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# Comparative analysis of burn area between google earth engine and manual digitization using the NBR algorithm

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## ABSTRACT

**Background:** Indonesia, as the third-largest tropical forest country in the world, is experiencing significant forest degradation driven by illegal logging, land-use conversion, and recurrent wildfires. Peatland ecosystems, particularly in Kubu Raya District, West Kalimantan, are highly susceptible to fire due to their organic-rich composition and seasonal desiccation. This study aims to assess the spatial distribution and severity of forest and land fires in Kubu Raya from 2019 to 2023 using remote sensing and geographic information system (GIS) techniques. **Methods:** Hotspot data from the Fire Information for Resource Management System (FIRMS) MODIS were analyzed to determine fire occurrences, while Sentinel-2 imagery was utilized to calculate the Normalized Burn Ratio (NBR) index for burn severity estimation. Image analysis was conducted using both manual digitization and the Google Earth Engine (GEE) platform to compare accuracy, efficiency, and spatial representation of burned-area detection. **Findings:** The findings indicated that 2023 recorded the largest burned area, covering 832,188.98 ha, predominantly within peatland zones. Accuracy assessment demonstrated that the GEE-based method achieved higher reliability, with overall accuracy and kappa statistic values of 86% and 74%, respectively, outperforming the manual approach. The spatial distribution of fire hotspots revealed that peat-dominated areas were more vulnerable to large-scale fires due to their hydrological characteristics. **Conclusion:** The results highlight that GEE provides a rapid, consistent, and accurate technique for burn area detection and fire severity analysis. Integrating cloud-based remote sensing with conventional GIS enhances monitoring capabilities for sustainable peatland management. **Novelty/Originality:** The novelty of this research lies in its comparative accuracy evaluation between automated and manual burn area mapping. This study provides new methodological insights for fire monitoring across Indonesia's tropical peatlands, demonstrating the advantages of cloud-based platforms for large-scale environmental assessments.

**KEYWORDS:** burn severity; peatland fires; remote sensing.

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## 1. Introduction

Indonesia is widely recognized as one of the world's largest holders of tropical forest resources, ranking third after Brazil and the Democratic Republic of the Congo in terms of tropical forest extent (Gaveau et al., 2021). According to the Ministry of Environment and Forestry (KLHK), approximately 94.1 million hectares of Indonesia's land area were classified as forest in 2019, representing around 50.1 percent of the country's total terrestrial area (Putri, 2020). These forests serve as critical ecological assets supporting biodiversity, climate regulation, hydrological balance, and local livelihoods. However, the long-term condition of Indonesia's forests has been increasingly threatened by intensifying

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anthropogenic pressure. Over the past decades, forest degradation and land-cover transformation have been driven primarily by illegal logging, agricultural expansion, plantation development, and recurring forest and land fires that occur across various regions (Schmidt et al., 2024). As population density grows and natural resources become more heavily exploited by commercial interests, competition for land has intensified, contributing to the progressive decline in forest cover and ecological integrity (Horton et al., 2021; Austin et al., 2019).

Among the most critical contributors to environmental degradation in Indonesia are forest and peatland fires, which are responsible for substantial greenhouse gas emissions and extensive ecological disturbance. Peatland fires, in particular, release enormous amounts of carbon due to the thick, organic-rich soils that burn both above and below the surface (Fanin & van der Werf et al., 2017; Page & Hooijer, 2016). Many of these fires are linked to human activities, such as land clearing, drainage of peatlands for agriculture, and unsustainable land-use practices, although climatic factors like drought and El Niño events further amplify fire risk (Field et al., 2016). These interactions create feedback loops in which disturbed ecosystems become increasingly vulnerable to subsequent fires. Ecosystem degradation from fire events disrupts biodiversity, alters nutrient cycling, damages soil structure, and triggers long-term changes in vegetation composition. Meanwhile, the economic impacts often manifest in significant losses to agricultural yield, interruptions to forestry activities, and increased costs for fire suppression and rehabilitation (Schmidt et al., 2024; Kiely et al., 2019). Social implications are equally severe, with haze exposure causing public-health emergencies, school closures, reduced visibility for transportation, and heightened risks for vulnerable populations.

Kubu Raya Regency in West Kalimantan exemplifies regions facing chronic fire vulnerability due to its biophysical and socio-economic characteristics. Much of the regency is situated on deep peatland soils that have accumulated over thousands of years from slowly decomposing organic matter in water-saturated conditions (Xu et al., 2018; Page et al., 2011). These peatlands act as natural hydrological regulators, absorbing and storing water during the rainy season and slowly releasing it during dry periods. However, human interventions such as drainage canal construction, peatland clearing, and conversion to plantations increasingly disrupt this hydrological balance. As peat soils dry, they become highly flammable, and fires can burn underground for extended periods, making them extremely difficult to extinguish (Turetsky et al., 2015). During severe droughts, especially those associated with El Niño events, fire frequency and intensity in regions like Kubu Raya increase dramatically. Given these complex conditions, comprehensive assessment of burned areas and monitoring of fire severity are essential for informing effective environmental management strategies, restoration planning, and regulatory policy enforcement.

In recent years, remote sensing technologies have emerged as indispensable tools for detecting, monitoring, and analyzing forest and land fires across large landscapes. Their ability to capture spatially explicit data over broad areas and at repeated time intervals makes them valuable for both early warning and post-fire assessment (Bousquet et al., 2022). Satellite-based hotspot detection, commonly derived from sensors such as MODIS and VIIRS, provides rapid identification of thermal anomalies that signal potential fire activity (Giglio et al., 2016). While these hotspot datasets offer timely alerts, they do not always correspond perfectly with actual fire events due to limitations in resolution, atmospheric interference, and detection sensitivity. Therefore, integrating hotspot data with spectral indices derived from multispectral imagery offers a more robust method for identifying fire-impacted areas.

Spectral indices such as the Normalized Burn Ratio (NBR) are widely used to estimate fire severity by measuring reflectance differences before and after fire events. The NBR utilizes the near-infrared and shortwave-infrared bands to highlight vegetation loss and soil exposure, making it highly effective for mapping burned areas in both mineral soil and peatland environments (Key & Benson, 2006; Gaveau et al., 2021). Sentinel-2 imagery, with its high spatial resolution (10-20 meters) and frequent revisit time, provides significant

advantages for local to regional fire assessment, especially in dynamic tropical regions like Kalimantan. Using Google Earth Engine (GEE), Sentinel-2 data can be processed efficiently through cloud-based computation, enabling rapid and large-scale analysis of NBR and other fire-related indicators.

Meanwhile, manual digitization techniques in GIS remain widely used for detailed mapping of burned areas, especially when integrating local knowledge or validating satellite-derived outputs. Manual interpretation allows analysts to assess burned-area patterns based on visual cues, but it is more time-consuming and prone to subjective interpretation (Arisanty et al., 2022). Comparing automated NBR-based burned-area mapping from GEE with manually digitized results provides valuable insights into differences in spatial accuracy, operational efficiency, and representation of fire extent. Such comparative approaches help evaluate the applicability of automated remote-sensing workflows for regional fire monitoring and contribute to the refinement of methodologies for environmental management in Indonesia. Taken together, the application of remote sensing for fire assessment in Kubu Raya Regency offers an opportunity to better understand the spatial patterns and severity of fire disturbances, improve early-warning systems, and support more effective peatland management. Understanding the strengths and limitations of various mapping approaches can contribute to improved policy design, more effective restoration strategies, and stronger prevention measures to reduce future fire risks.

## 2. Methods

### 2.1 Study area

This research was conducted in October 2025 using secondary data derived from remote sensing in Kubu Raya District, West Kalimantan Province. Data processing and analysis were carried out at IPB University. Geographically, Kubu Raya District is located between coordinates 108°35' E – 109°58' E and 0°44' N – 1°01' S (Fig. 1). Climatologically, the region is influenced by a humid tropical climate characterized by high rainfall throughout the year; however, it still exhibits clear seasonal variation between wet and dry periods. These seasonal fluctuations strongly shape fire dynamics, particularly during peak dry months when vegetation and peat layers experience substantial moisture loss, increasing their susceptibility to ignition (Page et al., 2011). In addition, the presence of major river systems such as the Kapuas River and the Rasau River affects the hydrological conditions of the surrounding wetland ecosystems, including the stability of the peat water table, which plays a crucial role in reducing fire potential (Kettridge et al., 2015; Evans et al., 2019).

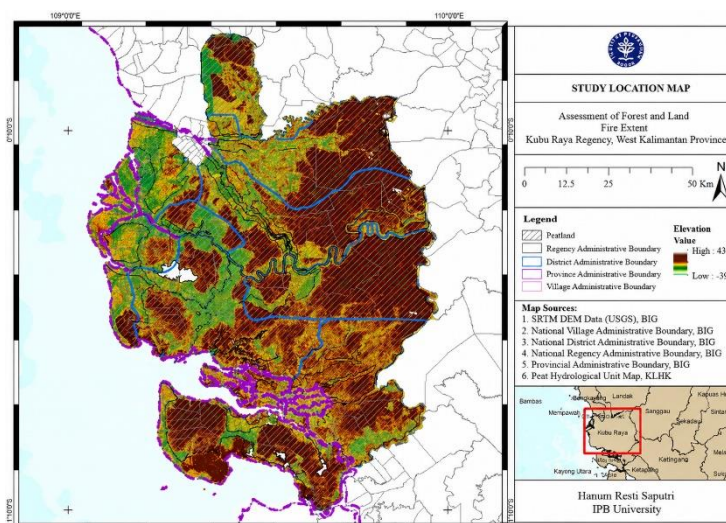


Fig. 1. Research location

## 2.2 Specific methods and techniques

The first stage of data collection involved downloading hotspot data in Kubu Raya District from 2019 to 2023. Hotspot data served as an initial reference for image analysis, used to determine the fire occurrence period and the appropriate time range for satellite imagery acquisition. The hotspot data also acted as an indicator of forest and land fire events for fire detection purposes. In this study, hotspot data were obtained from NASA's FIRMS MODIS. FIRMS (Fire Information for Resource Management System) is a system developed by the National Aeronautics and Space Administration (NASA) to monitor and map global forest fires. FIRMS provides real-time information on hotspot locations, intensity, spatial distribution, and estimated burned areas worldwide (Muin & Rakuasa, 2023). The FIRMS MODIS data were accessed via the NASA website and imported into ArcGIS for further processing.

The second stage of data collection involved downloading administrative boundary data for Kubu Raya District and Indonesia. The Kubu Raya boundary data were used to define the spatial limits of the study area, ensuring that the analysis focused solely on the target region. The administrative boundary data of Indonesia were used to define official territorial divisions, thereby facilitating policy interpretation related to forest and land fires.

The third stage involved downloading Sentinel-2 imagery. Sentinel-2 is one of the primary satellites used in remote sensing, equipped with a multispectral instrument (MSI) offering spatial resolutions of 10 m, 20 m, and 60 m. This imagery is widely used for land-cover monitoring applications, including vegetation, soil, and water studies, as well as hydrological networks and coastal areas. Sentinel-2's main objective is global land monitoring, providing full Earth surface coverage every 10 days with one satellite or every 5 days using both Sentinel-2A and Sentinel-2B satellites (Julianto et al., 2020). Sentinel-2 imagery was used as the primary dataset for index analysis to determine forest and land fire severity levels.

Data processing began with the preparation of hotspot data for Kubu Raya from 2019 to 2023. The hotspot data, originally in shapefile format from NASA's FIRMS MODIS, were converted into .xls format for processing in Microsoft Excel. The conversion was performed using the Conversion Tools → Table To Excel function in ArcGIS 10.3. The first stage of image processing involved creating false-color composite imagery using Sentinel-2 data. The composite was generated by combining three spectral bands arranged in additive RGB (red, green, blue) format SWIR (Band 11), NIR (Band 8), and Green (Band 3). The false-color composite was created from post-fire Sentinel-2 imagery using the Composite Bands tool in ArcGIS 10.3.

The second stage of image processing involved delineating burned areas through visual interpretation and manual digitization. Delineation was conducted by drawing polygon vectors along the pixel boundaries of suspected burned areas. Visual observation was performed by comparing the color change in the composite image from green (pre-fire vegetation) to reddish-brown (post-fire burned area). This interpretation was assisted by overlaying hotspot distribution data as an indicator of areas showing spectral changes. Manual digitization of burned areas was conducted for the 2019 dataset, which was then used to assess the accuracy of burned-area detection between GEE-based and manual methods.

The third stage involved creating pre-fire and post-fire index images to estimate burned areas. The index used was the Normalized Burn Ratio (NBR), a widely applied fire severity index. This process was carried out using the Google Earth Engine (GEE) platform, which facilitates efficient burned-area estimation. The analysis identified burned areas based on threshold (treshold) values that must be met for classification as fire-affected pixels. According to PPPJL (2015), a pixel is classified as a burned area if it satisfies the following criteria:

$$\text{Condition 1 : if } \text{NBR}_{\text{post } ij} \leq \alpha \text{NBR} \quad (\text{Eq. 1})$$

$$\text{Condition 2 : if } \Delta \text{NBR } ij \geq \beta \text{NBR} \quad (\text{Eq. 2})$$

Assuming a normal distribution, the selected threshold values area:

$$a\text{NBR} = \mu\text{NBR}_{\text{post}} + 2\sigma\text{NBR}_{\text{post}} \quad (\text{Eq. 3})$$

$$\beta\text{NBR} = \mu\Delta\text{NBR} - 2\sigma\Delta\text{NBR} \quad (\text{Eq. 4})$$

The second data analysis stage was the accuracy assessment of the index-based estimation. The fire-severity accuracy assessment was conducted by comparing burned-area extents derived from NBR analysis on GEE with those obtained through manual digitization in ArcGIS 10.3. Burned-area data from both visual interpretation (manual) and GEE analysis were used as reference datasets for index accuracy testing, which was performed directly within the GEE platform. The overall accuracy (OA) was calculated using Equation 5, while the kappa statistic (KS) was derived using Equation 6:

$$OA = \frac{1}{N} \sum_{i=1}^r X_{ii} \times 100\% \quad (\text{Eq. 5})$$

$$KS = \frac{\sum_{i=1}^r X_{ii}}{N} \times 100\% \quad (\text{Eq. 6})$$

### 3. Results and Discussion

#### 3.1 General condition of Kubu Raya regency

Kubu Raya Regency is one of the youngest administrative regions in West Kalimantan Province, with its capital located in Sungai Raya District. Geographically, the regency lies between 0°13'40.83'' to 1°00'53.09'' S and 109°02'19.32'' to 109°58'32.16'' E. The district was officially established on July 17, 2007, following the administrative division of Mempawah Regency (formerly Pontianak Regency). Kubu Raya has a total area of 859,178.27 hectares, making it one of the largest lowland regencies in the province. The regional physiography is generally characterized by flat topography with low elevation, which significantly influences the pattern of water accumulation, hydrological dynamics, and the spatial distribution of peatlands.

Based on land characteristics, Kubu Raya is dominated by peatland ecosystems, which cover 697,383.24 hectares or 81.17% of the total land area, while mineral soils (non-peatland) constitute only 161,795.03 hectares or 18.83% (Table 1). The large extent of peat deposits directly affects the region's ecological processes, land use patterns, and environmental vulnerability. Hydrologically, peatlands act as major water reservoirs that regulate local and regional water balance; however, they also present complex challenges for land development, fire management, and sustainable landscape governance. Because of this peatland predominance, Kubu Raya is categorized as one of the high-risk regions for peatland degradation and fire disasters in West Kalimantan.

Kubu Raya is also known as one of the regencies that frequently experiences forest and land fires, especially during prolonged dry seasons. This recurring vulnerability is closely linked to intensive water loss in peat soils during drought periods, which drastically reduces the water table and increases peat flammability (Jawad et al., 2015). Once peat becomes dry, even small ignition sources can trigger large-scale and long-lasting fires due to the subsurface smoldering combustion characteristic of peat. Such fires are not only difficult to extinguish but also release significant amounts of greenhouse gases and aerosols, affecting regional air quality and contributing to climate change.

Ecologically, peatlands are an ecosystem formed by the long-term accumulation of organic materials under anaerobic, water-saturated conditions (Xu et al., 2018). Indonesia holds one of the largest peatland extents in the world, estimated between 13 and 26.5 million hectares, predominantly distributed across Sumatra, Kalimantan, and Papua (Muhayah & Asyasyifa, 2021). These peatland systems provide vital environmental functions, including carbon storage, hydrological regulation, climate stabilization, and habitat provision for diverse flora and fauna (Antonius, 2016). However, their fragile and sponge-

like soil structure creates a paradoxical condition: peatlands function as effective water absorbers during the rainy season yet become extremely vulnerable when moisture levels decline during dry periods. This hydrological fluctuation highlights the intrinsic sensitivity of peatland landscapes and underscores the importance of sustainable water management to minimize fire risk and ecological degradation.

In summary, the biophysical characteristics of Kubu Raya dominated by extensive peat masses, flat lowland morphology, and fluctuating hydrological conditions establish the regency as a landscape with both high ecological value and high environmental risk. Understanding the spatial distribution and ecological dynamics of peatland areas is therefore critical for designing effective fire management strategies, land-use planning, and peatland restoration policies in the region.

Table 1. Extent of peatland and non-peatland areas

No	Land type	Area (ha)	Percentage (%)
1	Peatland	697,383.24	81.17
2	Non-Peatland	161,795.03	18.83
Total		859,178.27	100

### 3.2 Distribution of hotspots in Kubu Raya regency 2019-2023

The application of remote sensing in forest and land fire studies commonly utilizes hotspot detection as an initial indicator of fire occurrence. A hotspot refers to a location that exhibits a relatively higher surface temperature than its surrounding area, based on a predefined thermal threshold detected by satellite sensors (Simanjuntak & Khaira, 2021). Nevertheless, the presence of hotspots does not always directly confirm the occurrence of an actual fire event. Aflahah et al. (2019) emphasize that the likelihood of a forest or land fire can be inferred when hotspots appear in high numbers and exhibit spatial clustering within a specific region. To enhance the reliability of hotspot-based fire detection, each hotspot is equipped with a confidence level parameter, which provides an estimate of the probability that the detected thermal anomaly truly represents an active fire. This confidence parameter reflects the degree of certainty associated with the hotspot classification, whereby the greater the confidence value, the higher the likelihood that the hotspot corresponds to a real fire on the ground (Shofiana & Sitanggang, 2020; Simanjuntak & Khaira, 2021).

As shown in Table 2, the highest number of hotspots with high confidence values (80-100%) occurred in 2019, reaching 300 points. This notable concentration of high-confidence hotspots indicates that 2019 was the period with the most significant potential for actual fire incidents in Kubu Raya Regency. When evaluated across the five years (2019-2023), hotspot distribution was dominated by the moderate confidence category (30≤80%), with a total of 959 hotspots. Meanwhile, hotspots in the high confidence category accumulated to 490 points, and those in the low confidence category (0≤30%) totaled 126 points. Based on these classifications, hotspots with confidence levels of 80-100% represent high fire potential and therefore require field verification to confirm on-site fire conditions. Conversely, hotspots categorized within the 30≤80% range indicate medium fire potential and warrant continuous monitoring to prevent possible escalation into widespread fires.

Altogether, the spatial and temporal patterns of hotspot confidence levels recorded from 2019 to 2023 provide valuable insight into the dynamics of fire vulnerability in Kubu Raya Regency. The observed distribution highlights both the variability of fire risks over time and the need for adaptive monitoring strategies. Integrating hotspot confidence data with other environmental indicators such as peatland hydrology, land use patterns, and meteorological conditions could further enhance early-warning systems and improve the accuracy of fire prevention and mitigation planning. Therefore, the analysis of hotspot confidence levels not only supports situational awareness but also plays a strategic role in designing evidence-based policies for forest and land fire management in Kubu Raya Regency.

Table 2. Hotspot confidence level

No	Year	0≤30%	30-80%	80-100%	Total
1	2019	63	490	300	853
2	2020	5	32	5	42
3	2021	17	128	101	246
4	2022	5	49	9	63
5	2023	36	260	75	371
Total		126	959	490	1575

Note: \*Data up to November 2023

The spatial distribution of hotspots in Kubu Raya Regency during the 2019–2023 period was identified across two major land types, namely peatland and non-peatland (mineral soil) areas (Table 3). The results indicate a strong dominance of hotspots occurring on peatlands, with a total of 1,440 points, whereas hotspots detected on non-peatland areas accounted for only 135 points throughout the five-year observation period. This pattern demonstrates that peatlands represent the most fire-prone landscape in the region and play a major role in driving forest and land fire events in Kubu Raya Regency. In 2019, the number of peatland hotspots reached 756 points, the highest record during the study period, reflecting extreme fire conditions and high susceptibility to burning, particularly during prolonged dry seasons. Although there was a sharp decrease in 2020, with only 39 peatland hotspots detected, the number rose again in the subsequent years. The resurgence of peatland hotspots in 2021 (235 points) and especially in 2023 (348 points) suggests that peat ecosystems remain vulnerable to fire and can experience rapid escalation when climatic and land-use pressures coincide. In contrast, hotspots on non-peatland areas were consistently low each year, with values ranging only from 2 to 22 points, indicating that mineral soil areas exhibit significantly lower flammability compared to peatlands.

Table 3. Distribution of hotspots by land type (peatland and non-peatland)

No	Year	Peatland	Non-Peatland	Total
1	2019	756	95	851
2	2020	39	2	41
3	2021	235	10	245
4	2022	62	6	68
5	2023	348	22	370
Total		1440	135	1575

Note: \*Data up to November 2023

Peatlands are highly susceptible to fire due to their ecological characteristics, including thick organic soil layers that store vast amounts of carbon, low water retention during drought, and the ability to sustain smoldering combustion for prolonged periods, even below the surface. Once peat becomes dry, fires are extremely difficult to extinguish and can spread across large areas, particularly in degraded peatlands that have undergone drainage, land-clearing, or land-conversion processes. Therefore, the concentration of hotspots in peatland areas highlights the substantial fire risk associated with peatland ecosystems in Kubu Raya Regency. Overall, the distribution of hotspots by land type demonstrates that peatlands are the primary landscape contributing to forest and land fires in the region. These findings reinforce the importance of peatland-focused fire mitigation strategies, including peat rewetting, hydrological restoration, prevention of drainage canal expansion, and stricter control of land-clearing activities. Strengthening community-based fire surveillance and early-warning systems within peatland zones is also essential to reduce the frequency and scale of future fires. The dominance of peatland hotspots underscores the need for policy interventions that prioritize peatland conservation and sustainable land management to minimize fire risk in Kubu Raya Regency.

The distribution of hotspots was also analyzed based on administrative subdistricts. As presented in Table 4, a total of 1,575 hotspots were detected across 10 subdistricts in Kubu Raya Regency during the 2019–2023 period, with substantial variation observed from year to year. The subdistrict with the highest number of hotspots was Sungai Raya, recording 456 hotspots over five years. This subdistrict has the largest land area and population within the regency (Saharjo & Ramadhania, 2019). The high number of hotspots in Sungai Raya is strongly associated with its extensive peatland coverage, which increases its susceptibility to fire, particularly during dry-season conditions when peat moisture decreases significantly. In contrast, Pontianak Utara recorded the lowest number of hotspots, with zero occurrences throughout the entire study period. This can be explained by the very limited extent of peatland within the subdistrict, resulting in lower fire risk and fewer land-use activities that may lead to ignition. The absence of peatland also suggests minimal community-driven land clearing practices that typically contribute to hotspot formation in other areas. Beyond peat distribution, the spatial variation of hotspots across subdistricts is influenced by a combination of environmental and climatic factors, including rainfall, solar radiation, air humidity, and seasonal weather dynamics. Anthropogenic activities such as land clearing practices further contribute to the fluctuating hotspot patterns observed over the five-year period. Overall, the data in Table 4 demonstrates that hotspot distribution in Kubu Raya Regency is shaped by the interaction between biophysical characteristics, climatic conditions, and human activities between 2019 and 2023.

Table 4. Distribution of hotspots by subdistrict

No	District	Year					Total
		2019	2020	2021	2022	2023	
1	Batu Ampar	285	7	5	1	39	339
2	Kuala Mandor	23	0	6	7	8	44
3	Kubu	119	1	36	2	3	161
4	Pontianak Utara	0	0	0	0	0	0
5	Rasau Jaya	41	5	65	20	31	165
6	Sungai Ambawan	18	2	6	2	9	37
7	Sungai Kakap	65	15	44	16	42	182
8	Sungai Raya	158	1	76	6	215	456
9	Teluk Pakedai	4	0	0	0	1	5
10	Tarentang	137	11	5	15	23	191
	Total	852	42	246	69	371	1575

### 3.3 Spatiotemporal condition of hotspots in Kubu Raya regency from 2019-2023

The spatiotemporal analysis of hotspot distribution based on FIRMS MODIS imagery revealed that in 2019, more than 800 hotspot points were detected in Kubu Raya Regency, with a distinct clustering pattern in specific areas. As illustrated in Figure 2, the highest concentration of hotspots was predominantly located in the central and southern parts of the regency, which are mainly characterized by land cover types such as plantations, shrublands, and degraded peatlands. These landscape types are ecologically vulnerable to fire, particularly when peat layers experience excessive drying during the dry season. This finding is consistent with Asyrowi et al. (2021), who emphasized that the occurrence of hotspots is strongly influenced by land function, land cover, land use, and soil characteristics, where peatlands and monoculture plantations represent landscape typologies with a high susceptibility to fire events. In addition to these biophysical drivers, climatic factors also played a crucial role in intensifying hotspot occurrences in 2019. A strong El Niño event during this period caused significant reductions in rainfall and prolonged drought conditions, which in turn accelerated peat desiccation and increased the accumulation of surface fuel loads (Aflahah et al., 2019). The interaction between extreme climatic conditions and vulnerable ecological landscapes ultimately led to a substantial rise in forest and land fire incidents, reflected in the dramatic increase in detected hotspot

counts throughout the year. Therefore, 2019 can be categorized as the most critical period in the last decade in relation to forest and land fire occurrence in Kubu Raya Regency, due to the strong synergy between biophysical and climatic factors.

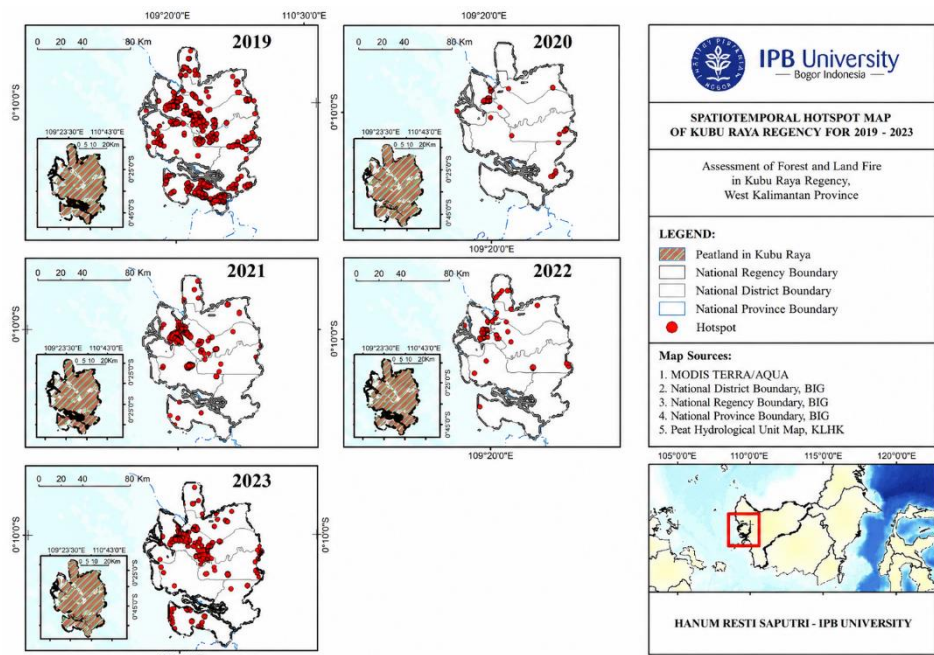


Fig.2. Spatiotemporal hotspots distribution

### 3.4 Burn area metode GEE dan digitasi tahun 2019-2023

Burned area refers to land surface that has undergone fire events originating from either natural processes or human activities, whether intentional or accidental. Before the burning occurred, these lands were generally covered by vegetation which, after combustion, transformed into degraded post-fire surfaces (Ramadhi, 2021). Thus, burned area reflects the actual fire-affected zones on the ground and serves as an essential indicator for assessing the extent and impact of forest and land fires within a specific region (Suwarsono et al., 2013). Based on the spatiotemporal distribution illustrated in Figure 3, the extent of burned areas in Kubu Raya Regency varied considerably across the five year period. In 2019, burned areas reached 6,146.01 ha, marking the beginning of a substantial fire episode. Although the highest number of hotspots was recorded in 2019, the spatial extent of burned areas continued to escalate the following year. In 2020, the burned area increased drastically to 15,565.82 ha, indicating that dry climatic conditions and land-use pressures allowed fires to propagate over larger land surfaces compared to the previous year. However, the burned area dropped significantly in 2021, covering only 4,908.47 ha, revealing a temporary reduction in fire spread, likely influenced by wetter climatic conditions, improved mitigation efforts, or a combination of both.

In 2022, burned areas increased again to 6,169.25 ha, reflecting a resurgence of fire events and showing that the region remained vulnerable to recurring fire episodes. The most notable spatial expansion occurred in 2023, with the burned area reaching 832,188.98 ha by far the largest extent recorded during the study period. This substantial escalation signifies an extreme fire event and highlights the severity of fire propagation in 2023, surpassing previous years by a remarkable margin. The pronounced expansion of burned areas suggests that ecological vulnerability and anthropogenic pressures such as peatland drainage, land clearing, and agricultural expansion may have contributed to widespread landscape flammability. The temporal pattern of burned areas underscores the persistent risk of fire throughout the study period, characterized by strong interannual variability and recurring escalation. The spatial distribution shown in Figure 3 indicates that burned areas

are not only large in magnitude, but also tend to concentrate in particular land clusters predominantly peat-dominated landscapes which are highly susceptible to ignition and long-lasting combustion.

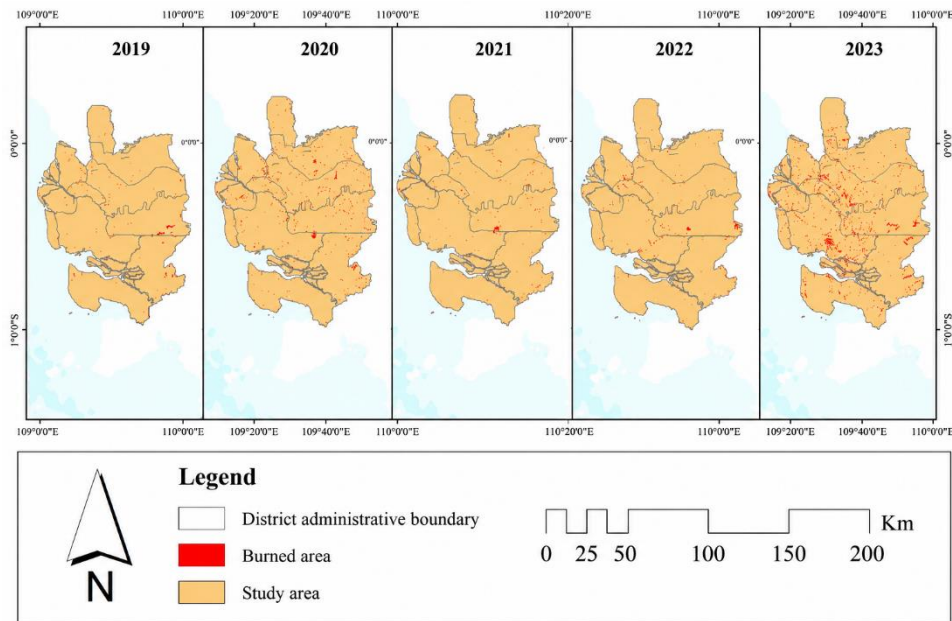


Fig 3. Spatiotemporal map of burned areas

The comparison between the Google Earth Engine (GEE) burn area detection and manual digitization, as illustrated in Figure 4, demonstrates significant differences in the delineation of burned areas in Kubu Raya District for the 2019 fire event. The GEE-based approach produced a more extensive and continuous burn area polygon, visualized in bright red and bounded by a clear outline. This result aligns closely with the dark-toned regions in the Sentinel-2 composite (bands 11-8-3), which are characteristic of post-fire surfaces due to the strong absorption in the near-infrared wavelength and increased reflectance in the shortwave infrared band. In contrast, the manual digitization method produced a noticeably smaller burn area polygon, with boundaries that did not fully capture the spatial distribution of fire-affected land. This difference suggests that manual interpretation is limited by the interpreter's ability to consistently recognize subtle visual cues such as tone, texture, and spatial association within complex landscapes.

The greater delineation accuracy observed in the GEE output indicates the advantages of automated or semi-automated approaches for burn area detection. Automated spectral-based processing can detect heterogeneous burn patterns—including mixed or partially burned zones that are commonly overlooked in manual digitization due to visual ambiguity. Additionally, the use of multiple spectral indices and thresholding techniques in GEE enhances the objectivity and reproducibility of burn area mapping. Meanwhile, the subjectivity of manual digitization introduces variability, which may reduce the consistency of results, especially in areas with overlapping fire scars and residual vegetation. Overall, the findings highlight that GEE provides a more reliable and systematic method for identifying burned areas compared to manual digitization. This is especially valuable in large and heterogeneous environments such as peatlands, where fire effects can vary greatly in intensity and spatial pattern. The improved accuracy and interpretability of GEE-derived outputs underline the importance of integrating automated remote sensing tools in fire monitoring and post-fire assessment workflows.

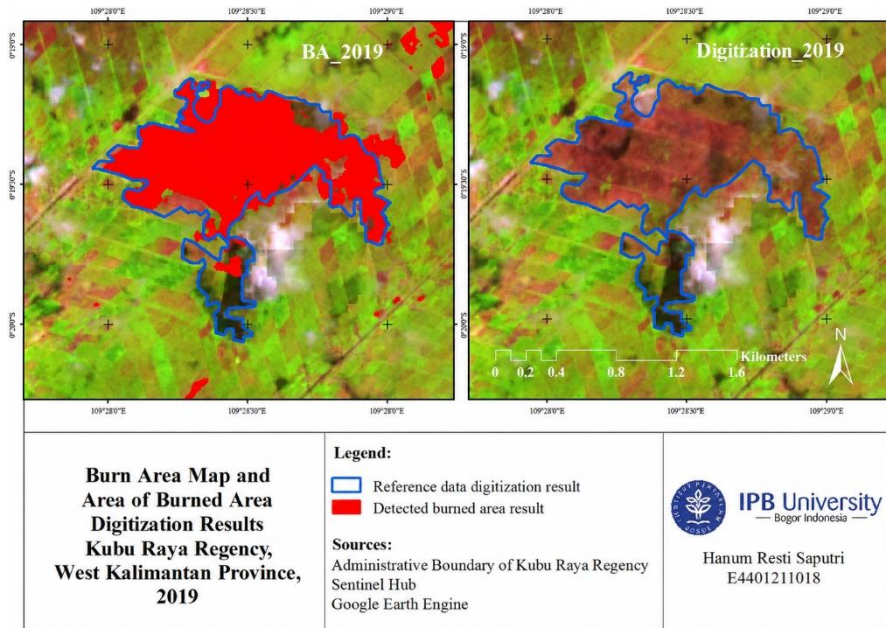


Fig 4. Burn area maps derived from GEE and manual digitization methods

### 3.5 Accuracy assessment of burn area using GEE and manual digitization methods in 2019

Remote sensing data are generated through interactions among various system components, including sensors, recording devices, and processing algorithms, each of which introduces specific characteristics and potential sources of error (Ramadhi, 2021). Therefore, an essential step in burned area analysis is the execution of an accuracy assessment to ensure the reliability and validity of the detection results. In this study, the accuracy assessment was conducted to evaluate the level of agreement between the classified burned areas and actual ground conditions. The assessment involved the computation of overall accuracy (%) and the kappa statistic as indicators of classification performance. A total of 100 validation points were employed, consisting of 50 points representing burned areas and 50 points representing non-burned areas. These validation points were cross-checked with the classification outputs to obtain the accuracy metrics. The entire accuracy assessment was performed using the Google Earth Engine (GEE) platform to maintain analytical consistency and computational efficiency.

Based on the accuracy assessment, the burned area classification generated using the Google Earth Engine (GEE) method demonstrated a higher level of accuracy compared to manual digitization. The results yielded an overall accuracy of 86% and a kappa statistic of 74%, indicating a strong level of agreement between the classification results and the reference data. The OA value of 86% reflects a high level of classification correctness, as values above 80% are generally considered reliable in remote sensing-based burned area mapping, where spectral variability and heterogeneous surface conditions often pose challenges. Meanwhile, the kappa value of 74% falls within the category of substantial agreement, demonstrating that the classification accuracy is not merely due to chance but represents a stable and robust detection performance. This is particularly important in post-fire environments, where mixed vegetation, varying soil moisture, and partial burn patterns frequently complicate the interpretation of satellite imagery. Overall, the combination of an 86% OA and a 74% kappa statistic underscores the strong performance of the GEE-based burned area classification. Compared to manual digitization, the GEE approach offers greater objectivity, consistency, and efficiency, making it more suitable for large-scale analyses such as peatland fire assessments in Kubu Raya Regency.

## 4. Conclusions

The distribution of hotspots in Kubu Raya Regency was relatively high. In 2019, the confidence level of 80-100% was categorized as high, with a total of 300 hotspot points. Meanwhile, over the five-year period (2019-2023), most hotspots were found within the 30-<80% confidence range, totaling 959 points. A higher confidence level indicates a greater likelihood that the detected hotspot truly represents an actual forest or land fire on the ground. The year 2023 recorded the largest burned area, covering approximately 832,188.98 ha. The burn area map for 2019 shows that the area delineated using the Google Earth Engine (GEE) method appeared more distinct and accurate compared to the manual digitization approach. An accuracy assessment was conducted to evaluate the reliability of the burn area detection process. Based on the analysis, the GEE-derived burn area demonstrated higher accuracy than the digitized method, with an overall accuracy of 86% and a kappa statistic of 74%. These findings confirm that the GEE-based approach provides a more reliable and efficient tool for mapping burned areas and assessing fire severity in peatland regions.

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## Author Contribution

H.R.S conceptualized the study, wrote, reviewed, and edited the article.

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The author declares no conflict of interest.

## Declaration of Generative AI Use

During the preparation of this work, the authors used Grammarly to assist in improving grammar, clarity, and academic tone of the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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