BIODIVERSITAS
Volume 23, Number 3, March 2022
Pages: 1420-1426

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d230328

Analysis of land cover changes due to forest fires in Gunung Leuser National Park, North Sumatra Province, Indonesia

ACHMAD SIDDIK THOHA♥, NABILLAH SARASWITA, NURDIN SULISTIYONO, DAVID WIRANATA, SRY MULYANI SIRAIT, RIVANDA INALDI

Faculty of Forestry, Universitas Sumatera Utara, Jl. Tri Dharma Ujung No. 1, Kampus USU Padang Bulan, Medan 20155, North Sumatra, Indonesia.
Tel./fax.: +62-618-201920, ♥email: a.siddik@usu.ac.id

Manuscript received: 14 November 2021. Revision accepted: 22 February 2022

Abstract. *Thoha AS, Saraswita N, Sulistiyono N, Wiranata D, Sirait SM, Inaldi R. 2022. Analysis of land cover changes due to forest fires in Gunung Leuser National Park, North Sumatra Province, Indonesia. Biodiversitas 23: 1420-1426.* Forest and land fires occur almost every year with significant impacts and losses on the environment and various sectors including conservation areas. Gunung Leuser National Park (GLNP) is a conservation area in danger of losing its forest cover due to slash-and-burn land clearing. This study aimed to analyze land cover changes due to forest and land fires in GLNP of North Sumatera Province. Data of hotspots, satellite images, land cover maps, and field verification were used to see the transition of land cover changes before and after forest and land fires. Temporal and spatial analyses were carried out to see the trend of these changes. Field surveys were also conducted to verify hotspots as locations for forest fires, burned land, and human activities causing the fires. This study found that 2010 had the highest hotspots reported from 2001 to 2019. There were indications of a fairly massive forest fire in 2010, as evidenced by the identification of burned land on satellite images. The burned land was near the outer boundary of the GLNP area and expanded into the area in the following period. Before 2010, the area of the non-forest cover was not too large. After 2010, there was an increase in non-forest land cover, presumably due to increased access to enter the area after the forest was cleared after the fire. During almost 20 years, the primary dryland forest in the study area remained only 6% of the initial area. At least more than 200 ha of forest area is reduced in the study area every year. The burned lands in the following years tended to become plantation land. Plantation land cover increased by around 90% during 2000-2019 in the research sites. This study expects that GLNP management and various parties need to prevent the expansion of forest clearing because the strategic role of GLNP as a world heritage is currently in danger.

Keywords: Forest fires, Gunung Leuser National Park, hotspots, land cover changes

INTRODUCTION

Forest and land fires occur almost every year, with significant impacts and losses in various sectors. Forest and land fires occur annually throughout Indonesia, produce large greenhouse gas emissions (Page et al. 2002) and cause regional air quality problems (Crippa et al. 2016). Land and forest fires in Indonesia are influenced by climate (Fanin and van der Werf 2017) and land cover changes (Prasetyo et al. 2016). A proper understanding of agricultural and plantation land management is needed to minimize fires and their related environmental impacts (Meijaard and Sheil 2019; Wijedasa et al. 2019).

Emissions resulting from forest and land fires in Indonesia contribute to climate change and exacerbate air quality problems (Crippa et al. 2016; Marlier et al. 2013). Major fires across Indonesia in 2015 produced 700-800 million tonnes of CO_2 (Huijnen 2016; Kiely et al. 2019), affecting 69 million people due to poor air quality (Crippa et al. 2016). Exposure to air pollution is estimated to cause 11,880 deaths in the short term (Crippa et al. 2016) and 100,300 premature deaths in the long term (Koplitz et al. 2016). Peatland areas experiencing rapid land cover changes and frequent fires in central and southern Sumatra and southwest Kalimantan contribute the most to regional air quality problems (Astiani et al. 2019; Reddington et al. 2014).

Major fires in Indonesia occur mainly during dry years associated with the El Nino Southern Oscillation and Indian Ocean Dipole (Fanin and Van der Warf 2017) with nonlinear fire sensitivity to dry conditions (Field et al. 2016). Moreover, deforestation has caused a lot of combustible material and increased the flammability of peat (Taufik et al. 2017). This indicates that anthropogenic land cover changes have altered the occurrence of fires throughout Indonesia.

The study by Gaveau et al. (2017) stated that fires occur every year in all areas of Indonesia, even in years without drought. Studies using satellites for fire detection (van der Werf et al. 2008; Fanin and van der Werf 2017) and burned areas (Giglio et al. 2018) provided updated information about fire occurrence and its relationship to climate change and land use.

Changes in land cover are mostly caused by human activities (Thoha and Ahmad 2018; Thoha et al. 2019). Studies identified that the causes of forest and land fires include a dispute over land ownership and use, forest degradation practices, and land clearing for plantations. Prasetyo et al. (2016) also found that land cover in Jambi Province tends to change from unmanaged land to plantation after fires incident.

This study focused on analyzing of the dynamics of various types and areas of land cover before and after fires in the Gunung Leuser National Park (GLNP), North Sumatera Province. The GNLP is known as an ecosystem with biodiversity in Sumatra Island. As a national strategic area, GLNP has a high value as a world heritage site but is in danger of losing its forest cover due to encroachment, illegal logging, land clearing for palm oil plantation, and road constructions (MoEF 2014). The previous research by Thoha et al. (2021) detected land cover change by satellite imagery but not have found how big the changing yet. This study aims to analyze land cover changes due to forest and land fires in GLNP, North Sumatera Province. This study is expected to provide recent information related to land cover dynamics in GLNP to assist forest management and forest and land fire control.

MATERIALS AND METHODS

Study area

This research was conducted around the Gunung Leuser National Park (GLNP), Langkat District, North Sumatra Province, Indonesia. The site of field data collection was in hotspot-detected areas in the GLNP area in North Sumatra Province. This research was conducted for six months from June to October 2021. The research site is presented in Figure 1.

Procedure

This study used secondary data of hotspots distribution in 2001-2019 obtained from the Terra/Aqua satellite with a Moderate-resolution Imaging Spectroradiometer (MODIS) sensor. It can be accessed from the NASA Active Fire Data website via https://firms.modaps.eosdis.nasa.gov/download, forest area map provided by the Ministry of Environment and Forestry (KLHK), and Landsat 8 OLI image of the GLNP area in 2000, 2005, 2010, 2013, 2016, and 2019 which can be downloaded from https://earthexplorer.usgs.gov.

The hotspots used were those from 2001-2019. The hotspots were monitored from remote sensing satellite data and were actual fire events occurring in the field. The higher the level of confidence, the higher the potential that the hotspot is a forest and land fire. Hotspots that have a strong indication of fire incidents have a level of confidence above 50% (Giglio et al. 2020). In this study, the hotspots were reclassified using a GIS tool, which was ArcGIS 10.8 to separate only hotspots with a confidence level above 80. The hotspots used in this study were those at all levels of confidence for determining temporal and spatial patterns. To determine locations that have strong indications of forest and land fire and land cover dynamics, hotspots with levels of confidence above 80 were used.

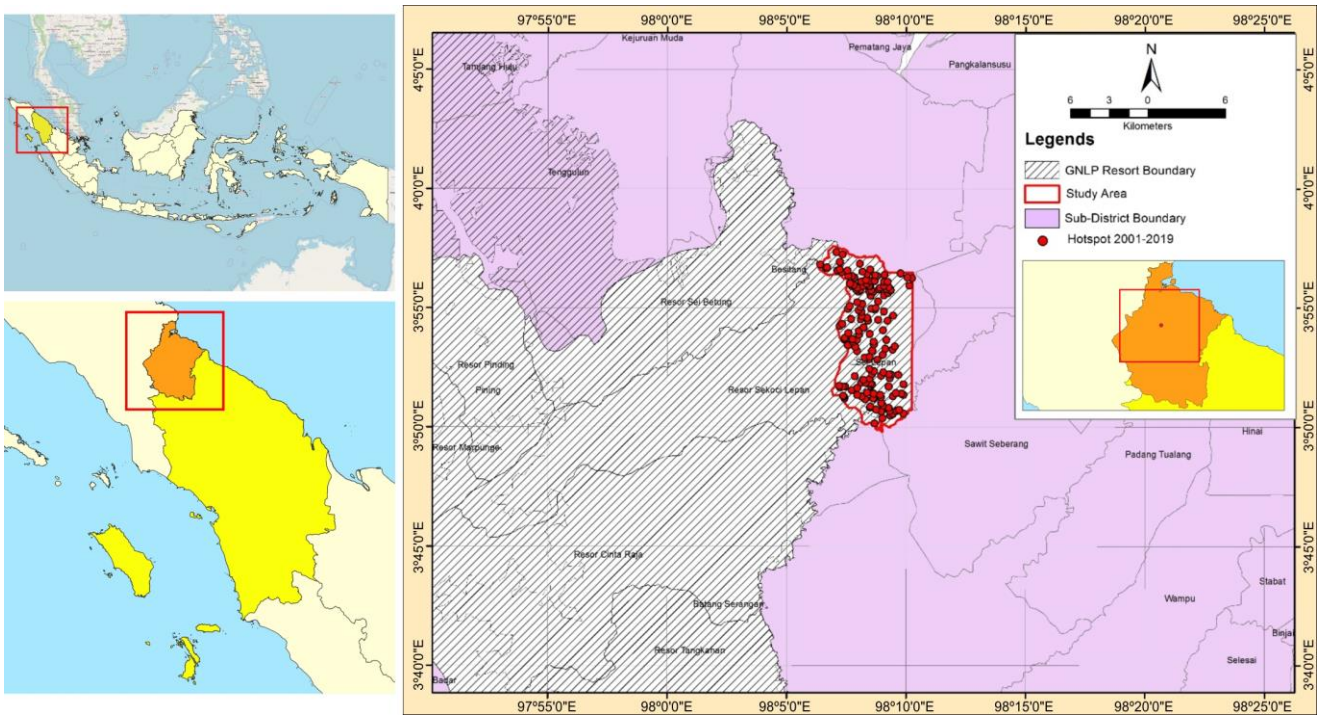

Figure 1. The study area of Gunung Leuser National Park of Langkat District, North Sumatra Province, Indonesia (red polygon)

Data analysis

The data analysis carried out consisted of analyzing the hotspots' temporal, spatial, and attribute data. The temporal data analysis was carried out to determine the distribution of hotspots from time to time, so the highest hotspot density was determined as the reference for the year of fire. The spatial data analysis consisted of image processing and land cover identification. The attribute data analysis analyzed the distribution of hotspots indicating strong forest fires based on the location of the conservation area, density, and distribution per land cover.

Field verification and interviews at selected locations based on hotspot density were carried out to determine land cover changes, including community farming patterns. Furthermore, community farming patterns in North Sumatra were also observed to determine the factors causing forest fires that resulted in land cover change/use. Analysis of causal factors was carried out to determine the impact caused by forest fires.

The land cover was identified using ArcGIS software version 10.3. The satellite image was classified using Landsat 5 and Landsat OLI 8 in 2001, 2005, 2010, 2013, 2016, and 2019. The land cover types were classified using visual interpretation methods only in hotspot detected areas of GLNP in the North Sumatera Province region. The visual interpretation method was based on the Technical Guidelines for Interpreting Medium Resolution Satellite Image to Update National Land Cover Data (KLHK 2020). The visual interpretation method was a land cover classification technique from satellite images by inferring the specific characteristics of objects in the image based on the color, shape, size, pattern, shadow, texture, and location. The attribute data analysis was carried out to make it easier to analyze changes in the type and area of land cover. The analysis of land cover changes was carried out by comparing land cover before and after the fires. During this period, land cover changes can be determined.

The accuracy test used in this study was the overall accuracy-test calculated using a confusion matrix. The calculated accuracy is overall accuracy calculated using the formula according to Firmansyah et al. (2019) as follows:

$$\text{Overall accuracy} = \frac{\sum_{i=1}^{r} xii}{n} 100\%$$

Xii : Diagonal value of the i-th row and i-th column of the contingency matrix
X+I : Number of pixels in the i-th column
Xi+ : Number of pixels in the i-th row
N : Number of pixels in the example

Overall accuracy is defined as the total class classified divided by the total class. In the process of making the training area, various combinations were made to obtain the best results in the accuracy test. The combinations were made with various sizes, including the combination of large, small, and moderate size training areas. The collection of accuracy test points was carried out through field surveys.

In the assessment of accuracy, there are main criteria for land cover classification systems from satellite imagery. According to Firmansyah et al. (2019), based on the guidelines for processing satellite data, the level of classification accuracy assessment used must not be less than 75%.

RESULTS AND DISCUSSION

Distribution of hotspots in the Gunung Leuser National Park

Over 19 years, hotspot fluctuations were detected in Gunung Leuser National Park, North Sumatera Province. There was an increase in the number of hotspots in 2004-2005, and then it decreased in the following year. Furthermore, there was a sharp increase in the number of hotspots in 2010. The year 2010 was used as a reference to trace the trajectory of land cover changes that were considered to be caused by forest fires in the GLNP forest area. The year 2010 was also used as a reference as the time of the occurrence of forest fires in GLNP of North Sumatera Province.

Figure 2 shows that Gunung Leuser National Park of North Sumatra Province area has a consistent distribution of hotspots in certain areas every year. Since the GLNP area is a conservation area with the status of a World Heritage Site and has received international attention, slight disturbances to the area must be investigated.

Identification of land cover in hotspot detected area

Analysis of land cover changes through satellite images shows the dynamics of land cover changes in areas detected by hotspots. The trajectory of land cover through analysis of satellite images in the GLNP of the North Sumatera Utara area is presented in Figure 3. In 2010, in the GLNP area in Langkat District, the most hotspots were detected in the 2001-2019 period. The presence of hotspots indicates land clearing by burning to clear forest land, which is converted to other uses such as agricultural land, plantations, or land claim purposes.

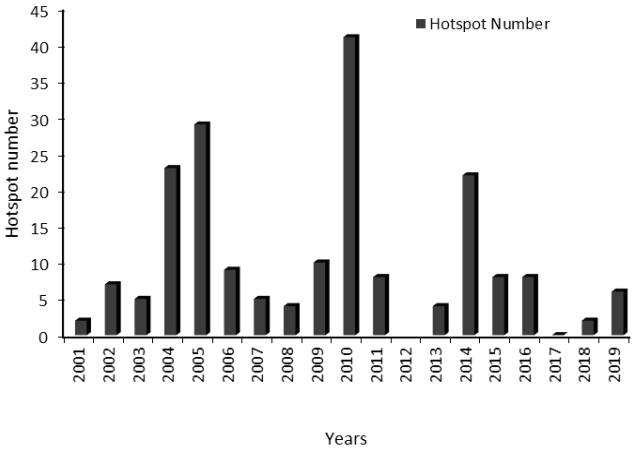

Figure 2. Hotspot number in GLNP of the North Sumatra Province, Indonesia area in 2001-2019

The land cover identified based on satellite image analysis shows that GLNP of the North Sumatera Utara area has not been entirely forested since 2000. In 2000, other land covers were found besides forests, consisting of plantations, dry agricultural land, and open land. The condition of forest cover declined in the GLNP of North Sumatera Utara area in 2010 is shown in Figure 3C. In 2010, many hotspots were detected in this area with an even distribution, with confidence levels above 80. Hotspots indicate land clearing by burning to clear forest land for conversion to other uses such as agricultural land, plantations, or land claims.

There were some land cover changes in 2000, 2005, 2010, 2013, 2016, and 2019. Before 2010 (Figure 3A and Figure 3B), there was a visible reduction in the land cover of primary dryland forest based on color and hue on the satellite image (dark green with a rough hue) to secondary dryland forest (green with rough hue), shrubs, and open land (yellow and red). In 2000, primary dryland forest cover began to decrease due to land clearing for open land and dryland agricultural land. Non-forest land cover is getting broader, and in 2005 it encroached on the area.

After 2010, forest conversion to non-forest in the GLNP area became more extensive. In 2013, based on the analysis of satellite image (Figure 3D), the area that changed to non-forest expanded to the west or into the GLNP area. In the following year's development, particularly in 2016-2019, the area of non-forest land in the GLNP area did not increase significantly (Figure 3E and Figure 3F).

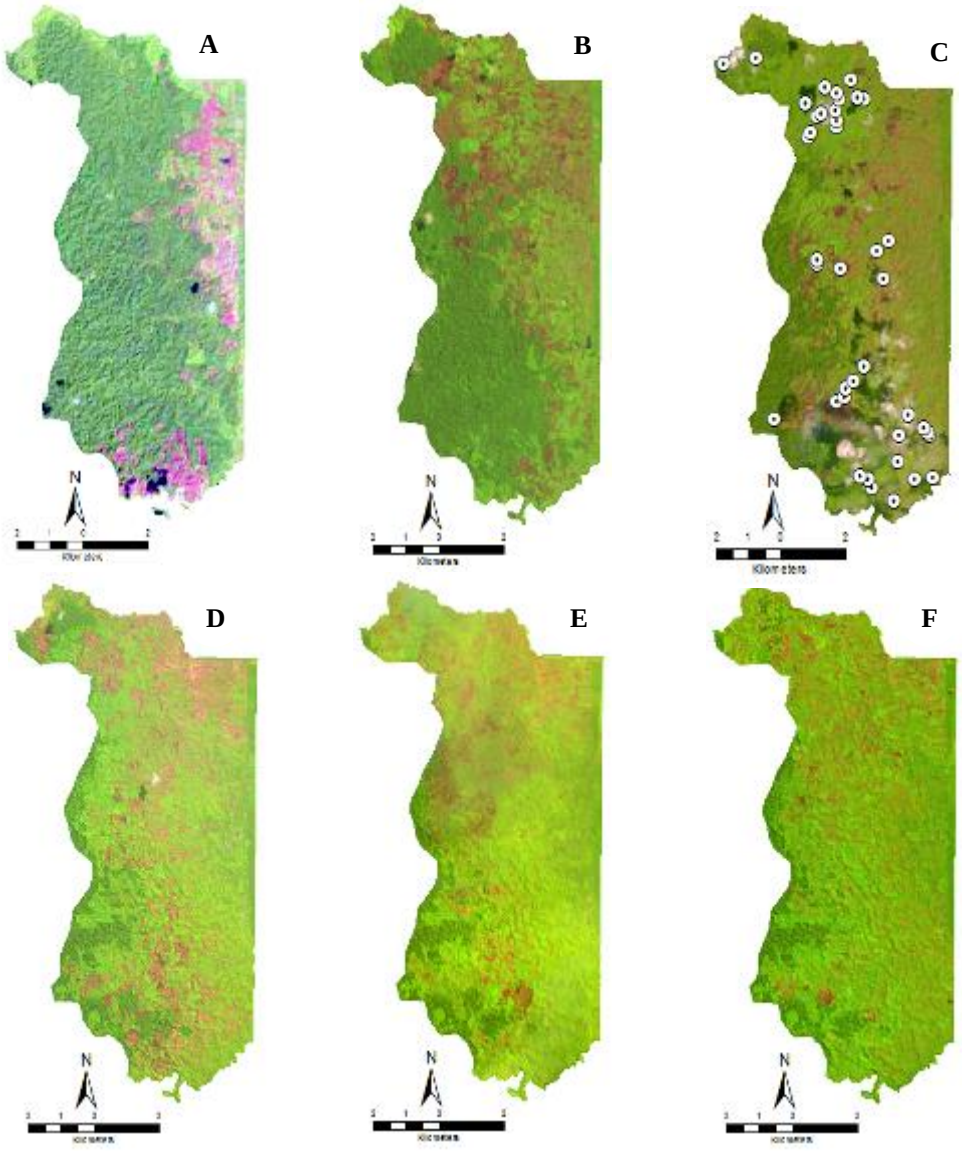

Figure 3. Natural Color Landsat image of hotspot detected area of GLNP, Langkat District, North Sumatra Province, Indonesia in 2000 (A), 2005 (B), 2010 (C) overlaid with hotspots (white circle), 2013 (D), 2016 (E), and 2019 (F)

Land cover changes in the GLNP area due to forest fires

Land cover changes that occurred in GLNP, Langkat District, North Sumatra due to fluctuating forest fires are shown in Figure 4 and Table 1. Land cover types (Table 1) identified in the research site were primary dryland forest, secondary dryland forest, plantation, open land, and shrubs. Forest land cover is decreasing, and in 2019, the GLNP area where hotspots were detected mostly was dominated by plantations.

From 2000 to 2019, the extent of primary dryland forest decreased (Table 1). This area was 4640.27 ha in 2000, but it has shrunk to 2359.19 ha by 2005. In 2010, the area of primary dryland forest decreased to 963.41 ha, then to 313.36 ha in 2016, and only 278.35 ha in 2019. During almost 20 years, the primary dryland forest in the study area remained only 6% of its original size. Every year, at least more than 200 ha of forest area is reduced in the study area.

From 2000 to 2019, the area of primary dryland forest declined by 94 percent compared to the previous year. In the meantime, the secondary dryland forest suffered year-to-year fluctuations from 2000 to 2019. The area was 331.05 ha in 2000, but it dropped to 155.30 ha in 2005. The area shrank drastically again to 17.71 ha in 2010, to 36.05 in 2013, to only 29.10 ha in 2016, and no longer remained in 2019. Table 1 shows the downward trend in the area of open land every year, from 1307.70 ha to 223.88 ha from 2000 to 2019. Based on the results of field observations, it was found that three areas were suspected of having land clearing by burning. The first was in the border area between Mekar Makmur Village and the Aceh Refugee Farm. The second was in the Aceh refugee farming area. The third was located on Mekar Makmur and Harapan Maju Villages border. All of these villages were located in Sei Lepan Sub-district, Langkat District, North Sumatra Province.

The accuracy test on the land cover classification results based on visual interpretation of the satellite imagery on the research site in 2019 obtained the accuracy value as shown in Table 2. Based on the accuracy-test results, the overall accuracy value was 97.5%. This value showed that the land cover classification results from the visual interpretation are stated to be accurate and closely similar to field conditions. The results of a study by Rini (2018) showed that the accuracy of an interpretation result can be used for analysis purposes if it has an accuracy level of at least 80-85%.

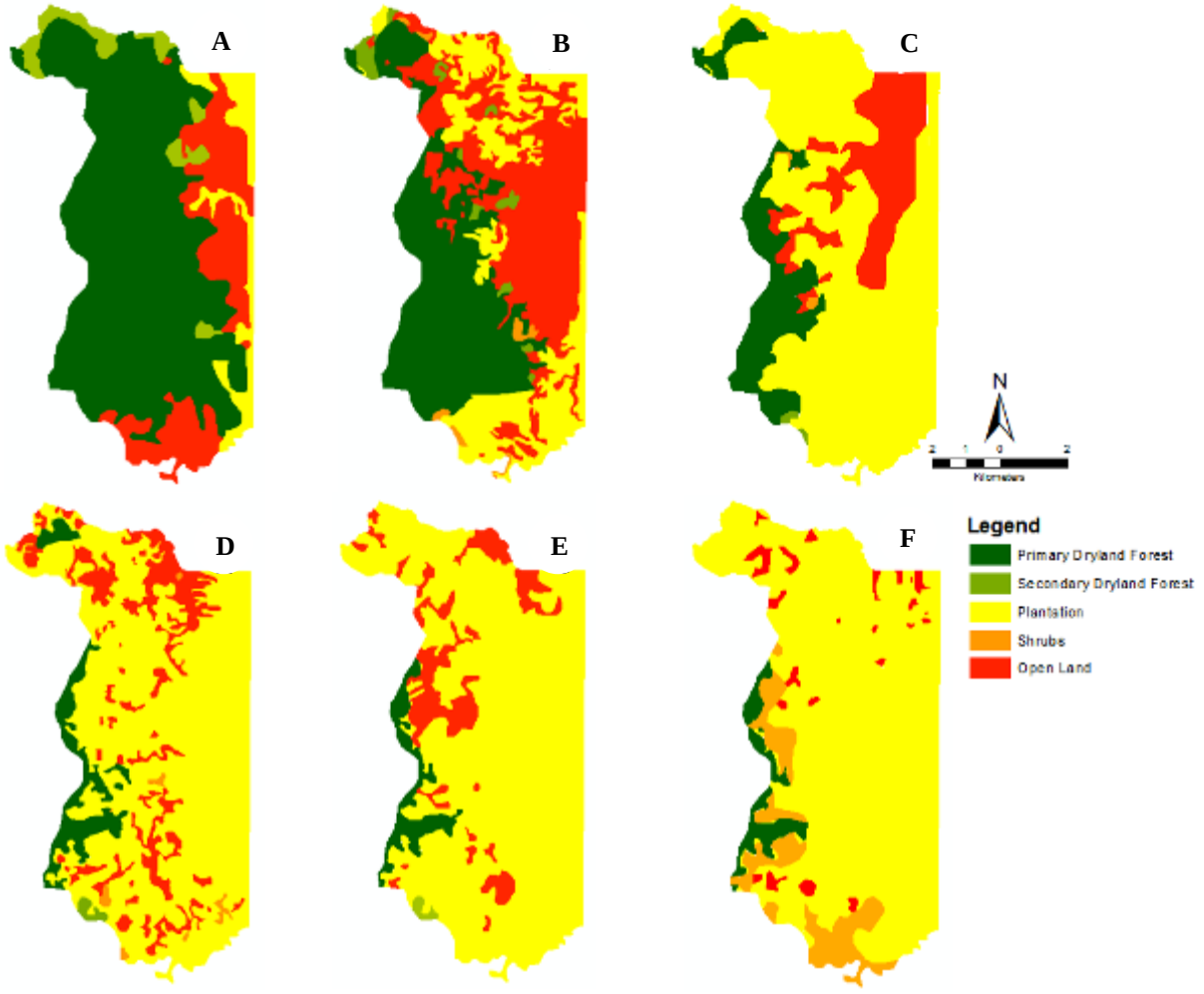

Figure 4. Map of land cover in the hotspot-detected area in the GLNP of Langkat District, North Sumatera Province, Indonesia area in 2000 (A), 2005 (B), 2010 (C), 2013 (D), 2016 (E), and 2019 (F)

Table 1. Land cover area in the hotspot-detected area in the GLNP area

Land cover type	Year/area (ha)					
	2000	2005	2010	2013	2016	2019
Primary dryland forest	4640.27	2359.19	963.41	460.66	313.36	278.35
Secondary dryland forest	331.05	155.30	17.71	36.05	29.10	0.00
Open land	1307.70	2452.93	1136.02	983.94	761.33	223.88
Plantation	504.79	1737.57	4611.09	5207.77	5680.02	5591.59
Shrubs	0.00	78.82	20.17	59.98	0.00	690.00

Table 2. Results of the validation of spatial analysis with survey points

	Land cover type	Field survey results					
		Primary dryland forest	Secondary dryland forest	Open land	Plantation	Shrubs	Total
Image analysis results	Primary dryland forest	0	0	0	0	0	0
	Secondary dryland forest	0	0	0	0	0	0
	Open land	0	0	1	0	0	1
	Plantation	0	0	0	38	1	39
	Shrubs	0	0	0	0	0	0
	Total	0	0	1	38	1	40

The calculation results: (1 + 38)/40)*100% = 97.5%

Discussion

In general, the climatic conditions in Indonesia in 2010 did not experience a climate anomaly in the form of El Nino, which triggered forest fires. The high number of hotspots is an indicator of forest and land fires, according to Giglio et al. (2020). The detection of the number of hotspots in GLNP of North Sumatera Utara area was suspected to be due to human activities for land clearing by burning.

Plantations are a type of land cover that has grown from 2000 to 2019. The area of the plantation in the GLNP region in the study area increased from 504.79 ha in 2000 to 5591.59 ha in 2019. This means that plantations have increased by around 90% from 2000 to 2019. The land cover of shrubs in 2000 was not identified, but it reappeared in 2005 with an area of 78.82 ha and continued to develop until it reached 690 ha in 2019.

The dynamics of land cover change explain the extent of degraded forest, and it turned into non-forest land cover due to land clearing activities by burning. Besides, forest fires also make the area more accessible, allowing other human activities that tend to convert forest into non-forest cover. A study by Adrianto et al. (2019) also found a strong relationship between forest loss and increasing hotspots in the area. Areas that experienced changes in land cover to non-forest were increased fire activity. Studies by Thoha and Ahmad (2018) and Thoha and Triani (2021) also confirm that non-forest areas, especially shrubs, reeds, and dryland agriculture, are the main areas for initial fires in North Sumatra.

Plantations often appeared on burned lands. A study by Prasetyo et al. (2016) found traces of land cover changes after the forest and land fires, in which the forest and shrubland covers turned into plantations. The study by Thoha et al. (2019) found that the most common cause of fires was land conversion to plantations. The land that had been burned became plantations in the next period.

Conservation areas indeed encounter severe challenges against the threat of forest and land fires. Tata et al. (2018) studied in Riau found a strong relationship between hotspots and forest function where conservation areas had high scores in forest and land fire activities.

Based on the results of interviews with communities around the area, land cover changes due to forest encroachment have occurred since the 1990s. This is strengthened by the results of a study by Purwanto (2016) which found that encroachment in the Besitang of GLNP area began after the influx of Acehnese refugees due to armed conflict. The Acehnese refugees who had no place to live encroached on the forest by opening up new areas for shelter and eventually establishing a settlement. Until that time, the Acehnese refugee settlements were spread out in a number of refugee blocks covering a number of villages, including Sekoci, Sei Minyak, Barak Induk, Dammar Hitam, and so on.

The study by Zaitunah et al. (2019) also mentioned a change in forest cover to dryland agricultural land, which was quite extensive in the Besitang watershed, including the GLNP area. Purwanto's research (2016) found that the encroachment area in GLNP in 2011-2013 in Sekoci Village alone reached 6,800 ha. Encroachment was also found in other villages like Cinta Raja, Sei Lepan, and Lau Sekelam Villages.

Overall, conservation areas like GLNP encounter the threat of land cover changes, one of which is carried out with a slash-and-burn system. Detection of land cover changes through hotspots can control illegal activities within the GLNP area. Hotspots with confidence levels above 80 can be used as a strong indicator that there has been land clearing activity by burning in the area. Furthermore, these data can be used as a basis for subsequent handling, both for activities to prevent illegal activities, patrols, law enforcement, and ecosystem restoration. The

findings of the study very important to promote implication of biodiversity conservation program in the future.

ACKNOWLEDGEMENTS

This study was funded by the Deputy for Strengthening Research and Development of the Ministry of Research and Technology/National Research and Innovation Agency, Indonesia, for the Fiscal Year of the Basic Research Scheme with Agreement/Contract Number of 12/E1/KP.PTNBH/2021. We also express our gratitude to the Gunung Leuser National Park Office for providing support in data collection.

REFERENCES

Adrianto HA, Spracklen DV, Arnold SR. 2019. Relationship between fire and forest cover loss in Riau Province, Indonesia between 2001 and 2012. Forest 10 (10): 889. DOI: 10.3390/f10100889.

Astiani D, Taherzadeh MJ, Gusmayanti E, Widiastuti T, Burhanuddin. 2019. Local knowledge on landscape sustainable-hydrological management reduces soil CO_2 emission, fire risk and biomass loss in West Kalimantan Peatland, Indonesia. Biodiversitas 20 (3): 725-731. DOI: 10.13057/biodiv/d200316.

Crippa P, Castruccio S, Archer-Nicholls S, Lebron GB, Kuwata M, Thota A, Sumin S, Butt E, Wiedinmyer C, Spracklen DV. 2016. Population exposure to hazardous air quality due to the 2015 fires in Equatorial Asia. Sci Rep 6 (1): 37074. DOI: 10.1038/srep37074.

Fanin T, van der Werf GR. 2017 Precipitationfire linkages in Indonesia (1997-2015). Biogeosciences 14 (18): 3995-4008. DOI: 10.5194/bg-14-3995-2017.

Field RD, van der Werf GR, Fanin T, Fetzer, EJ, Fuller, R, Jethva H, Levy R, Livesey NJ, Luo M, Torres O, Helen MW. 2016. Indonesian fire activity and smoke pollution in 2015 show persistent nonlinear sensitivity to El Niño-induced drought. Proc Nat Acad Sci USA 113 (33): 9204-9209. DOI: 10.1073/pnas.1524888113.

Firmansyah S, Gaol JL, Susilo, SB. 2019. Perbandingan klasifikasi SVM dan Decision Tree untuk pemetaan mangrove berbasis objek menggunakan citra satelit Sentinel-2B di Gili Sulat, Lombok Timur. Journal of Natural Resources and Environmental Management 9 (3): 46-757. DOI: 10.29244/jpsl.9.3.746-757. [Indonesian]

Gaveau DLA, Salim MA, Hergoualc'H K, Locatelli B, Sloan S, Wooster M, Marlier ME, Molidena E, Yaen H, DeFries R, Verchot L, Murdiyarso D, Nasi R, Holmgren P, Sheil D. 2014. Major atmospheric emissions from peat fires in Southeast Asia during non-drought years: evidence from the 2013 Sumatran fires. Sci Rep 4 (1): 1-7. DOI: 10.1038/srep06112.

Giglio L, Boschetti L, Roy DP, Humber ML, Justice CO. 2018. The Collection 6 MODIS burned area mapping algorithm and product. Remote Sens Environ 217: 72-85. DOI: 10.1016/j.rse.2018.08.005.

Giglio L, Schroeder W, Hall JV, Justice CO. 2020. MODIS Collection 6 Active Fire Product User's Guide Revision C. National Oceanic and Atmospheric Administration. https://lpdaac.usgs.gov/documents/876/MOD14_User_Guide_v6.pdf [06-10-2021]

Huijnen V, Wooster MJ, Kaiser JW, Gaveau DLA, Flemming J, Parrington M, Inness A, Murdiyarso D, Main B, van Weele M. 2016. Fire carbon emissions over maritime Southeast Asia in 2015 largest since 1997. Sci Rep 6 (1): 1-8. DOI: 10.1038/srep26886.

Kementerian Lingkungan Hiudp dan Kehutanan (KLHK). 2020. Petunjuk Teknis Penafsiran Citra Satelit Resolusi Sedang Untuk Update Data Penutupan Lahan Nasional. Direktorat Inventarisasi dan Pemantauan Sumber Daya Hutan Direktorat Jenderal Planologi Kehutanan Kementerian Kehutanan. Jakarta. [Indonesian]

Kiely L, Spracklen DV, Wiedinmyer C, Conibear L, Reddington CL, Archer-Nicholls S, Lowe D, Arnold SR, Knote C, Khan MF, Latif MT, Kuwata M, Budisulistiorini SH, Syaufina L. 2019. New estimate of particulate emissions from Indonesian peat fires in 2015. Atmos Chem Phys 19 (17): 11105-11121. DOI: 10.5194/acp-19-11105-2019.

Koplitz SN, Mickley LJ, Marlier ME, Buonocore JJ, Kim PS, Liu T, Sulprizio MP, DeFries RS, Jacob DJ, Schwartz J, Pongsiri M, Myers SS. 2016. Public health impacts of the severe haze in Equatorial Asia in September-October 2015: Demonstration of a new framework for informing fire management strategies to reduce downwind smoke exposure. Environ Res Lett 11 (9): 94023. DOI: 10.1088/1748-9326/11/9/094023.

Marlier ME, Ruth SD, Apostolos V, Patrick LK, James TR, Drew TS, Yang C, Greg F. 2013. El Niño and health risks from landscape fire emissions in Southeast Asia. Nat Clim Change 3 (2): 131-136. DOI: 10.1038/nclimate1658.

Meijaard E, Sheil D. 2019. The moral minefield of ethical oil palm and sustainable development. Front For Global Change 2: 22. DOI: 10.3389/ffgc.2019.00022.

Ministry of Environment and Forestry (MoEF). 2014. State of Conservation Status of the World Heritage in Indonesia. World Heritage Property Tropical Rainforest Heritage of Sumatra (N 1167). [Indonesian]

Page SE, Siegert F, Rieley JO, Boehm HDV, Jaya A, Limin S. 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997. Nature 420, 61-5. DOI: 10.1038/nature01131.

Prasetyo LB, Dharmawan AH, Nasdian FT, Ramdhoni S. 2016. Historical forest fire occurrence analysis in Jambi Province during the period of 2000-2015: Its distribution & land cover trajectories. Proc Environ Sci 33: 450-459. DOI: 10.1016/j.proenv.2016.03.096.

Purwanto E. 2016. Strategi Anti-Perambahan di Tropical Raintforest Heritage of Sumatra: Menuju Paradigma Baru. Debut Press, Jogjakarta. [Indonesian]

Reddington CL, Yoshioka M, Balasubramanian R, Ridley D, Toh YY, Arnold S, Spracklen DV. 2014. Contribution of vegetation and peat fires to particulate air pollution in Southeast Asia. Environ Res Lett 9 (9): 094006. DOI: 10.1088/1748-9326/9/9/094006.

Rini S. 2018. Kajian kemampuan metode neural network untuk klasifikasi penutup lahan dengan menggunakan citra Landsat-8 OLI (kasus di Kota Yogyakarta dan sekitarnya). Jurnal Geomedia 16 (1): 1-12. DOI: 10.21831/gm.v16i1.20974. [Indonesian]

Tata HL, Narendra BH, Mawazin. 2018. Forest and land fires in Pelalawan District, Riau, Indonesia: Drivers, pressures, impacts and responses. Biodiversitas 19 (2): 544-551. DOI: 10.13057/biodiv/d190224,

Taufik M, Torfs PJJF, Uijlenhoet R, Jones PD, Murdiyarso D, Van Lanen HAJ. 2017. Amplification of wildfire area burnt by hydrological drought in the humid tropics. Nat Clim Change 7, 428-431. DOI: 10.1038/nclimate3280

Thoha AS, Ahmad AG. 2018. Modeling of forest and land fires vulnerability level in North Sumatra Province, Indonesia. EnvironmentAsia 11 (3): 1- 14. DOI: 10.14456/ea.2018.34.

Thoha AS, Saharjo BH, Boer R, Ardiansyah M. 2019. Characteristics and causes of forest and land fires in Kapuas District, Central Kalimantan Province, Indonesia. Biodiversitas 20 (1): 110-117. DOI: 10.13057/biodiv/d200113.

Thoha AS, Sulistiyono N, Saraswita N, Wiranata D, Sirait SM, Inaldi R. 2021. Identification of land cover changes before and after forest and land fires in conservation areas of North Sumatra, Indonesia. IOP Conf Ser: Earth Environ Sci 912 (1): 012026. DOI: 10.1088/1755-1315/912/1/012026.

Thoha AS, Triani H. 2021. A spatial model of forest and land fire vulnerability level in the Dairi District, North Sumatra, Indonesia. Biodiversitas 22 (8): 3319-3326. DOI: 10.13057/biodiv/d220827.

van der Werf GR, Dempewolf J, Trigg SN, Randerson JT, Kasibhatla PS, Giglio L, Murdiyarso D, Peters W, Morton DC, Collatz GJ, Dolman AJ, DeFries RS. 2008. Climate regulation of fire emissions and deforestation in equatorial Asia. Proc Nat Acad Sci U S A 105 (51): 20350-20355. DOI: 10.1073/pnas.0803375105.

Wijedasa LS, Jauhiainen J, Könönen M, Lampela M, Vasander H, Evers S, Yule CM, Varkkey H, Lupascu M, Parish, F. 2017. Denial of long-term issues with agriculture on tropical peatlands will have devastating consequences. Glob Change Biol 23 (3): 977-982. DOI: 10.1111/gcb.13516.

Zaitunah A, Samsuri, Amaliah P. 2019. Landcover change analysis of Besitang watershed, Langkat North Sumatra. J Phys Conf Ser 1282 (1): 012090. DOI: 10.1088/1742-6596/1282/1/012090.