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Spatial-Temporal Analysis of Land Cover Change and Oil Palm Expansion in Gunung Mas

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Abstract: The area of oil palm plantations in Indonesia has increased over time. The growth of oil palm plantations even exceeds the percentage of the area of paddy fields, especially in Gunung Mas Regency. This phenomenon is accompanied by the implementation of "Regional Regulation No. 1 of 2020 concerning Land Fire Control". The regulation aims to prevent land fires due to human activities. However, local people believe that burning can increase land productivity. As a result, many people convert their land to plant oil palm, because it is considered to guarantee economic improvement compared to paddy fields. Remote sensing satellite imagery is the basis and main source in the analysis. With spatio-temporal analysis, mapping of land use changes in a certain period of time and its relationship with the distribution of agricultural wet and dry areas. As a result, the proportion of palm oil land in Gunung Mas Regency is higher than the proportion of paddy fields. If oil palm expansion continues in the future, agricultural drought could become more widespread.

Keywords: Expansion of oil palm, Land use change, Paddy Fields, Remote sensing, Spatio-Temporal Analysis

INTRODUCTION

Oil palm plants are excellent in countries with tropical climates (Paterson, 2021). Indonesia has all aspects of being the world's largest palm oil producer (BPS Kalimantan Tengah, 2024). As the global population continues to grow, it is estimated that demand for vegetable oils will increase to nine billion people by 2050 (Nelson et al., 2010). Consumers may switch to vegetable oils containing trans fats due to health concerns (World Health Organization Regional Office for Europe, 2015) and demand for biofuel blends will increase due to concerns about climate change (Castiblanco et al., 2013). When calculated, oil palm produces the highest oil per unit of land in the world (Carter et al., 2007). The Indonesian government is pushing oil palm plantations as an alternative to support rural development and boost the economy. In addition, palm oil is cheaper to produce and less expensive than most alternative vegetable oils (Santika et al., 2019). Recently, the archipelago's oil palm plantations have soared significantly, with 22 of Indonesia's 33 provinces developing oil palm plantations. Kalimantan and Sumatra are the two most prominent islands of oil palm plantation centers in the archipelago. The oil palm commodity occupies these two islands by approximately 90% (Purba & Sipayung, 2017). Based on data from The Central Agency of Statistics (BPS, 2020), the area of oil palm plantations in Indonesia has increased at a significant rate each year.

Since the enactment of "Undang-Undang (UU) No. 32/2009 (Law No. 32 of 2009 concerning Environmental Protection and Management)" in conjunction with "Undang-Undang (UU) No. 11/2020 (Law No. 11 of 2020 concerning Job Creation)", then the issuance of "Perpu No. 2/2022 (Perpu No. 2 of 2022 concerning Job Creation)" which is officially stipulated through "Undang-Undang (UU) No. 3/2023 (Law No.3 of 2023 concerning Agreement Between the Government of the Republic of Indonesia and the Government of the Republic of Singapore on Defence Coorperation)", the substance of the Perpu contains an article that clearly prohibits the practice of burning to clear land. This is clearly prohibited in article 69 paragraph 1 which reads "Everyone is prohibited from clearing land by burning". Burning forests is a community culture, so a fair perspective is needed to see this phenomenon (Christiawan, 2020). Palm oil production in Indonesia comes from three types of plantation ownership: private, community and government-owned (Hasan et al., 2022; Imbiri et al., 2023). Private and government-owned plantations are managed by companies with better managerial skills than community-owned plantations (Zhao et al., 2022).

The Central Agency of Statistics revealed that the area of oil palm plantations has increased significantly from 166,926.09 Ha in 2018 to 344,972.75 Ha in 2022. This indicates that there is a lot of land clearing for oil palm by local people who were originally paddy farmers. This was accompanied by a significant increase in the production of smallholder plantation oil palm, which amounted to 277,700.52 tons in 2018 to 901,997.18 tons in 2022. Local communities are shifting from paddy field to oil palm plantations because it is considered to guarantee economic improvement, although environmental sustainability will have a long impact (Colchester et al., 2011). This is reinforced by the Kompas news which states that the reason for this transition is due to regulations governing the prohibition of burning to clear land and the high production costs of paddy field so that paddy production in Central Kalimantan has decreased. On the other hand, based on BPS data, the harvest area of paddy plants has decreased with a harvest area of 125,870.05 ha in 2021 to 109,756.22 in 2022 (BPS Kalimantan Tengah, 2024), while BPS data for Gunung Mas Regency 2021-2022 shows that the table explains that both the area and productivity of paddy harvests in Gunung Mas Regency in the 2021-2022 range have decreased very significantly.

The impacts of oil palm expansion have been examined through several studies. Oil palm expansion due to economic value has an impact on social conflicts between farmers, overlapping independent farmers' land with mines and Cultivation Rights (HGU) and ecological impacts such as threatening biodiversity, erosion, flooding, changes in air temperature, and environmental services (Amalia et al., 2019). Another impact is the increase in the economic vulnerability of oil palm farmer households to the impact of oil palm expansion and homogeneous farming activities when there is a phenomenon of declining palm oil prices (Hidayah et al., 2016). The existence of political elements that often encourage oil palm expansion continues to occur in Central Kalimantan and contributes to the environmental problems caused (Ayu, 2021). Based on the description and expansion of oil palm in Gunung Mas Regency, this paper wants to analyze ecological changes that focus on Land Cover Change of Oil Palm and Paddy Fields in Gunung Mas Regency in 2013 and 2023 and the condition of water content and land dryness during that time.

METHODS

The quantitative method used in this study is also supported by a spatial analysis approach. The reason for using qualitative methods is due to the in-depth and comprehensive analysis of the dynamics of land change and oil palm expansion due to the implementation of regulations in the region, and its impact on ecology. The spatial analysis approach was chosen to be a strong tool in providing information on the location of oil palm expansion temporally, to be able to analyze the ecological variations caused.

Primary and secondary data are needed in the analysis process of this paper. The use of primary data is in the form of spatial data, namely remote sensing satellite images in 2013 and 2023 which are processed cloud-based using the Google Earth Engine platform. Remote sensing data is classified as a type of primary data because it is still raw data that will be processed by researchers in extracting values to bring up the information needed. The selection of the 10-year range is based on three years after the implementation of regulations in 2010 and additional regulations in 2020. Meanwhile, the secondary data used comes from various related literature. The following are the types of images and their sources in this study.

Table 1. Data, Spatial Resolution, and Sources

Data	Satellite Image	Spatial Resolution	Sources
Land Cover	Landsat 8 Level 2, *Collection* 1, Tier 2 Imagery	30 meters	USGS
NDWI (*Normalized Difference Wetness Index)*	MODIS (*Moderate Resolution Imaging Spectroradiaometer)* Imagery	500 meters	NASA LP DAAC in USGS EROS CENTER
NDDI (*Normalized Difference Drought Index*)	MODIS (*Moderate Resolution Imaging Spectroradiaometer)* Imagery	500 meters	NASA LP DAAC in USGS EROS CENTER
LST (*Land Surface Temperature*)	Landsat 8 *Collection* 1 Tier 2 TOA *Reflectance* Imagery	30 meters	USGS
Digital Elevation Model	IFSAR, TERRASAR, ALOS PALSAR	5 meters and 11,25 meters	Badan Informasi Geospasial

The selection of Landsat 8 imagery for land cover mapping is based on its wide coverage area (Rafsenja et al., 2020). With a spatial resolution of 30 meters, the Landsat 8 recording area can cover one district/city. Another advantage is that Landsat 8 imagery provides data since 2013. This study highlights land cover changes in 2013 and 2023, so the wide range of Landsat 8 data availability is suitable for use in this study.

The processing of Gunung Mas Regency land cover data using Landsat 8 imagery through the Google Earth Engine platform by applying a type of guided classification method called CART (Classification and Regression Trees) algorithm. CART (Classification and Regression Trees) is included in a non-parametric method which is a variable of one or more predictor variables or independent variables (Ghiasi et al., 2020). The CART algorithm discards insignificant variables as a whole and selects significant variables on its own so that it will speed up the data analysis process (Prabawati et al., 2019). That way, the CART algorithm can handle large amounts of data in a shorter time (Hartfield et al., 2011).

The level of error in the classification will be tested for accuracy to determine the percentage of accuracy in the mapping results (Sampurno & Thoriq, 2016). The results of the land cover accuracy test are said to be good if they are above 85% (Anderson et al., 1976). The accuracy of mapping accuracy uses an error matrix or confusion matrix so that overall accuracy is obtained later. However, in this study, overall accuracy was obtained by coding through Google Earth Engine (GEE).

$$\text{User's accuracy} = \frac{Xii}{X+i} x100\%$$
$$\text{Producer's accuracy} = \frac{Xii}{Xi+} x100\%$$
$$\text{Overall accuracy} = \frac{\sum xii}{N} x100\%$$

Explanation:

Xii = the diagonal value of the contingency matrix in the i-th row and i-th column
$Xi+$ = the number of pixels in the i-th row
$X+i$ = the number of pixels in the i-th column

The selection of MODIS imagery for NDDI mapping is because MODIS has a high temporal resolution of 2 days, making it suitable for monitoring rapid changes, sensitive to changes in the land surface, such as floods, droughts, forest fires, and others (NASA, n.d.). The month analyzed is August, where August is the peak of the dry season per year which is characterized by the least amount of rainfall compared to other months, namely 61 mm / month with an average of 6.8 hours of sunshine per day in 2023 (BPS Kalimantan Tengah, 2024). NDDI (Normalized Difference Drought Index) is an index useful in mapping the level of agricultural drought in a particular area based on NDVI (Normalized Difference Vegetation Index) as well as NDWI (Normalized Difference Water Index). NDDI is extracted using the equation below:

$$\text{NDDI} = \frac{NDVI - NDWI}{NDVI + NDWI}$$

To get the NDDI value, the formula above can be used. Where, NDVI is obtained from the extraction of NIR and Red bands, while NDWI is obtained from the extraction of NIR and SWIR bands (Cahyono et al., 2023). In MODIS images, NIR is the reflectance value of channel 2, Red is the reflectance value of channel 1, and SWIR is the reflectance value of channel 6.

The NDDI index value has a range of 0.01 to 1, where if the value is closer to 0.01, the vegetation and soil moisture have a higher water content, otherwise the value is closer to 1, meaning that the vegetation and soil moisture contain lower water or in the sense of getting drier. The classification of the NDDI value range is as follows:

Table 2. Classification of Agricultural Drought Levels

Drought Classification	NDDI Value
Normal	NDDI < 0,01
Mild Dryness	0,01 <= NDDI <0,15
Moderate Drought	0,15 <= NDDI <0,25
Severe Drought	0,25 <=NDDI < 1
Very Severe Drought	NDDI >= 1

Source: Cahyono et al., 2023

Meanwhile, the Normalized Difference Wetness Index (NDWI) uses the same satellite image as NDDI, MODIS. The selection of MODIS imagery in addition to its high temporal resolution of 2 days, MODIS imagery also has the availability of image data in 2013. NDWI is used in analyzing agricultural land moisture using the shortwave infrared (SWIR) channel as well as the near infrared (NIR) channel with the formula below:

$$\text{NDWI} = \frac{NIR - SWIR}{NIR + SWIR}$$

Based on the clarification of NDWI values from reference sources, if the NDWI value is more than negative 1 and less than 0 then it is included in the non-water body class, if the value is more than 0 and less than 0.33 it is included in the medium wetness class, while if the NDWI value is above 0.33 and less than 1 it is included in the high wetness class.

Table 3. NDWI Wetness Level Classification

Wetness Classification	NDWI Value
Non-Body of Water	-1 < NDWI < 0
Moderate Wetness	0 < NDWI < 0,33
High Level Wetness	0,33 < NDWI < 1

Source: Permata et al., 2022

In this study, land surface temperature data was also used. The calculation of land surface temperature is done with the equation:

$$\text{LST} = \frac{BT}{\{1+[(\frac{\lambda BT}{c2})ln\in\lambda\,]\}}$$

Explanation:
TB = *Temperature Brightness* (°C)
λ = *Central Wavelength of Emitted Radiance*
c2 = h x $\frac{c}{s}$ = 1.4388 x 1^{-2} mK = 14388 μmK

The classification of surface temperature numbers is divided into five classes. The classification of LST classes is depicted in Table 4.

Table 4. LST Classification

Land Surface Temperature (LST) Class	Range
Very Low Class	<20°C
Low Class	20°C – 25°C
Medium Class	25°C – 30°C
High grade	30°C – 35°C
Very High Class	>35°C

Source: Sasky et al., 2017

This research uses spatio-temporal analysis techniques. Spatio-temporal analysis can be defined as data analysis with a reference source on data that has time attributes as well as absolute and relative location attributes in three-dimensional space, and includes its processes and methodologies (Dong & Guo, 2021). This analysis was chosen because it is able to present multidimensional dynamic information and correlations with visualized results in the form of land cover change maps, soil moisture maps, and agricultural drought maps. The analysis of land cover in 2013 and 2023 can provide an overview of land changes from paddy fields to oil palm plantations, proving the existence of oil palm expansion.

The analysis of soil moisture and agricultural drought is carried out with the Normalized Difference Water Index (NDWI), Normalized Difference Drought Index (NDDI), and Land Surface Temperature (LST) in the twists and turns of the dynamics of land cover changes that occur. Reporting from the website (Sentinelhub, 2020), NDWI is an index used in monitoring and detecting changes in water content in a water body. NDDI is an index used in monitoring drought in an agricultural area or an agricultural area experiencing drought (Maida, 2023), where NDDI analysis is different from meteorological drought monitoring which is studied with SPI (Standardized Precipitation Index). LST is the Earth's surface temperature that plays a role in the analysis of monitoring water content in water bodies, water quality and the environment (Insan & Prasetya, 2021). In the process, the dynamic relationship of land cover change between paddy fields and oil palm plantations is related to the water content of a surface.

RESULT AND DISCUSSION

Analysis of Land Cover Change Due to Oil Palm Expansion

The many economic benefits and potential offered by oil palm yields have attracted many rice farmers to switch to oil palm plantations (Feintrenie et al., 2010). Supported by good trade management and quality control efforts (certification), the growth of oil palm production is promising for farmers (Utoyo & Yolandika, 2018). However, farmers still have to look at land capability and the availability of land infrastructure where oil palm can be optimal under certain conditions (Krishna et al., 2017). The prohibition of land clearing by burning opens up higher opportunities for farmers to plant oil palm (Nopembereni, 2019). The increase in the conservation of paddy fields into oil palm plantations is supported by economic factors (Fahri et al., 2014). The practice of shifting cultivation with a slash-and-burn forest system is no longer the main method of agriculture for the Dayak community (Peraturan Daerah Provinsi Kalimantan Tengah, 2020). The government's aim in implementing this prohibition is to avoid cases of forest and peatland fires affecting the community. The regional regulation prohibiting land clearing by burning has the potential to conflict with shifting cultivation that has been intervened by the government (Wildayana, 2015).

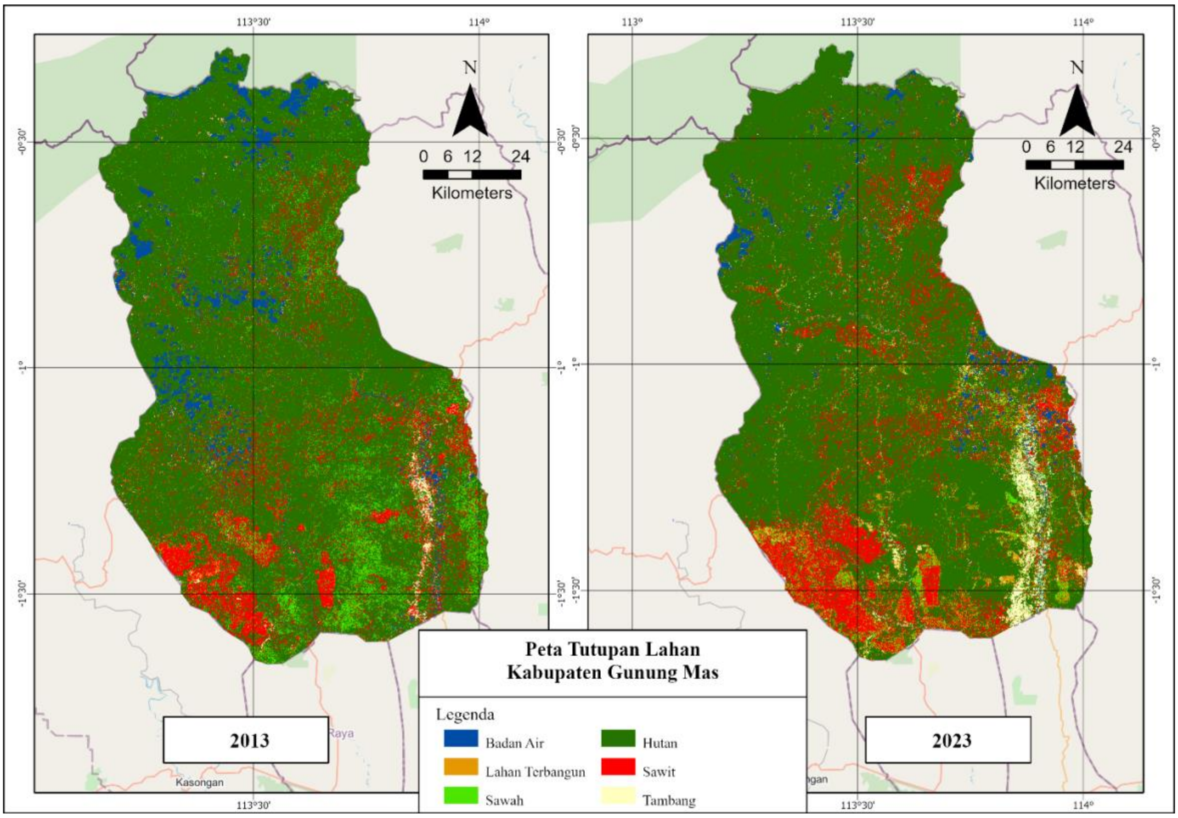


Figure 1. Land Cover in 2013 and 2023
Source: Data Processing, 2024

Based on the results of the analysis, land cover is classified into 6 classes, namely water bodies, built-up land, paddy fields, forests, palm oil, and mines. Based on the results of data processing, it can be seen that there have been changes in land cover over the last 10 years, from 2013 to 2023. The extent of land cover change in 2013 and 2023 is explained in Table 5.

Table 5. Extent of Land Cover Change

Land Cover Class	2013 (km^2)	2023 (km^2)	Percentage Change
Water body	69,2	35,7	-31,94%
Built-up land	26,6	350,8	+85,90%
Paddy field	708,7	286,4	-42,44%
Forest	6916,7	6935,6	+0,14%
Palm	1164,3	1325,6	+6,48%
Mine Site	72,2	221,8	+50,88%

Source: Data Processing, 2024

Based on the area table, it can be seen that there is a significant change between oil palm and paddy fields. In 2023, palm oil increased by 161.3 km2 or about 6.48% of its initial area in 2013. On the other hand, paddy fields actually experienced a decrease in area of up to 422.3 km2 or 42.44% of its initial area in 2013. The drive to expand oil palm plantations has proven to be the cause of land exhaustion in rural areas, thus hampering the development of food commodities (Pipian et al., 2023). The decrease in the area of paddy fields is one of the impacts of oil palm expansion. Paddy fields have changed their land cover to palm oil because they are considered more profitable (Melisa & Wulandari, 2021). In fact, this significant decrease in paddy fields can be very worrying because it can disrupt food stability in the future (Prasada & Rosa, 2018). This food instability leads to food insecurity, either in the form of a decrease in food stock or in a broader sense involving food insecurity (Pipian et al., 2023).

Analysis of the Slope of Oil Palm Expansion to Water Content and Drought Conditions of the Land

Oil palm expansion can be accompanied by ecological changes. This study examines the potential ecological changes that occur along with oil palm expansion.

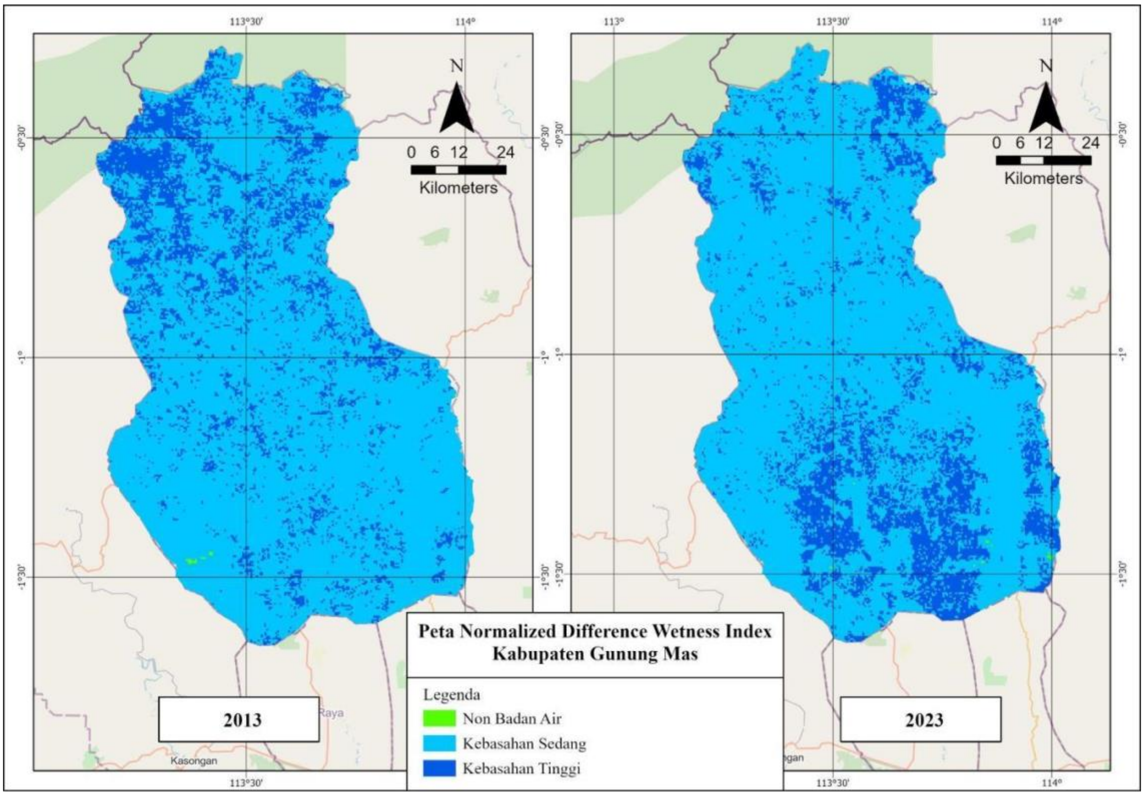
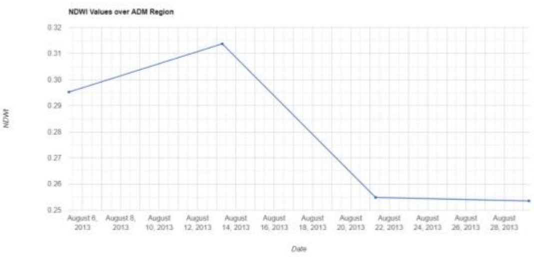


Figure 2. Wetness Level Map of Gunung Mas Regency for 2013 and 2023
Source: Data Processing

Based on the results of data processing, the level of wetness in Gunung Mas District in 2023 is dominated by a moderate level of wetness with only a small portion included in the high wetness class. In 2023, there was an addition and displacement of high wetness areas marked in dark blue in the southeastern part of Gunung Mas District. In August 2013, the highest NDWI value was 0.31 and the lowest was 0.25. In August 2023, the highest value was 0.3 and the lowest was 0.17. The average NDWI value in 2013 was 0.28. On average, the NDWI value decreased by 0.01 from 2013 to 2023.

Table 6. Comparison of NWDI Values for 2013 and 2023

NDWI August 2013	NDWI August 2023
	
Average value: 0,28	Average value: 0,27

Source: Data Processing

Based on the literature review, in the northern part of Gunung Mas Regency, more precisely in Damang Batu Sub-district and Tumbang Marikoi Village, there are two legal oil palm companies that have expanded from the land conversion of community gardens and locations in this village that have decreased water absorption, resulting in flooding when it rains with high rainfall. This was caused by illegal mining activities and oil palm expansion due to the decline in the selling value of rubber that occurred between 1960-2015. The emergence of palm oil companies, mining, Forest Concession Rights (HPH) resulted in reduced forest land, temperature changes, floods, droughts, river and lake water pollution, and landslides (Usop & Iskandar, 2020). Mining activities are reinforced by those who state that community gold mining reaches 3,630 miners with 726 suction machines (Inswiasri, 2011 in Siburian, 2016). Mobile mining with the fact that the community objected to applying for a legal mining permit resulted in many ex-mining pits that had to go through rehabilitation and naturalization stages in restoring damaged soil functions (Siburian, 2016). Land changes from vegetation to open mining land result in reduced water absorption capacity (Fransisca, 2023). In Tanjung Riu Village (located in the center of Gunung Mas Regency), 40% of the land cover is former mining activities (Putrawiyanta et al., 2023). The rampant mining activities in this village have had a negative impact on the morphology of the surrounding environment (Yusevi et al., 2021).

However, the older oil palm causes an increase in the total pore space, moisture content, water content, and permeability of the soil (Megayanti et al., 2022). Therefore, based on this, the northern part of Gunung Mas District experienced a decrease in NDWI class from high wetness to medium wetness, which is assumed to be a result of the oil palm expansion. The NDWI method is used to detect the level of wetness or standing water on a land surface. Thus, the presence of oil palm results in high water absorption and causes the

NDWI value to decrease. Whereas in the central part of Gunung Mas Regency where there has been a fairly extensive land change into former mines resulting in reduced water absorption and this is shown through the NDWI value in the middle of Gunung Mas Regency (especially Tanjung Riu Village) experiencing an increase in NDWI value which means that there is inundation and the level of water wetness that can be detected through MODIS imagery (Figure 2). Whereas in the southeastern part of Gunung Mas Regency where mining land cover is detected (Figure 3), in August with the assumption of the dry season the least rainfall results in the absence of puddles and wetness levels detected.

Agricultural drought is a condition of water shortage to the point of being unable to meet agricultural needs or can be interpreted as a shortage or unfulfilled water supply from various water sources. Agricultural drought is caused by several factors that influence each other. Significant factors that influence agricultural drought include rainfall, slope, land cover, landform, and soil texture (Maulana et al., 2021). Agricultural drought information can be seen as follows which is processed through NDDI. The results of NDDI processing can be reviewed in Figure 3.

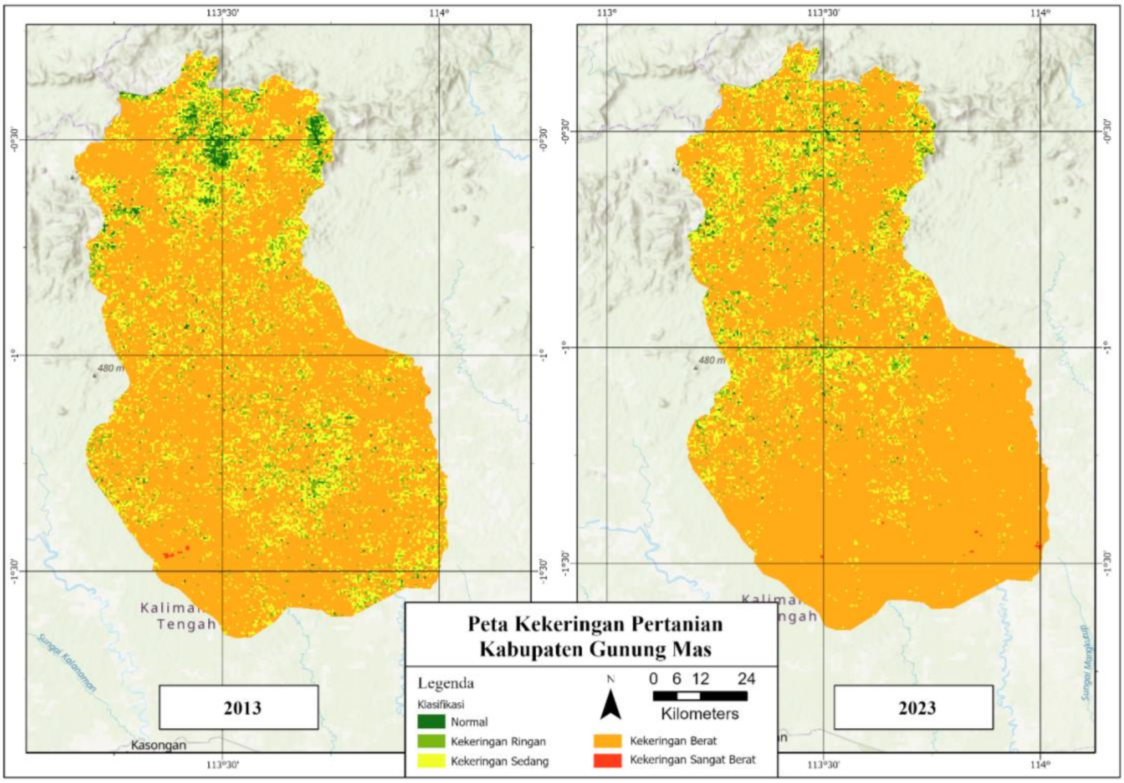
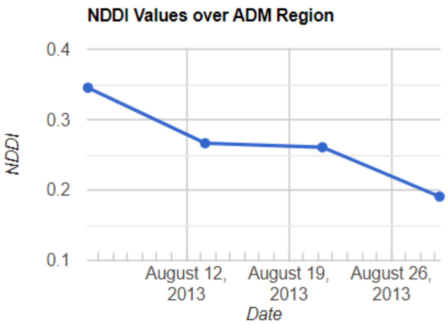
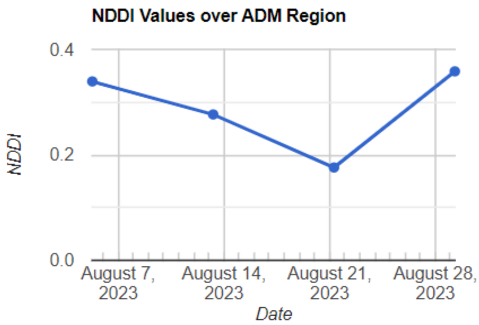


Figure 3. Map of Agricultural Drought in 2013 and 2023
Source: Data Processing

Looking at the agricultural drought maps for 2013 and 2023, agricultural drought in Gunung Mas Regency is not so alarming, but it is expanding, especially in the southern region. It can be seen that the northern part, which was initially categorized as normal to mild drought in 2013, will be categorized as moderate to severe drought in 2023. In the southern part, which was still mostly categorized as moderate drought in 2013, the dominance has changed to the category of severe drought and there are even some points that fall into the category of very severe drought.

Table 7. Comparison of NDDI Values for 2013 and 2023

NDDI August 2013	NDDI August 2023
	
Average value: 0,29	Average value: 0,32

Source: Data Processing, 2024.

The closer the number 1, the drier the region will be. The average NDDI value of the four MODIS data recorded in August 2013 was 0.29, while in 2023 it was 0.32, meaning that in a span of 10 years there was a decrease in the average NDDI value in August by 0,3.

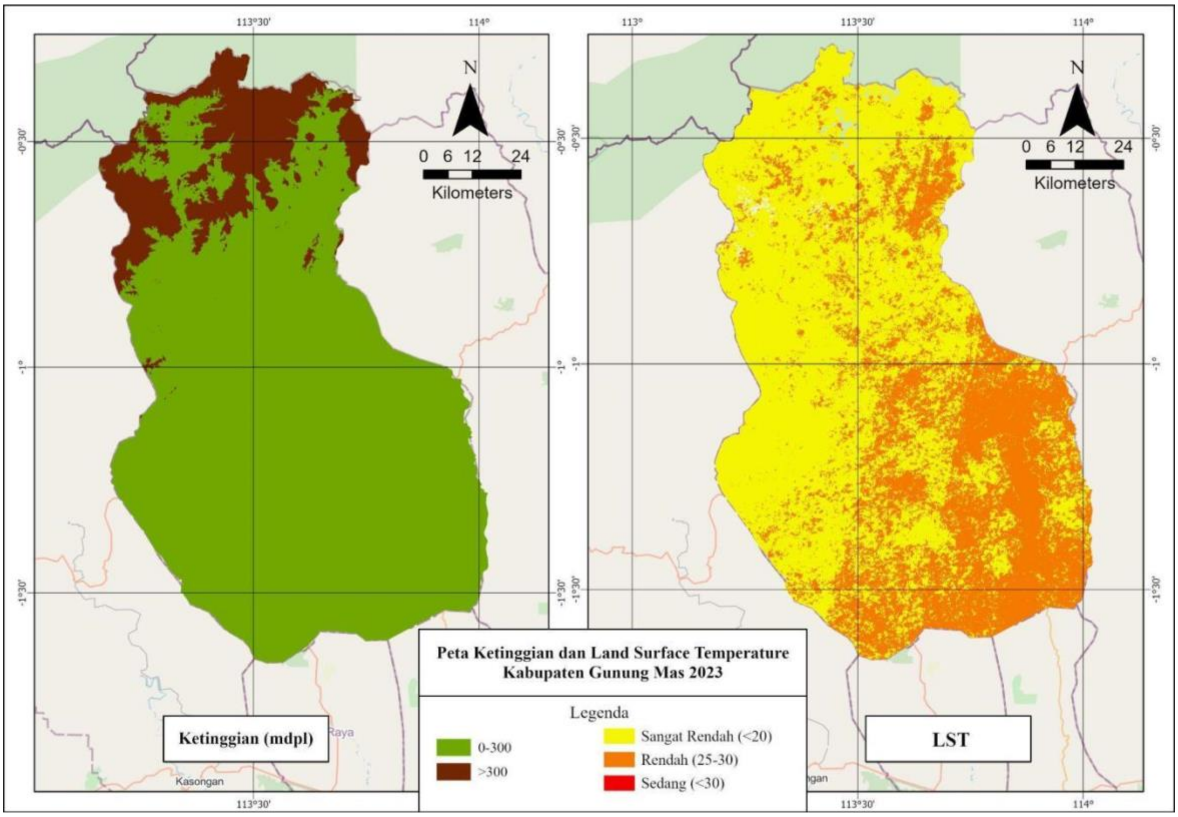


Figure 4. Altitude and LST Map of Gunung Mas Regency 2023
Source: Data Processing

It is suspected that the potential for oil palm expansion will continue into the future, which will result in more widespread agricultural drought. When viewed from the distribution of wetness locations, the southern part of Gunung Mas District has 'potential' water that can be utilized for paddy fields. Ideally, oil palm land can increase the economic power and paddy fields to support food estate activities and local food security. On the other hand, without looking at the traditional agricultural practices of the Ngaju Dayak community, which are actually not only to fulfill their survival but also to maintain ecological balance. The practice of shifting cultivation is carried out in order to adapt to the challenges of low soil fertility and with simple agricultural technology. This agricultural practice consists of several processes, namely the first process of selecting land clearing locations with characteristics close to water sources, not steep slopes, and usually carried out in May-July. This is followed by a second process of cutting down vegetation and allowing it to dry out and then burning it in August. The ash from burning the land is considered a fertilizer that can provide soil fertility. After that, it is used to plant agricultural crops such as paddy and corn. When the cleared land begins to lose its fertility, which is about two or three years, farmers return to clear new land. To maintain ecological sustainability, the community is prohibited from clearing land on peat soil or this is referred to as the pali system. In addition, during the burning process, the community prevents the fire from spreading by cutting down the vegetation between the land to be cleared and the forest area. Meanwhile, the land left behind will be re-grown with vegetation (Nopembereni, 2019).

CONCLUSIONS

The ban on land clearing by burning since 2020 has resulted in a reduction in the area of paddy fields accompanied by the expansion of oil palm plants. Spatial-temporal changes in land cover of oil palm and paddy fields for 10 years occurred quite massively. Oil land plantation has expanded by 6.48%, meanwhile the changes in paddy fields has decreased by 42.44%. With the expansion of oil palm land, the agricultural drought index in Gunung Mas Regency is categorized as severe drought. Nevertheless, there is still potential water content that should be utilized for paddy fields. This study provides a new perspective that rice field agriculture faces challenges amidst the uncontrolled expansion of oil palm so that it can reduce the level of rice food security. This emphasizes the balance between economic transformation and sustainable conservation.

RECOMMENDATIONS

Reviewing the implementation of "Regional Regulation Number 1 of 2020 concerning Forest Fire Control" which has an impact on the massive expansion of oil palm plantations.

This fact makes land cover change from paddy fields to oil palm plantations very intense. The results of this analysis can be a reference for relevant stakeholders to review regional strategic policies so that they are integrated.

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