resilience, and water sustainability, as well as tropical peatland with significant social and economic effects. The reduction of deforestation generates multiple economic, social, and ecological benefits by safeguarding the climate and other ecosystem services provided by forests. Understanding the relative contribution of different drivers is needed to guide policies in maintaining natural forest cover (Doggart et al., 2020; Lawrence et al., 2022; Silva Junior et al., 2021). Therefore, monitoring land status or condition is desired in the context of sustainable land use. The only practical and affordable method for obtaining essential data on the environment is through satellite remote sensing, given the geographical and temporal scales of relevance (G. M. Foody, 2003; Giles M Foody et al., 2001).

For the next 100 years, the biggest threat to ecological systems is changing land cover, which is a significant driver of environmental change (Chapin et al., 2000). The serious degradation of the vast peatlands of Indonesia since the 1990s is the proximate cause of the haze endangering public health in Indonesian Sumatra and Borneo, Singapore, Malaysia, and Thailand. Moreover, peatlands that have been drained and cleared for plantations are a major contributor to greenhouse gas (GHGs) emissions (Chapin et al., 2000; Mitchard, 2018). Remote sensing has been extensively used to track significant land cover changes, which include amendments to existing land cover or a complete change. The majority of remote sensing research are concentrated on changes in land cover rather than those with an equal or greater environmental impact (Lambin, 1999). The soil and water systems are extremely vulnerable to changes in vegetation due to large and heavy rainfall as well as quick biochemical and mineral breakdown processes (Taddese, 2001).

According to (Moutinho, 2005; Prabowo et al., 2017), deforestation is affected by policy, social economics, season of event, and spatial aspects. The rate of deforestation is strongly correlated to location, distance from a village or city, road access, and connectivity (Poor et al., 2019). Therefore, the intensity of deforestation greatly varies between different locations, regions, and periods (Reddy et al., 2019). Deforestation is strongly influenced by legislation law, and political settings (A., 2001).

Deforestation is forest cover change into a non-forest area or region for other uses permanently but the term is still debatable (W.D. & I.A.P., 1997). FAO states that deforestation

is the conversion of forest to other land use. The concept is interpreted as a reduction of tree canopy cover to less than minimum threshold of 10% for a long term with a minimum tree height of 5 meters at minimum area of 0.5 ha (Ferraz et al., 2009; Puyravaud, 2003; W.D. & I.A.P., 1997). Deforestation is defined as the conversion of natural forest into other land cover, showing that logging in plantation forests is not considered deforestation. The conversion of natural forests into plantations counts as deforestation (Kemen G. Austin et al., 2019; Basuki et al., 2022; Wegscheider et al., 2019).

The impact is huge and cover multiple aspects including economy, biodiversity, and livelihood of local communities (Carlson et al., 2000; Ridder, 2007). Global communities are also affected by deforestation to increase climate change (Thomas et al., 2004). Furthermore, concern has risen due to the increase in environmental disasters associated with climate change such as flooding, hurricanes, and dryness (Iwata et al., 2014; Suk et al., 2020; Suwarno et al., 2015; Yoshioka et al., 2021). Among anthropogenic activities, Land Use and Land Cover Change (LULC) and deforestation are the main triggers of biodiversity decline. The alteration of forests into plantation or cultivated areas has created fragmentation and loss of habitat and resulted decline in biodiversity on earth. Furthermore, loss of biodiversity leads to loss of ecosystem services such as climate regulation, water purifying, and many forest products (Jaenicke et al., 2010).

Indonesia has a central role in climate change mitigation due to large forest cover (Koh et al., 2015; Ridder, 2007; Wegscheider et al., 2019). As the largest province, Central Kalimantan possesses more than 7 million ha of forest cover which accounts for approximately 49% of the total area. This province is recognized as the largest GHGs emitter produced from deforestation and forest fires between 1990 to 2015 (Wegscheider et al., 2019). Additionally, Central Kalimantan consists of 30% peatland and the stored carbon has a positive correlation with the thickness of the peat (Wegscheider et al., 2019). In this context, the mitigation program should be focused on decreasing degradation and conserving forest carbon stock.

The government of Indonesia (GoI) has developed some programs and initiatives to tackle climate change. The commitment of GoI to mitigating climate change is reflected in the National Determined Contribution (NDC). There is a strong commitment to reduce GHGs emissions by 29% unconditionally and 41% with support from international funding. Some programs include Reduction Emission from Deforestation and Forest Degradation Plus (REDD+), low carbon development, peat restoration, and revegetation (Basuki et al., 2022; Suroso et al., 2022) conducted by government institutions, NGOs, private sector, universities, and local communities.

The management of areas, specifically forests, influences the occurrence of disasters. Most of the disasters were caused by anthropogenic activities such as the conversion of forest areas to river basins. Natural disasters in 2020 were floods and forest and land fires, while the types with rare occurrences included landslides, tornadoes, and high tides. In addition, floods most frequently occur in Kotawaringin Barat and Seruyan Districts. The number of communities affected in 2021 was recorded at 370,004 across 725 villages/wards. Forest and land fires have been relatively rare since 2020 due to high rainfall throughout the year and the short dry season (BPS Kalteng, 2022; Kusin et al., 2022; SI, 2015; Venelia et al., 2021).

Central Kalimantan Province has contributed to the achievement of the emission reduction target or NDC. The province has great opportunities in mitigating climate change with a significant forested area. However, several factors must be considered, including preparing an emission reduction strategy, institutional strengthening, and preparation of Forest Reference Level (FRL) using the latest methods according to guidance developed by the Ministry of Environment and Forestry (Suroso et al., 2022; Wegscheider et al., 2019).

Identifying and characterizing the cause of GHGs emissions is crucial in determining the mitigation strategy. For instance, deforestation needs to be identified, measured, and classified to obtain the best strategy for reducing the phenomenon. Another benefit is the support of land-based data to measure the target of mitigation programs (Liu et al., 2019; Touma et al., 2021; Ullah et al., 2022). The probability of achieving the NDC target increases by implementing the method. Therefore, this research aims to characterize deforestation by assessing the trend, location, and cause.

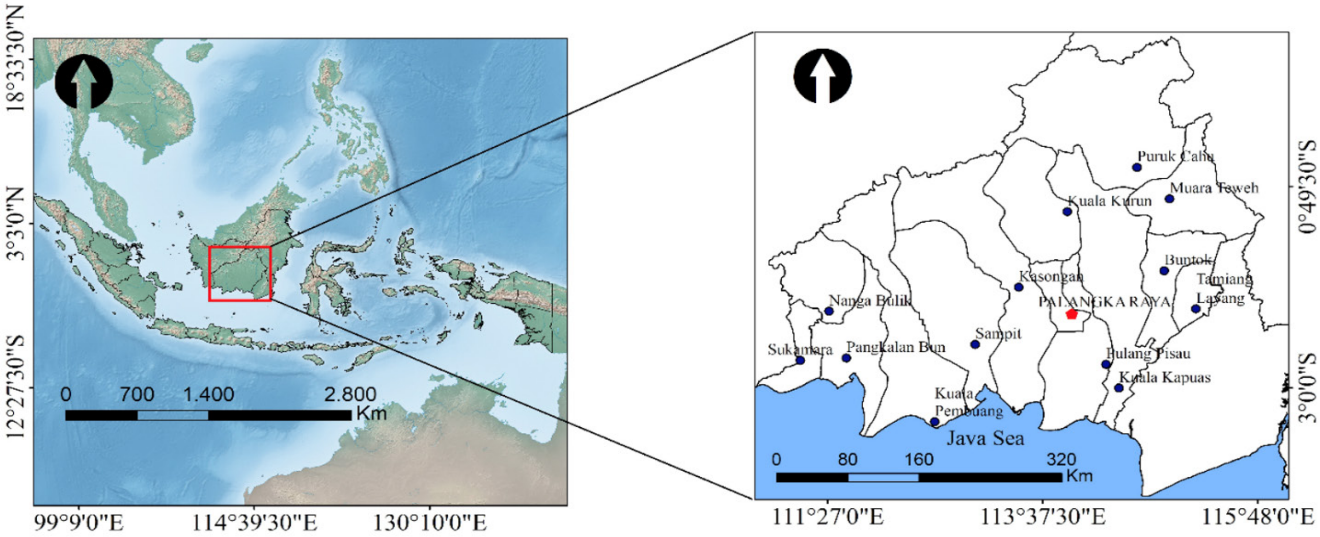

Figure 1. Map of research site in Central Kalimantan Province, Indonesia

2. Methods

Research Setting

This research was located in Central Kalimantan as a unit analysis. Based on Indonesian Internal Affair Ministry Degree Number 58 in 2021, the province cover an area of 153.413,06 km^2, divided into 13 Districts and 1 Municipal, as shown in **Figure 1**. In 2021, the total number of communities of Central Kalimantan Province accounted for 2.70 million with an increment rate of 0.90% (BPS Kalteng, 2022; SI, 2015).

Central Kalimantan has a tropical climate with a temperature range of 21.2^0 C to 34.8^0 C (Hendrik et al., 2010; Hirano et al., 2012; Page et al., 2004; Tawaraya et al., 2007). The available sunlight is between 52% - 69%, creating favorable conditions for agriculture and plantations. Furthermore, the social and ecosystem conditions are influenced by rivers. The southern part is a flat low land with an altitude of 1 to 9 m above sea level, while the northern part is mountainous and hilly. The river, altitude, and contour also influence the type of ecosystem. Peat swamps and lowland forests dominated the southern area, while highland dipterocarps forests are prominent in the northern part (BPS Kalteng, 2022).

The ecosystem of Central Kalimantan is heavily influenced by the presence of rivers from a socio-economic perspective. In some areas without land access, rivers play an important role in transportation, hence many settlements are located on riverbanks. In the context of economic benefits, rivers are used for fishing, gold prospecting, and daily water needs. There are 11 major rivers and 33 tributaries spread throughout the Central Kalimantan region. The longest and shortest are the Barito and Kumai Rivers with a length of 900 km and 175 km, respectively. Furthermore, the province contains about three million hectares of peatland located between 0^o 45' N and 3^o 3' S, as well as 111^o and 116^o E (Boehm & Siegert, 2001; BPS Kalteng, 2022).

Based on the Central Kalimantan Provincial Spatial Plan for 2021, the total allocation for protected forest is 3,630,142 ha and 12,120,330 ha for productive forest area. From the proportion of protected forest areas, the provincial government allocated 600,000 ha and 35,627 for Customary and Grand Forest Parks (or Taman Hutan Rakyat/TAHURA). In the future, the role of indigenous communities in managing and conserving nature must be increased (BPS Kalteng, 2022; Laksminarti, 2019; Supriatna et al., n.d.).

Data and Analysis

Land cover maps were issued by the Ministry of Forestry and Environment (MoFE) Republic of Indonesia. The period time of deforestation analysis followed the procedure of the 2nd FRL of Indonesia, which was 2006 – 2020 (Murdiyarso et al., 2011). However, the Ministry of Environmental and Forestry (MoEF) did not publish land cover maps for 2007, 2008, and 2010. MoEF classified natural forest land cover into 6 classes, namely primary dryland, secondary dryland, primary swamp, secondary swamp, primary mangrove, and secondary mangrove. Meanwhile, non-natural forest cover is classified into 15 classes, namely plantation forest, pure dry agriculture, mixed dry agriculture, dry shrub, wet shrub, savanna and grasses, paddy field, open swamp, fishpond/ aquaculture, transmigration areas, settlement areas, port and harbor, mining areas, bare ground, and open water (Margono et al., 2014).

Based on the description, this research used Landsat satellite images covering Central Kalimantan from 2000 to 2020. These images were selected to show cloud-free mosaics and provide a clear view of the Earth surface. According to Indonesian Standard Land Cover Classification (SNI) 7645:2010, the images were segmented into 15 different land cover classes, allowing for an accurate analysis of deforestation, reforestation, and degradation patterns. Deforestation was calculated by overlaying land cover map of the previous year (T0) with the following year (T1). The conversion from natural to non-natural forest category was measured using

Table 1. Forest area classification in Central Kalimantan.

Central Kalimantan Provincial Spatial Plan	Area (ha)
A. Protected Forest Area	
1. Protection Forest	1,391,604
2. Customary Forest	600,000
3. Wildlife Sanctuary	57,389
4. Strict Nature Reserve	198,597
5. National Park	1,168,284
6. Nature Recreation Park	2,954
7. Grand Forest Park	35,627
8. Natural Reserve on Ex-Mega Rice Project	154,002
9. Black water conservation	17,626
10. Reserve Region	23
11. Other Protected Area	4,036
Total A	3,630,142
B. Production Forest Area	
1. Limited Production Forest	3,335,571
2. Production Forest	3,896,706
3. Convertible Production Forest	2,258,274
4. Other Area	2,629,779
Total B	12,120,330
Total A + B	15,750,472

ArcGIS version 10.2. Land cover was also identified before deforestation to track the cause. The interpretation of the Landsat LDCM (*Landsat Data Continuity Mission*) data served as the basis for the estimation of deforestation rate for 2006 – 2020 (Ardiyanto et al., 2022).

The equation of annual forest cover change is used to calculate the annual deforestation rate as reported by the compound interest rule (Ferraz et al., 2009; Puyravaud, 2003). The recommended annual deforestation rate (r) was more intuitive than the previous formula used by FAO (q) (Puyravaud, 2003). The R-value is higher than q and the difference in the two formulas is lower than the sampling error. The rate of forest cover change yearly (r, %/year) is calculated based on initial (A1, ha) in the early period (T1, year) and extensive end (A2, ha) in the final period (T2, year), which is formulated as follows (Puyravaud, 2003):

$$r = \left(\frac{1}{T2 - T1}\right) + ln\left(\frac{A2}{A1}\right)$$

Field observation was conducted to identify land use type and validate the result from satellite images. Before the preprocessing of satellite imagery, an extensive field activity was performed using GPS equipment and an unmanned aerial vehicle (UAV/drone). This field activity was performed to (1) obtain accurate location of point data for each land cover class included in the classification scheme, (2) establish training sites and (3) create an independent data set reserved for accuracy assessment. Field survey activities were carried out to validate recent forest cover with 80% accuracy of map results. This includes the selection of sample areas representing various forest types and conditions, field data collection using GPS, cameras, and field notebooks to record forest cover, tree species, and signs of disturbance as well as comparing field observations with satellite images and LiDAR data to assess accuracy. Furthermore, overall and user accuracies should be calculated for different forest cover classes. Land cover categories of focus were burnt areas, peat swamp forest, resettlement, barren land, mangrove, and herbaceous land. Results from land cover change analysis were analyzed using descriptive statistics to calculate the average deforestation each year and the standard error.

3. Result and Discussion

Deforestation rates in Central Kalimantan fluctuated in each computation due to dynamic changes in land cover. Natural forest has reduced to 1.5 million hectares between the period of 2006 to 2020. Swamp and dry secondary forests experienced high deforestation, while primary and secondary mangroves are subjected to a decreased level. The rate of deforestation fluctuated during the period of analysis but showed a decreasing trend. The phenomenon decreases sharply from 418,524 ha/year to 56,421 ha/year between 2006 to 2009 and 2011 to 2012. Subsequently, the trend increased slightly to 86,305 ha/year from 2012 to 2013.

Table 2. Change in natural forest cover between 2006 – 2020 (in hectares).

Type of Forest	2006	2020
Primary Dry Land Forest	1,204,400	1,058,780
Primary Swamp Forest	44,339	32,373
Primary Mangrove Forest	2,796	1,777
Secondary Dry Land Forest	4,874,912	4.287.854
Secondary Swamp Forest	2,355,643	1,706,985
Secondary Mangrove Forest	21,940	21,148
Total	**8,504,029**	**7,108,917**

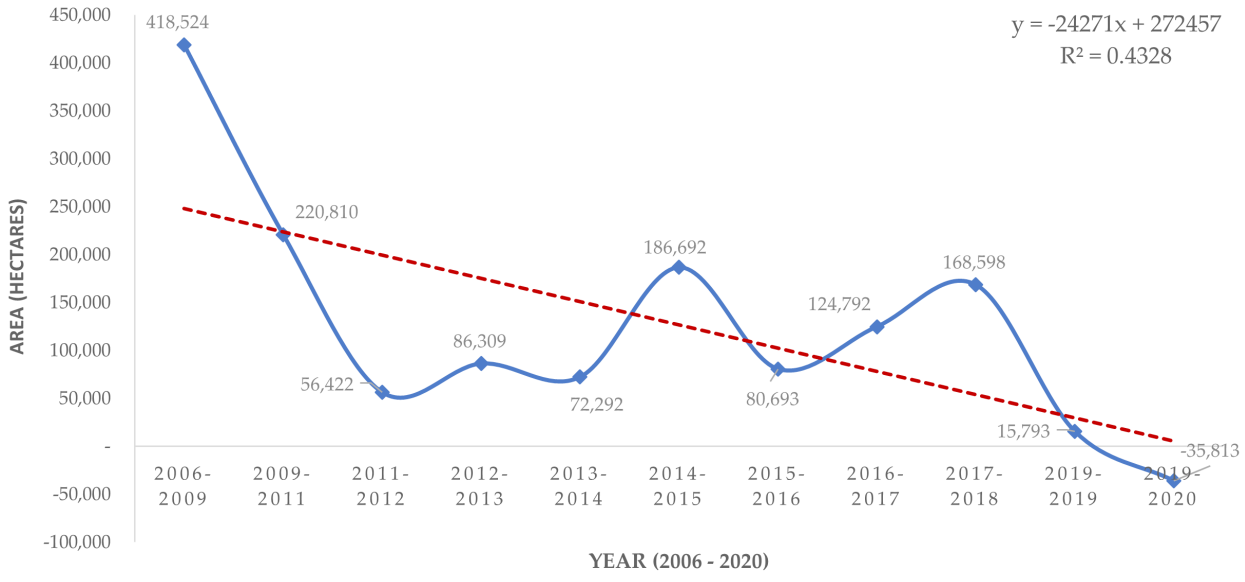

Figure 2. The trend of deforestation in Central Kalimantan, Indonesia

Considering the trend, deforestation is categorized into decreased and increased periods. Decreased era occurred from 2006 to 2012, 2013 to 2014, 2015 to 2016, and 2018 – 2020. **Figure 2** shows that increased trends take place between 2012 to 2013, 2014 to 2015, and 2016 to 2018. Interesting phenomena occurred between 2019 to 2020 where deforestation rate recorded a negative 35,812 ha. During this period, natural forests increased and the trend of deforestation continued to decline from 2019 to 2020 due to anthropogenic, natural, and government policies.

The total rate of deforestation in Central Kalimantan was 117,445 ha/yr and the process initiated forest degradation. Secondary forest converts into other land cover such as plantation and agriculture with increased detriment (**Table 3**). The analysis found that dry and swamp primary forests experienced deforestation. Similarly, natural and mangroves experienced a relatively small rate of deforestation.

This research found that natural forests in Central Kalimantan had converted into 15 land use types. The dominant land use resulting from deforestation were shrubs, open areas, plantations, and agricultural land. Additionally, natural forests contain swamp areas and water bodies such as lakes and water ponds.

The average amount of deforestation in each category is presented in **Table 4**. Swamp and dry secondary forests had the highest deforestation rate of 59,317.81 ha/year and 55,938.56 ha/year respectively. Mangroves suffered less from deforestation because the ecosystem was less favorable for plantations. Large-scale oil palm or forest plantations require fertile soil with sufficient water supply.

The 1.5 million natural forests were converted into 373,816.39 hectares of peatland soil. Approximately 24% of deforestation in Central Kalimantan targets peat ecosystems in carbon stock and emitting higher GHGs into the atmosphere. **Figure 3** compares the proportion of peat and mineral soil, where forests in 2006 were slightly different from 2020. In 2006, the proportion of forests on peat soil was higher than soil in 2020. This figure shows that mineral soil is more desirable than peat soil due to forest clearing for various purposes.

Most of the deforestation in Central Kalimantan within the range time of 2006 to 2020 arose in secondary swamps and dry forests. This figure also shows several areas experiencing reforestation between the 2006 to 2020 period. Approximately 18% of forests were replaced by 54% of plantations between 1995 and 2000. Additionally, 30.2 million hectares of non-forest land across the country matched the biophysical requirements for oil palm development (K. G. Austin et al., 2017; Poor et al., 2019).

There were four types of disturbances distinguished during field and aerial observation. These include (1) no disturbance: tall and large peat swamp forest trees possessing closed canopy without human exploitation; (2) old, exploited forests: ex-logging railways and stamping areas colonized by pioneer tree species in Sebangau Catchment such as *Combretocarpus*

Table 3. The rate of annual deforestation between 2016-2020 (in hectares)

Type of Forest	Deforestation (ha yr-1)	SE (ha yr-1)
Primary Dry Land Forest	312.74	96.86
Primary Swamp Forest	976.08	490.46
Primary Mangrove Forest	7.53	6.56
Secondary Dry Land Forest	55,938.56	11,125.25
Secondary Swamp Forest	902.61	262.97
Secondary Mangrove Forest	59,317.81	11,574.10
Total	**117,455.33**	**23,556.20**

Table 4. Land use type resulted from deforestation in Central Kalimantan, Indonesia

Strata	AD post deforestation (ha yr-1)	SE (ha yr-1)
Port and Harbor	0.00	0.00
Plantation forest	1,369.55	1,187.90
Paddy Field	35.87	22.95
Bare ground	28,507.95	10,588.18
Savanna and Grasses	0.00	0.00
Settlement areas	90.96	83.04
Perennial crops	10,855.18	2,951.76
Mining areas	3,217.44	690.18
Dry cultivation	593.53	290.78
Dry cultivation and Shrub	10,624.07	5,016.19
Swamp	1,419.46	294.19
Shrub	30,271.34	5,399.42
Wetland Shrub	30,424.46	5,974.28
Fishpond/aquaculture	5.13	5.06
Transmigration Areas	22.72	23.58
Open Water	17.67	12.76
Total	**117,455.33**	**32,540.27**

Notes: AD (After Deforestation); SE (Standard Error)
Note: SE (Standard Error)

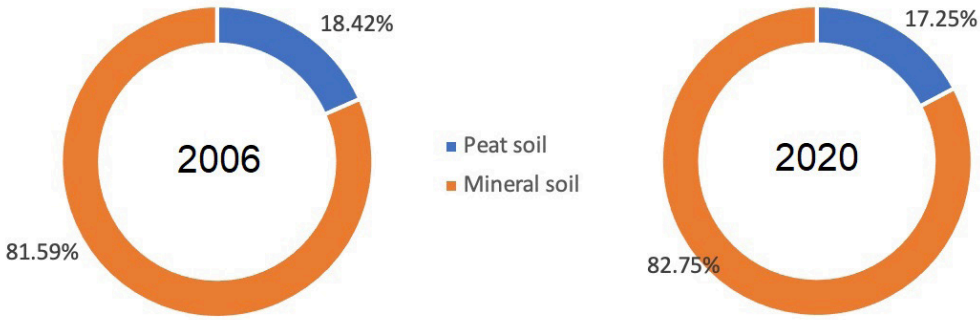

Figure 3. Comparison of deforestation on mineral soil and peat soil between 2006 and 2020 in Central Kalimantan (Indonesia)

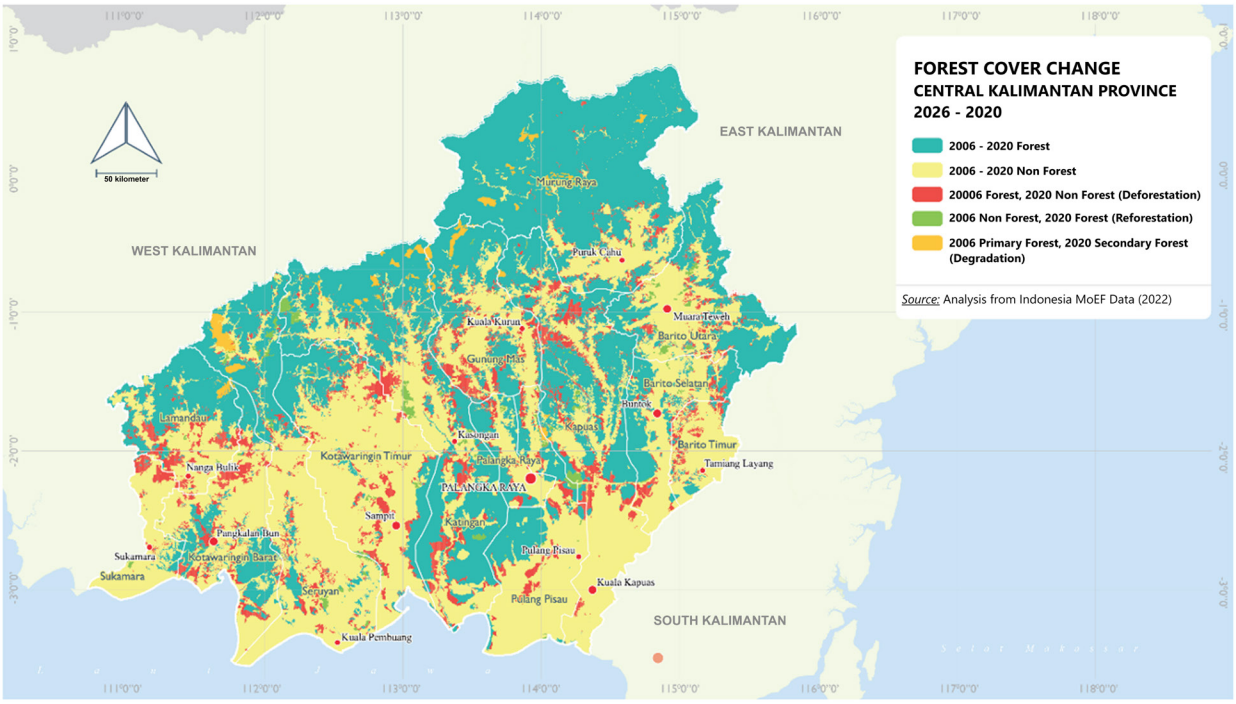

Figure 4. Map of Deforestation and Forest Degradation in Central Kalimantan Province, Indonesia (2006 – 2020).

rotundatus (tumeh) and *Macaranga* sp., (3) land clearing by the local community for agriculture and settlement, and (4) burnt areas affected by El-NINO fire events.

The lowland forest is inhabited more than the highland parts. In addition, low elevation, access, and soil conditions make the lowland forest of Central Kalimantan favorable for oil palm and timber plantations (Kemen G. Austin et al., 2019; Curran et al., 2004; Gaveau et al., 2009; Margono et al., 2014). Protected forests in lowlands decreased by 56% from 1985 through 2001 (Curran et al., 2004). The rate of expansion was 450,000 ha/year and replaced forested areas (K. G. Austin et al., 2017; Kemen G. Austin et al., 2019).

In 2015, Central Kalimantan in Kalimantan/Borneo (~15.3 million hectares) had the third-largest relative forest cover (~49% of the total provincial area), the greatest absolute forest cover (~7.5 million ha), and the highest percentage of forests (~7.5 million ha). The province contributed the biggest percentage (38%) of all emissions from deforestation for the analyzed period from 1990 to 2015 (BPS Kalteng, 2022; Wegscheider et al., 2019). Central Kalimantan has two national parks in the lowland area, namely Sebangau and Tanjung Puting National Park. The two protected areas play as bulwarks, holding and resisting deforestation. However, concern arises for the conservation since rapid deforestation occurred in surrounding and buffer zone areas.

Deforestation rate was relatively high between 2006 to 2011 because of policy and development priorities. During this time, the government created an investment ambiance, high incentives, and attractive leases inviting investors to develop large-scale oil palm and timber plantations (Bissonnette & De Koninck, 2015). A European ban on high-deforestation palm oil from 2000 to 2015 led to a global price premium of 8.9% on low-deforestation, preventing 21 374 ha (1.60%) and 21.1 million tCO_2 (1.91%) emissions (Busch et al., 2022; Murdiyarso et al., 2011).

Oil palm is a highly profitable commodity and has become the main reason for the expansion of the commodity. This works closely with the cooperative sector and individual farmers and producers of palm oil production (Pachmann, 2021). After 2011, deforestation rate slowed down due to the moratorium policy. The government banned the establishment of oil palm plantations on peatland (Murdiyarso et al., 2011) but deforestation rose between 2015 and 2019 due to widespread forest fires triggered by ENSO (*El Niño–Southern Oscillation*) condition (Susilo et al., 2013). The incidence of frequent ENSO events with major land development projects

led to an increased risk of repeated fire events in tropical peatland areas (Hendrik et al., 2010). Furthermore, forest fires are an important cause of environmental alteration and land degradation or conversion through human activities.

The combination of degraded ecosystems generated from previous deforestation and the long dry season caused uncontrolled forest fires. Even though deforestation and emission rates have decreased from 1990 to 2015, the trend is not uniformly present across the five provinces. The rates in West and North Kalimantan appear to be rising, hence each province has a different chance of meeting carbon reduction goals (Wegscheider et al., 2019). After 2019, deforestation in Central Kalimantan slowed down and became negative in association with the absence of a long dry season and the occurrence of the COVID-19 pandemic. In this context, the pandemic prompted illegitimate, opportunistic forest cutting and mining in tropical countries, endangering forest ecosystems and the inhabitants (Brancalion et al., 2020a, 2020b; Céspedes et al., 2022; CI, 2020; Laudares, 2020; M et al., 2021).

Considering the negative effect of deforestation, the government launched a program called FOLU Net Sink to sequestrate GHGs bigger than the emissions from forestry and other land use sectors. The goal of FOLU net sink is articulated in 5 main strategies, namely reduction of emission from deforestation and forest degradation, the establishment of plantations, sustainable management, forest rehabilitation, and management of peat ecosystem (BPS Kalteng, 2022; *Submission by Indonesia National Forest Reference Level For Deforestation, Forest Editor in Chief*, 2022). Forest vegetation and soils are very important in relation to carbon sinks, even though deforestation and degradation contribute 17% of emissions. Tropical and subtropical forests hold more than half of the carbon dioxide (CO_2) in the atmosphere.

The result may contribute to the achievement of the Indonesia NDC by informing the decision-makers about the characteristics of deforestation in Central Kalimantan. Additionally, the primary causes of land-use changes are the increase in agriculture and deforestation. Since peat swamp forest ecosystems can support extraordinarily high biodiversity and enormous amounts of carbon, deforestation possesses negative effects on the entire planet (DeFries et al., 1999; Miettinen et al., 2011). Research was also carried out on the causes of unsuccessful forest law enforcement policies and initiatives over the past 20 years, beginning with the first Forest Law Enforcement, Governance, and Trade Conference held in Bali in 2001 (Kemen G. Austin et al., 2019; Pachmann, 2021; Wijaya et al., 2019). Government policies handling and preventing deforestation and degradation at the provincial level include mainstreaming green growth and low-carbon development at regional and sectoral development planning, including protection and restoration management of peat and mangrove ecosystems.

There are several difficulties in deforestation research, including the rapid changes in regulation related to the use of forests and land for other uses such as national policies on food estate programs, forest and land fires occurring due to the long drought (ENSO), as well as encroachment for agriculture, settlements, and illegal mining. Therefore, further and detailed research is needed on serial and integrated spatial analysis of land use changes in Central Kalimantan using ecological, economic, and socio-cultural methods with the inclusion of experts from various scientific disciplines. A key challenge is predicting the future form, pace, and patterns of deforestation and forest degradation in Central Kalimantan amidst Indonesia's capital relocation to East Kalimantan and strategic policies addressing the growing food crisis, migration, and drought (Kodir et al., 2021; Rahmat et al., 2021)

4. Conclusion

In conclusion, deforestation in Central Kalimantan showed a declining trend influenced by policy and anthropogenic activities. From the total of 1.5 million ha of forest loss within the analysis period, the phenomenon mostly occurred in peat swamps and dry secondary forests where human activities were relatively high. Deforestation led to degraded areas including shrubs, open areas, savanna, and cultivated systems such as agriculture and plantations.

Government policies, specifically regulations regarding the eradication of illegal logging, forest and land fires, social forestry, carbon economic value, and the participation of forestry-related stakeholders could reduce deforestation and changes in land use from forest to non-forest. The results also determined the target location for rehabilitation strategy and method to prevent further deforestation.

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