

Article

Not peer-reviewed version

Deforestation Characteristic during a Period 2006 - 2020 over Tropical Forest in Central Kalimantan, Indonesia

[Hendrik Segah](#) * , Afentina Afentina , Fatkhurohman Fatkhurohman , Yusuf Aguswan , Naru Takayama

Posted Date: 19 September 2023

doi: 10.20944/preprints202309.1263.v1

Keywords: Deforestation; Forest Fires; Central Kalimantan; Land Use and Land Cover Change



Preprints.org is a free multidiscipline platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Article

Deforestation Characteristic during a Period 2006–2020 over Tropical Forest in Central Kalimantan, Indonesia

Hendrik Segah ^{1,*}, Afentina ^{1,2}, Fatkhurohman ³, Yusuf Aguswan ¹ and Naru Takayama ⁴

¹ Forestry Department, University of Palangka Raya, Palangka Raya 73112, Central Kalimantan, Indonesia

² Research and Community Services, University of Palangka Raya, Palangka Raya 73112, Central Kalimantan, Indonesia; afentina@for.upr.ac.id

³ Environment & GIS Expert. Palangka Raya 73112 Central Kalimantan, Indonesia; fatkhurohman@gmail.com

⁴ Department of Environmental Engineering, Osaka Institute of Technology, Osaka 535-8585, Japan; naru.takayama@oit.ac.jp

* Correspondence: segah@for.upr.ac.id

Abstract: Deforestation brings vast and detrimental impact on the environment, economy, and social aspects of community. Thus, it is important to assess and analyze deforestation to inform the decision maker that oversees issued policy and development strategies. The present study aims to characterize deforestation in Central Kalimantan between 2006 - 2020. Utilized land cover map issued by Indonesian Ministry of Environment and Forestry, we analyzed the change in natural forest cover using Remote Sensing and Geographical Information System (GIS) to find the rate the trend, location, and land cover replacement of deforestation in Central Kalimantan Province, Indonesia. The research found that during the period Central Kalimantan lost 1.5 million ha of natural forest with the rate of deforestation 117,000 ha/year. In general, the deforestation shown decrease trend and fluctuated during the period. Deforestation majority takes place at secondary swamp and dry forest that are located at south part of the island. Most of deforestation resulted shrubs, plantations, and agriculture land. The finding of this research could be used as a base to determine the target location for rehabilitation strategy and approach to prevent further deforestation.

Keywords: deforestation; forest fires; central kalimantan; land use and land cover change

1. Introduction

The tropics are seeing fast economic growth, which naturally puts great strain on the region's natural resources, most notably its forests. Pressures on the land have massive effects on ecosystem resilience, soil and water sustainability, and tropical peatland in Indonesia, all of which have significant social and economic effects. Reducing deforestation can generate multiple economic, social and ecological benefits by safeguarding the climate and other ecosystem services provided by forests. Understanding the relative contribution of different drivers of deforestation is needed to guide policies seeking to maintain natural forest cover [1–3]. Therefore, monitoring land status or condition is desired in the context of sustainable land use. The only practical and affordable way to get the essential data on the environment is through satellite remote sensing, given the geographical and temporal scales of relevance [4,5].

For at least the next 100 years, the biggest threat to ecological systems will come from changing land cover, one of the most significant drivers of environmental change. The serious degradation of the vast peatlands of Indonesia since the 1990s is the proximate cause of the haze that endangers public health in Indonesian Sumatra and Borneo, and also in neighbouring Singapore, Malaysia and Thailand. Moreover peatlands that have been drained and cleared for plantations are a major contributor to greenhouse gas emissions [6,7]. Remote sensing has been extensively utilized to track significant land cover changes, as those brought on by deforestation. But these are only some of the problems. Land cover change has two parts: those where the land cover is amended and those where

the cover type is changed. The majority of remote sensing studies have concentrated on changes in land cover rather than those that could have an equal or greater environmental impact [8]. The soil and water systems are extremely vulnerable to changes in vegetation, and especially for forest covering, in tropical areas due to the large and frequently heavy rainfall as well as quick biochemical and mineral breakdown processes [9].

Based on studies by [10,11], deforestation is affected by policy, social economic, season of event and spatial aspects. The rate of deforestation strongly correlated to location, distance from village or city, road accesses and connectivity [12]. As result, the intensity of deforestation greatly varies between different location, regions, and period of time [13]. Some researchers analyzed that deforestation in Indonesia strongly influenced by legislation and law, and political setting [14].

Impact of deforestation is huge and covered multiple aspects including economy, biodiversity, and local communities' livelihood [15,16]. Global communities are also affected by the deforestation as it accelerates climate change [17]. Furthermore, concern rises due to the increase of environmental disaster associate to climate change such as flooding, hurricane, and dryness [18–21]. Among anthropogenic activities, Land Use and Land Cover Change (LULC) and deforestation are the main triggered of biodiversity decline. The alteration of forests into plantation or cultivated area 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 [22].

Indonesia particularly Central Kalimantan has a central role in climate change mitigation due to its large forest cover [16,23,24]. As the largest province in Indonesia, Central Kalimantan owns more than 7 million ha forest cover that accounted approximately 49% from the total area of Central Kalimantan. On other hand, this province is also recognized as the largest Green House Gases (GHGs) emitter produced from deforestation and forest fire during a period 1990-2015 [23]. Beside large forest cover, Central Kalimantan also consists of 30% peatland which is rich in carbon stock. The carbon stored in peat has a positive correlation with the thick of the peat [23]. Thus, mitigation program in Central Kalimantan should focused on decreasing degradation and conserving forest carbon stock. Such kind of program will significantly mitigate the production of GHGs.

Government of Indonesia (GoI) develops some programs and initiative as a mean to tackle climate change. The commitment of GoI in mitigating climate change is reflected in the National Determined Contribution (NDC). Indonesia has strong commitment to reduce GHGs emission 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 program, peat restoration program and revegetation [25,26]. The program is run by various sectors encompassing government institutions, NGOs, private sector, universities, and local communities.

The management of areas, especially forests, has an influence on the occurrence of disasters in Central Kalimantan. Most of the disasters in Central Kalimantan were caused by anthropogenic activities such as the conversion of forest areas and damage to river basins. Natural disasters that often occur in Central Kalimantan in 2020 are floods and forest and land fires, while the types of natural disasters that rarely occur are landslides, tornadoes, and high tides. Floods most frequently occur in Kotawaringin Barat and Seruyan Districts, while forest fires in 2020 are relatively rare. The number of residents affected by floods in 2021 was recorded at 370,004 people spread across 725 villages/wards throughout Central Kalimantan. Forest and land fires have been relatively rare since 2020, one of the reasons being the high rainfall throughout the year and the short dry season [27–30].

Central Kalimantan Province, through various schemes has attempted to contribute to the achievement of emission reduction target or NDC. With a significant forested area, Kalteng has great opportunities in mitigating climate change in Indonesia. However, there is much that needs to be done, including preparing an emission reduction strategy, institutional strengthening, and the preparation of Forest Reference Level (FRL) using the latest methods according to guidance developed by the Ministry of Environment and Forestry [23,26].

Identify and characterize the cause of GHGs emission is crucial in determining the mitigations strategy. For instance, deforestation as the main cause of GHGs emission in Central Kalimantan need to be identify, measure and classified in order to find the best strategy to slow down the deforestation and rehabilitate degraded forest. Another benefit by characterized deforestation is the support of land-based data to measure the target of mitigation programs [31–33]. By implementing these approaches, the probability of achieving the NDC target will increase. The study aims to characterize deforestation in Central Kalimantan by assessing the trend of deforestation, the location, and the cause of deforestation.

2. Materials and Methods

2.1. Research Setting

This research was located in Central Kalimantan as unit analysis. Based on Indonesian Internal Affair Ministry Degree Number 58 in 2021, Central Kalimantan cover an area of 153.413,06 km², that divided into 13 Districts and 1 Municipal (shown in Figure 1). In 2021, the total residents of Central Kalimantan Province accounted for 2.70 million with the rate of resident increments 0.90% [29,30].

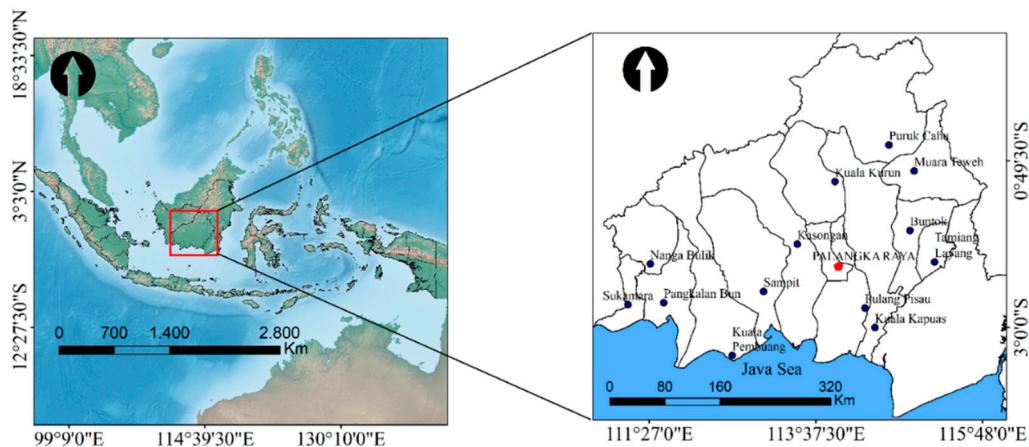


Figure 1. Map of research site in Central Kalimantan Province, Indonesia.

Central Kalimantan has a tropical climate with the temperature ranged from 21.2⁰ C to 34.8⁰ C [34–37]. The sunlight available abundantly ranged from 52% - 69%, creating favorable conditions for agriculture and plantations. The condition of social and ecosystem condition influenced by the river. 11 big rivers and 33 small rivers found in Central Kalimantan and the Barito rivers is the longest river that reach 900 km length. The south part of Central Kalimantan is flat low land with altitude 1-9 meter above sea level. Whist the north side is mountain area and hilly contour. Beside rivers, the altitude and contour also have influence on the type of ecosystem. Peat swamp forest and low land forest dominated South area and high land dipterocarps forest is dominant at north side [30].

Central Kalimantan's ecosystem is heavily influenced by the presence of rivers. From a socio-economic perspective, rivers also play an important role for the community. In some areas where there is no land access yet, rivers still play an important role in transportation so that in general, many settlements for the people of Central Kalimantan are located on riverbanks. Rivers also play an important role from an economic standpoint, rivers where people catch fish, look for gold and provide water for their daily needs. There are 11 major rivers and 33 tributaries spread throughout the Central Kalimantan region. The longest river is the Barito River with a length of 900 km, while the shortest river is the Kumai River with a length of 175 km. Central Kalimantan contains about three million hectares of peatland which is one of the largest unbroken peatland in the world and located between 0^o 45' N and 3^o 3' S, between 111^o and 116^o E [30,38].

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. As shown in Table 1,

from the proportion of protected forest areas, the provincial government allocated 600,000 ha for Customary Forests and 35,627 for Grand Forest Parks (or Taman Hutan Rakyat/TAHURA). It is hoped that in the future the role of indigenous peoples in managing and conserving nature will be increased [30,39,40].

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

2.2. Data and Analysis

We used land cover maps issued by Ministry of Forestry and Environment (MoFE) Republic of Indonesia. The period time of deforestation analysis followed procedure of the 2nd FRL of Indonesia, which are 2006 – 2020 [41]. However, the MoEF did not publish land cover maps of 2007, 2008 and 2010. Deforestation in this study defined as the conversion of natural forest into other land covers, this imply that the logging in plantation forest do not considered as deforestations, otherwise, the conversion of natural forest into plantation forest count as deforestation [23,25,42].

MoEF classified natural forest land cover into 6 classes: primary dryland forest, secondary dry land forest, primary swamp forest, secondary swamp forest, primary mangrove forest and secondary mangrove forest. Meanwhile non-natural forest cover classified into 15 classes: 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 [43].

We calculated deforestation in each year by overlaying the landcover map of the previous year (T0) with the landcover map of following year (T1). Using ArcGIS version 10.2, we measured the conversion from natural forest category into non-natural forest category. We also identified the land cover post deforestation to tract the cause of deforestation. The interpretation of the Landsat LDCM (Landsat Data Continuity Mission) data served as the basis for the estimation of the deforestation rate for the years 2006 – 2020 [44]. Field observation was conducted to identify the land use type and validate the result from satellite images. Result from land cover change analysis then analyzed further using statistic descriptive to calculate the average deforestation each year and the standard error.

3. Results

Data indicated that deforestation rates in Central Kalimantan had fluctuated in each computation. This takes place because of the dynamic changes in land cover brought on by human activities that result in the loss of forest cover. In total, between the period 2006 – 2020 natural forest in Central Kalimantan has reduced 1.5 million hectares. Swamp secondary forest and dry secondary forest experienced deforestation the most, while mangrove primary forest and mangrove secondary forest less deforested (see Figure 3). The rate of deforestation fluctuated during the period of analysis, however in general showed a decreasing trend. As Table 2 shows between 2006 – 2009 to 2011 – 2012 deforestation decrease sharply, falling from 418,524 ha/year to 56,421 ha/year. The trend then rises slightly to 86,305 ha/year in 2012 – 2013.

Table 2. The change of 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

Considering the rise and the down of the trend, deforestation in Central Kalimantan could categorized into decrease period and increase period. Decreased era occurred in period 2006 – 2012, 2013 – 2014, 2015 – 2016 and 2018 – 2020. On other hand, Figure 2 shows increasing trends take place in 2012 – 2013, 2014 – 2015, and 2016 – 2018. Interesting phenomena occurred between 2019 – 2020 where deforestation rate recorded negative 35,812 ha. This indicated that between this period covered natural forest is increasing.

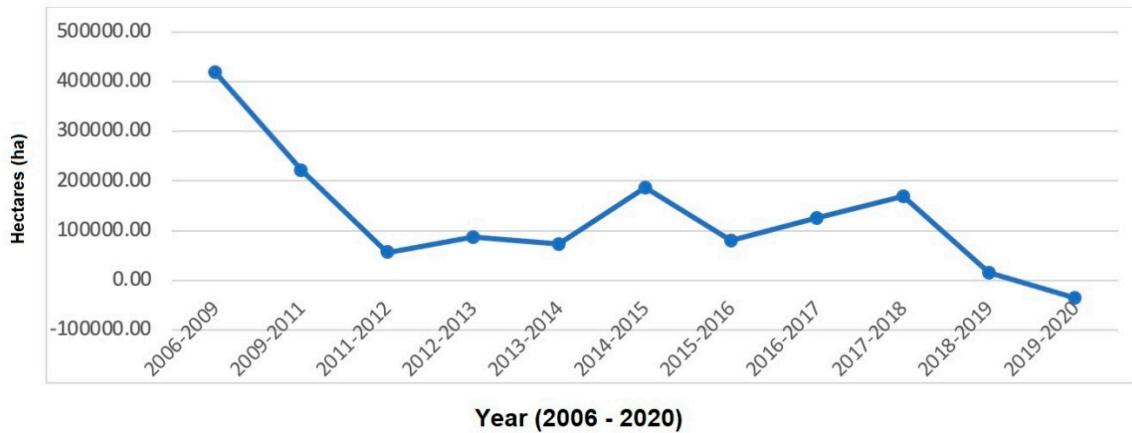


Figure 2. The trend of deforestation in Central Kalimantan, Indonesia. This trend of deforestation continues to decline until 2019-2020 due to various causes, both anthropogenic, natural and government policies.

Total rate of deforestation in Central Kalimantan was 117,445 ha/yr. Usually the process of deforestation initiates forest degradation, the change from primary forest into secondary forest. When the detriment continues, the secondary forest converts into other land covers such as plantation and agriculture (see in Table 3). However, deforestation also could happen from primary forest that change into other land cover type. Our analysis found that dry primary forest and swamp primary

forest experienced deforestation. All natural forest criteria, mangrove forest experienced a relatively small rate of deforestation.

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

Note: SE (Standard Error).

Analysis on the change of land cover, this research found that natural forest in Central Kalimantan had converted into 15 land use types. The dominant land use resulting from deforestation were shrubs, open area, plantations, and agriculture land. Besides that, natural forest clearing especially in swamp forest generates swamp area and water body such as lake and water pond.

The average amount of deforestation in each forest category is presented in Table 4. As we can see from that table swamp secondary forest and dry secondary forest had the highest deforestation rate 59,317.81 ha/year and 55,938.56 ha/year respectively. Mangrove forests suffered less from deforestation because mangrove ecosystem was less favorable for plantations. Large scale oil palm plantations or forest plantations require fertile soil with sufficient water supply, thus low land and dry land forest are favorable.

Table 4. The 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).

Of the 1.5 million natural forests that converted into other land use system 373,816.39 hectare were taken in peatland soil. On other words, as much as 24% of deforestation in Central Kalimantan targeted peat ecosystem that rich in carbon stock and as consequences, emit higher GHGs into the atmosphere. Figure 3 shows comparing the proportion of forest on peat soil and mineral soil, we

found that forest in 2006 has slightly different from forest in 2020. In 2006 the proportion of forests on peat soil was to some extent higher than forest on peat soil in 2020.

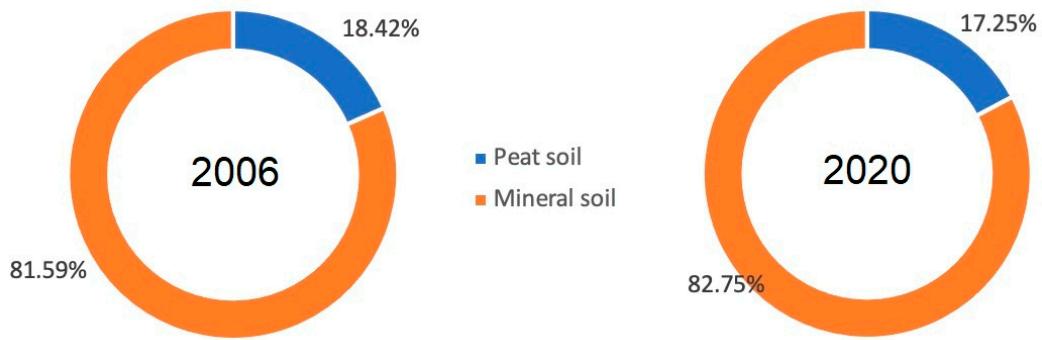


Figure 3. Comparison of deforestation on mineral soil and peat soil between 2006 and 2020 in Central Kalimantan (Indonesia). This figure shows that mineral soil is more desirable than peat soil due to forest clearing for various purposes.

4. Discussion

This research found that most of deforestation in Central Kalimantan within range time 2006 – 2020 arisen in secondary swamp and dry forest, which is located mostly at low land area in south part as shown in Figure 4. This finding is consistent with the finding that from 2010 to 2015, just 18% of forests were replaced by plantations, down from 54% between 1995 and 2000. Additionally, it is estimated that 30.2 million hectares of non-forest land across the country match the biophysical requirements for oil palm development [12,45].

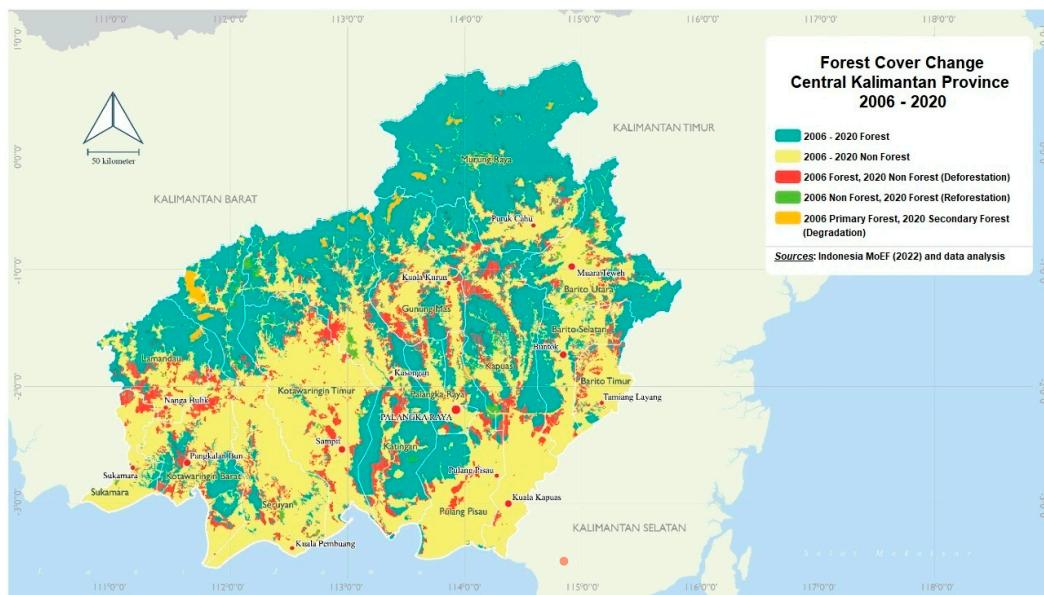


Figure 4. Map of Deforestation and Forest Degradation in Central Kalimantan Province, Indonesia (2006 – 2020). This figure also shows several areas that experienced reforestation during the 2006 - 2020 period, both those that occurred naturally and from reforestation activities.

The low land forest is inhabited more than high land parts. In addition, low elevation, access and soil condition make lowland forest of Central Kalimantan favorable for oil palm and timber plantations [42,43,46,47]. Protected forest in lowland Kalimantan decreased by 56% in period of 1985

– 2001 [46]. The rate of oil palm plantation expanded was 450,000 ha/year and replacing forested area in lowland area [42,45].

As of 2015, Central Kalimantan, the largest of the five provinces in Kalimantan/Borneo (~15.3 million hectares), still 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). Additionally, it is the province that contributed the biggest percentage (38%) of all emissions from deforestation for the whole analyzed period from 1990 to 2015 [23,30]. Central Kalimantan has two national parks in the lowland area, Sebangau National Park, and Tanjung Puting National Park. The two protected areas play as bulwark, holding and resisting deforestation. However, concern arises for the conservation of these two national parks since rapid deforestation occurred in surrounding and buffer zone areas.

The deforestation rate was relatively high in the period 2006 – 2011 because of policy and development priority from the government. During this range of time, the government is creating investment ambience, high incentive and attractive leases inviting investors to develop large scale oil palm and timber plantations [48]. In comparison to what actually happened, it was estimated that a European ban on high-deforestation palm oil from 2000 to 2015 would have resulted in a global price premium of 8.9% on low-deforestation palm oil, preventing 21 374 ha (1.60%) less deforestation and 21.1 million tCO₂ (1.91%) less deforestation-related emissions in Indonesia [41,49].

Oil palm is a lucrative and highly profitable commodity and has become the main reason for the expansion of this commodity in Kalimantan. It works closely with the cooperative sector and individual farmers, producers of palm oil production (Indonesia is the world's largest producer and plans to increase its production up to 40 million tons annually by 2020) [50]. After 2011, deforestation rate slowed down, following moratorium policy. Government banned the establishment of oil palm plantation on primary and peatland [41]. However, deforestation rose again between 2015 – 2019 as a result widespread forest fire that triggered by ENSO (*El Niño–Southern Oscillation*) condition [51]. It has become obvious that the incidence of more frequent ENSO events, coupled with major land development projects that involve drainage of the surface peat, is leading to an increased risk of repeated fire events in tropical peatland areas [34]. Furthermore, forest fires are an important cause of environmental alteration and land degradation or conversion through human activities.

The combination of degraded ecosystem generated from previous deforestation and long dry season caused forest fire uncontrolled. Even though Kalimantan's deforestation and emission rates have decreased overall from 1990 to 2015, this trend is not uniformly present across the five provinces. Even the rates in West and North Kalimantan appear to be rising. Thus, each province on Kalimantan Island has a different chance of meeting its carbon reduction goals [23]. After 2019, the deforestation in Central Kalimantan slowed down and even negative that associated with the absence of long dry season and the occurring of COVID-19 pandemic. But otherwise, evidence reveals that the COVID-19 epidemic has prompted illegitimate, opportunistic forest cutting and mining in tropical nations, endangering forest ecosystems and the inhabitants that depend on them [52–57].

Considering the negative effect of deforestation, recently The Government of Indonesia launched program called FOLU Net Sink. This program aims to sequester GHGs bigger than the emission from forestry and other land use sectors. The goal of FOLU net sink articulate in 5 main strategies: reduction emission from deforestation and forest degradation, establishment of forest plantations, sustainable forest management, forest rehabilitation and management of peat ecosystem[30,58]. Forest vegetation and soils continue to be important on carbon sinks, even though deforestation and forest degradation contribute to around 17% of the world's greenhouse gas emissions. Together, tropical and subtropical forests hold more than half of the carbon dioxide (CO₂) in the atmosphere.

The result of this research may contribute to the achievement of the Indonesia NDC by inform the decision makers about the characteristic of deforestation in Central Kalimantan as the largest province in Indonesia. Additionally, the primary causes of land-use changes are the increase of agriculture and deforestation. Given that peat swamp forest ecosystems in Central Kalimantan also could support extraordinarily high biodiversity and enormous amounts of carbon, deforestation in

this area has the potential to have negative effects on the entire planet [59,60]. Research on the causes of the 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, would help Indonesia's efforts and those of other nations [42,50,61].

5. Conclusions

Deforestation in Central Kalimantan as the largest province in Indonesia in the period 2006 – 2020 has shown a decline trend that influenced by policy and anthropogenic activities. From the total of 1.5 million ha forest loss within the analysis period, deforestation mostly occurred in peat swamp and dry secondary forest were human activities relatively high. Deforestation resulted in degraded areas such as shrubs, open areas and savanna and cultivated systems including agriculture and plantations.

Government policies, especially regulations regarding the eradication of illegal logging, forest and land fires, social forestry, carbon economic value, and the involvement of all forestry related stakeholders are at least able to reduce deforestation and changes in land use in the study area from forest to non-forest. The finding of this research could be used as a base to determine the target location for rehabilitation strategy and approach to prevent further deforestation.

Author Contributions: Conceptualization, H.S. and A.; methodology, H.S., A. and F.; software, H.S. and F.; validation, Y.A., A. and H.S.; formal analysis, H.S., A., Y.A. and N.T.; investigation, H.S., A., F., Y.A. and N.T.; resources, A., H.S. and F.; data curation, A., F. and H.S.; writing—original draft preparation, H.S. and A.; writing—review and editing, H.S., A., Y.A. and N.T.; visualization, F., H.S., Y.A. and A.; supervision, H.S. and N.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: This study used LANDSAT images data obtained from The U.S. Geological Survey/USGS (https://www.usgs.gov/centers/eros#/Find_Data/Products_and_Data_Available/ETM, accessed on January – June 2022). Forest Land Cover Map/Information on the Thematic Spatial Data of Indonesian Land Cover Scale 1: 250,000 can be found on the Ministry of Environment and Forestry's website (<https://sigap.menlhk.go.id/sigap/metadata-detail/117>, accessed on 15 April – 1 May 2022). Sector Map, Ministry of Agrarian Affairs and Spatial Planning/Indonesian National Land Agency (<https://bhumi.atrbpn.go.id/>, accessed on January – June 2022).

Acknowledgments: We would like to thank our colleagues from the Central Kalimantan Provincial Forestry Service, the Central Kalimantan Regional Planning and Research Agency and developing partners (Non-Government Organizations and International Organizations) in Central Kalimantan, as well as from the Center for Development of Science, Technology and Peatland Innovation (PPIIG) University of Palangka Raya, Indonesia for their support and collaborations.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Silva Junior CHL, Pessôa ACM, Carvalho NS, Reis JBC, Anderson LO, Aragão LEOC. The Brazilian Amazon deforestation rate in 2020 is the greatest of the decade. *Nat Ecol Evol.* 2021;5(2):144–145. doi:10.1038/s41559-020-01368-x
2. Lawrence D, Coe M, Walker W, Verchot L, Vandecar K. The Unseen Effects of Deforestation: Biophysical Effects on Climate. *Front For Glob Chang.* 2022;5(March):1–13. doi:10.3389/ffgc.2022.756115
3. Doggart N, Morgan-Brown T, Lyimo E, et al. Agriculture is the main driver of deforestation in Tanzania. *Environ Res Lett.* 2020;15(3). doi:10.1088/1748-9326/ab6b35
4. Foody GM, Cutler ME, McMorrow J, et al. Mapping the biomass of Bornean tropical rain forest from remotely sensed data ESTIMATION AND MAPPING. Published online 2001:379–387.
5. Foody GM. Remote sensing of tropical forest environments: Towards the monitoring of environmental resources for sustainable development. *Int J Remote Sens.* 2003;24(20):4035–4046. doi:10.1080/0143116031000103853
6. Chapin FS, Zavaleta ES, Eviner VT, et al. Consequences of changing biodiversity. *Nature.* 2000;405(6783). doi:10.1038/35012241
7. Mitchard ETA. The tropical forest carbon cycle and climate change. *Nature.* 2018;559(7715):527–534. doi:10.1038/s41586-018-0300-2

8. Lambin EF. Monitoring forest degradation in tropical regions by remote sensing: Some methodological issues. *Glob Ecol Biogeogr.* 1999;8(3-4):191-198. doi:10.1046/j.1365-2699.1999.00123.x
9. Taddese G. Land degradation: A challenge to Ethiopia. *Environ Manage.* 2001;27(6). doi:10.1007/s002670010190
10. Prabowo D, Maryudi A, Senawi, Imron MA. Conversion of forests into oil palm plantations in West Kalimantan, Indonesia: Insights from actors' power and its dynamics. *For Policy Econ.* 2017;78:32-39. doi:10.1016/J.FORPOL.2017.01.004
11. Moutinho P. (1) (PDF) Tropical Deforestation and Climate Change.; 2005.
12. Poor EE, Jati VIM, Imron MA, Kelly MJ. The road to deforestation: Edge effects in an endemic ecosystem in Sumatra, Indonesia. *PLoS One.* 2019;14(7). doi:10.1371/journal.pone.0217540
13. Reddy CS, Bird NG, Sreelakshmi S, et al. Identification and characterization of spatio-temporal hotspots of forest fires in South Asia. *Environ Monit Assess.* 2019;191. doi:10.1007/s10661-019-7695-6
14. Casson A. Decentralisation of Policies Affecting Forests and Estate Crops in Kutawaringin Timur District, Central Kalimantan.; 2001. doi:10.17528/cifor/001057
15. Carlson DS, Kacmar KM, Williams LJ. Construction and Initial Validation of a Multidimensional Measure of Work-Family Conflict. *J Vocat Behav.* 2000;56(2). doi:10.1006/jvbe.1999.1713
16. Ridder RM. Forestry Department Food and Agriculture Organization of the United Nations GLOBAL FOREST RESOURCES ASSESSMENT 2010 OPTIONS AND RECOMMENDATIONS FOR A GLOBAL REMOTE SENSING SURVEY OF FORESTS. Published online 2007. Accessed August 19, 2023. www.fao.org/forestry
17. Thomas CD, Cameron A, Green RE, et al. Extinction risk from climate change. *Nature.* 2004;427(6970):145-148. doi:10.1038/nature02121
18. Suk JE, Vaughan EC, Cook RG, Semenza JC. Natural disasters and infectious disease in Europe: A literature review to identify cascading risk pathways. *Eur J Public Health.* 2020;30(5). doi:10.1093/eurpub/ckz111
19. Yoshioka N, Era M, Sasaki D. Towards integration of climate disaster risk and waste management: A case study of urban and rural coastal communities in the Philippines. *Sustain.* 2021;13(4). doi:10.3390/su13041624
20. Iwata K, Ito Y, Managi S. Public and private mitigation for natural disasters in Japan. *Int J Disaster Risk Reduct.* 2014;7. doi:10.1016/j.ijdrr.2013.12.005
21. Suwarno A, Hein L, Sumarga E. Governance, decentralisation and deforestation: The case of central Kalimantan Province, Indonesia. *Q J Int Agric.* 2015;54(1).
22. Jaenicke J, Wösten H, Budiman A, Siegert F. Planning hydrological restoration of peatlands in Indonesia to mitigate carbon dioxide emissions. *Mitig Adapt Strateg Glob Chang.* 2010;15(3):223-239. doi:10.1007/s11027-010-9214-5
23. Wegscheider S, Purwanto J, Margono BA, et al. Current achievements to reduce deforestation in Kalimantan. *Indones J Geogr.* 2019;50(2):109-120. doi:10.22146/ijg.23680
24. Koh JHL, Chai CS, Benjamin W, Hong HY. Technological Pedagogical Content Knowledge (TPACK) and Design Thinking: A Framework to Support ICT Lesson Design for 21st Century Learning. *Asia-Pacific Educ Res.* 2015;24(3). doi:10.1007/s40299-015-0237-2
25. Basuki I, Adinugroho WC, Utomo NA, et al. Reforestation Opportunities in Indonesia: Mitigating Climate Change and Achieving Sustainable Development Goals. *Forests.* 2022;13(3). doi:10.3390/f13030447
26. Suroso DSA, Setiawan B, Pradono P, Iskandar ZS, Hastari MA. Revisiting the role of international climate finance (ICF) towards achieving the nationally determined contribution (NDC) target: A case study of the Indonesian energy sector. *Environ Sci Policy.* 2022;131. doi:10.1016/j.envsci.2022.01.022
27. Venelia H, Nisa K, Wibowo RA, Muda MA. Robust Biplot Analysis of Natural Disasters in Indonesia from 2019 To 2021. *J Apl Stat Komputasi Stat.* 2021;13(2). doi:10.34123/jurnalasks.v13i2.349
28. Kusin K, Sulistiyanto Y, Usup A, Ardianor. Carbon Monoxide (CO) and Particulate Matter (PM2.5) Concentration at Central Kalimantan, Indonesia. In: *IOP Conference Series: Earth and Environmental Science.* Vol 1111. ; 2022. doi:10.1088/1755-1315/1111/1/012006
29. SI. Central Kalimantan In Figures 2015. *Stat Indones.* Published online 2015.
30. BPS Kalteng. Provinsi Kalimantan Tengah Dalam Angka. *Provinsi Kalimantan Tengah Dalam Angka.* Published online 2022.
31. Touma D, Stevenson S, Lehner F, Coats S. Human-driven greenhouse gas and aerosol emissions cause distinct regional impacts on extreme fire weather. *Nat Commun.* 2021;12(1). doi:10.1038/s41467-020-20570-w
32. Ullah A, Raza K, Nadeem M, et al. Does Globalization Cause Greenhouse Gas Emissions in Pakistan? A Promise to Enlighten the Value of Environmental Quality. *Int J Environ Res Public Health.* 2022;19(14). doi:10.3390/ijerph19148678
33. Liu D, Guo X, Xiao B. What causes growth of global greenhouse gas emissions? Evidence from 40 countries. *Sci Total Environ.* 2019;661. doi:10.1016/j.scitotenv.2019.01.197

34. Segah H, Tani H, Hirano T. Detection of fire impact and vegetation recovery over tropical peat swamp forest by satellite data and ground-based NDVI instrument. *Int J Remote Sens.* 2010;31(20):5297-5314. doi:10.1080/01431160903302981
35. Tawaraya K, Turjaman M, Ekamawanti HA. Effect of arbuscular mycorrhizal colonization on nitrogen and phosphorus uptake and growth of *Aloe vera* L. *HortScience.* 2007;42(7):1737-1739. doi:10.21273/hortsci.42.7.1737
36. Page SE, Wust RAJ, Weiss D, Rieley JO, Shotyk W, Limin SH. A record of Late Pleistocene and Holocene carbon accumulation and climate change from an equatorial peat bog (Kalimantan, Indonesia): Implications for past, present and future carbon dynamics. *J Quat Sci.* 2004;19(7):625-635. doi:10.1002/jqs.884
37. Hirano T, Segah H, Kusin K, Limin S, Takahashi H, Osaki M. Effects of disturbances on the carbon balance of tropical peat swamp forests. *Glob Chang Biol.* 2012;18(11):3410-3422. doi:10.1111/j.1365-2486.2012.02793.x
38. Boehm H, Siegert F. Ecological impact of the One Million Hectare Rice Project in Central Kalimantan, Indonesia, using Remote Sensing and GIS. *Pap Present 22nd Asian Conf Remote Sens.* 2001;5(November):6. <http://www.crisp.nus.edu.sg/~acrs2001/pdf/126boehm.pdf>
39. Supriatna T, Lukman S, Daraba D. Planning Strategy Spatial Plan for the Province of Central Kalimantan. :8705-8715.
40. Laksminarti L. Rekonstruksi Hukum Pengaturan Rencana Tata Ruang Wilayah Provinsi Kalimantan Tengah Berbasis Keberlanjutan Lingkungan. *Restorica J Ilm Ilmu Adm Negara dan Ilmu Komun.* 2019;5(2). doi:10.33084/restorica.v5i2.1074
41. Murdiyarno D, Dewi S, Lawrence D, Seymour F. Indonesia's Forest Moratorium: A Stepping Stone to Better Forest Governance?; 2011.
42. Austin KG, Schwantes A, Gu Y, Kasibhatla PS. What causes deforestation in Indonesia? *Environ Res Lett.* 2019;14(2). doi:10.1088/1748-9326/aaf6db
43. Margono BA, Potapov P V., Turubanova S, Stolle F, Hansen MC. Primary forest cover loss in indonesia over 2000-2012. *Nat Clim Chang.* 2014;4(8). doi:10.1038/nclimate2277
44. Ardiyanto SY, Saraswati R, Soponyono E. Law Enforcement and Community Participation in Combating Illegal Logging and Deforestation in Indonesia. *Environ Ecol Res.* 2022;10(4):450-460. doi:10.13189/eer.2022.100403
45. Austin KG, Mosnier A, Pirker J, McCallum I, Fritz S, Kasibhatla PS. Shifting patterns of oil palm driven deforestation in Indonesia and implications for zero-deforestation commitments. *Land use policy.* 2017;69(September):41-48. doi:10.1016/j.landusepol.2017.08.036
46. Curran LM, Trigg SN, McDonald AK, et al. Lowland Forest Loss in Protected Areas of Indonesian Borneo. *Science (80-).* 2004;303(5660). doi:10.1126/science.1091714
47. Gaveau DLA, Epting J, Lyne O, et al. Evaluating whether protected areas reduce tropical deforestation in Sumatra. *J Biogeogr.* 2009;36(11). doi:10.1111/j.1365-2699.2009.02147.x
48. Bissonnette JF, De Koninck R. Large plantations versus smallholdings in Southeast Asia: historical and contemporary trends. *Conf L Grabbing, Confl Agrar Transform Perspect from East Southeast Asia.* 2015;(12).
49. Busch J, Amarjargal O, Taheripour F, et al. Effects of demand-side restrictions on high-deforestation palm oil in Europe on deforestation and emissions in Indonesia. *Environ Res Lett.* 2022;17(1). doi:10.1088/1748-9326/ac435e
50. Pachmann A. Corruption and Deforestation in Indonesia. *Reg Form Dev Stud.* 2021;2(2):55-62. doi:10.15181/rfds.v25i2.1745
51. Susilo GE, Yamamoto K, Imai T, Ishii Y, Fukami H, Sekine M. The effect of ENSO on rainfall characteristics in the tropical peatland areas of Central Kalimantan, Indonesia. *Hydrol Sci J.* 2013;58(3). doi:10.1080/02626667.2013.772298
52. Brancalion PHS, Broadbent EN, de-Miguel S, et al. Emerging threats linking tropical deforestation and the COVID-19 pandemic. *Perspect Ecol Conserv.* 2020;18(4):243-246. doi:10.1016/j.pecon.2020.09.006
53. M L, Almukthar N, Edbey K, et al. Deforestation, Air Pollution And Brasilian Covid-19 Variant. *Int J Med Healthc REPORTS.* 2021;01(01). doi:10.51521/ijmhr.2021.1103
54. Laudares H. Is deforestation spreading COVID-19 to the indigenous peoples? *Covid Econ vetted real-time Pap.* 2020;(53).
55. CI. Poaching, deforestation reportedly on the rise since COVID-19 lockdowns. *Conserv Int.* Published online 2020.
56. Céspedes J, Sylvester JM, Pérez-Marulanda L, et al. Has global deforestation accelerated due to the COVID-19 pandemic? *J For Res.* Published online 2022. doi:10.1007/s11676-022-01561-7
57. Brancalion PHS, Broadbent EN, de-Miguel S, et al. Emerging threats linking tropical deforestation and the COVID-19 pandemic. *Perspect Ecol Conserv.* 2020;18(4). doi:10.1016/j.pecon.2020.09.006
58. Submission by Indonesia NATIONAL FOREST REFERENCE LEVEL FOR DEFORESTATION , FOREST Editor in Chief. Published online 2022.

59. Miettinen J, Shi C, Liew SC. Deforestation rates in insular Southeast Asia between 2000 and 2010. *Glob Chang Biol.* 2011;17(7). doi:10.1111/j.1365-2486.2011.02398.x
60. DeFries RS, Townshend JRG, Hansen MC. Continuous fields of vegetation characteristics at the global scale at 1-km resolution. *J Geophys Res Atmos.* 1999;104(D14). doi:10.1029/1999JD900057
61. Wijaya A, Firmansyah R, Said Z, Nathania B. Monitoring of Indonesia tropical rainforests and land cover change using hybrid approach of time series landsat data. In: *International Geoscience and Remote Sensing Symposium (IGARSS)*. Vol 2019-July. ; 2019. doi:10.1109/IGARSS.2019.8900121

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.