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Technical Study on Tin Mining Land Openings to Determine Post-Mining Reclamation Strategies

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Abstract

Background: Post-mining land reclamation is a crucial component of sustainable mining practices aimed at restoring degraded land to its original condition or to a new, ecologically functional state. In the Kemingking area, extensive illegal alluvial tin mining has significantly reduced reclamation effectiveness and increased the risk of long-term environmental degradation. Inadequate spatial documentation of land disturbances has further complicated the formulation of effective reclamation strategies.
Objective: This study aims to spatially analyze land openings resulting from both legal and illegal alluvial tin mining activities as a technical basis for formulating effective post-mining reclamation strategies.
Method: The research employed a multitemporal remote sensing approach using satellite imagery from 2004 to 2022 combined with UAV-based photogrammetry conducted between 2022 and 2024. Geographic Information System (GIS) analysis was applied to identify land-clearing dynamics, delineate pit boundaries, and evaluate surface morphology changes over time.
Result: The results demonstrate that medium-to-high-resolution UAV imagery (0.5–1 m) is more effective than satellite imagery in identifying land-clearing features, pit geometry, and surface morphology. Historical patterns of illegal land clearing from 2004 to 2019 were successfully mapped as baseline disturbance data. As of 31 December 2024, mapped land openings covered 44.79 ha of illegal mining areas and 110.32 ha of legal mining areas.
Conclusion: Effective reclamation planning for alluvial tin mining areas requires integration of UAV-derived data and multitemporal GIS analysis. This approach provides essential technical inputs for landform reconstruction, pit reconfiguration, and material estimation for land regrading, thereby strengthening post-mining reclamation strategies.

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INTRODUCTION

Monitoring land clearing in metallic mineral mining areas is a strategic issue in sustainable mining management, particularly in areas with a history of illegal mining. Indonesia's history of tin mining, which lasted from the 17th century to the regional autonomy era, has affected land conditions, particularly on the islands of Bangka, Belitung, and Singkep (Hadi et al., 2025). Uncontrolled conventional mining (TI) activities have caused significant land degradation, including the formation of unrecoverable pits (Nurtjahya & Fournita Agustina, 2015). This study focuses on the identification, classification, and differentiation of legal and illegal mining openings for alluvial tin commodities in the Kemingking area using multitemporal satellite imagery analysis and drone photogrammetry data. The research problem is based on the discrepancy between land clearing realization and forest area utilization regulations and the need for reclamation planning based on precise spatial data (Hendrychová et al., 2020).

Satellite imagery, in the discipline of remote sensing, is a visual representation of the Earth's surface or other geospatial phenomena recorded by sensors placed on orbiting satellite platforms (Chuvieco, 2020). Satellite imagery can be used to monitor land-use changes in areas affected by mining activities, where these changes often have significant impacts on local ecosystems (Rizaldi et al., 2022). The accuracy achieved is directly proportional to the spatial resolution of the information contained in aerial photographs, which is more accurate than satellite-based imagery data. The integration of Geographic Information Systems (GIS) and land cover classification standards is positioned as a technical-analytical approach to assess land remediation readiness, support reclamation planning, and strengthen the basis for evidence-based decision-making in post-mining technical aspects (Basu & Mishra, 2023);(Hendrychová et al., 2020).

The observable biophysical cover on the earth's surface is a result of human arrangement, activity, and treatment carried out on certain types of land cover to carry out production activities. Changes or maintenance on the land cover is the definition of land cover according to the National Standardization Agency 2020. Land cover classes in the category of vegetation-dominant areas are derived from a conceptual approach to consistent physiognomic structures of plant form, cover form, plant height, and spatial distribution; while in the category of non-vegetation-dominant areas, class details refer to aspects of the surface of the cover, distribution or density, and height or depth of the object.

Holders of IUP and IUPK Production Operations are required to carry out reclamation and post-mining according to Article 2 Paragraph (2) of Government Regulation (PP) of the Republic of Indonesia Number 78 of 2010. Reclamation is an action carried out during the mining process to organize, restore, and improve the quality of the ecosystem and environment so that it can function again according to its intended use.

Mining reclamation is a crucial process for restoring the function and condition of land after mining. Mining activities often cause environmental damage, including changes in landforms, loss of vegetation, and decreased soil quality (Chamid et al., 2020);(Putra et al., 2017). Therefore, reclamation is crucial to avoid further negative impacts on the environment and surrounding communities (Etdria et al., 2022);(Ismail, 2021);(Prassetia & Isniarno, 2023);(Hadi et al., 2025). In this context, reclamation is considered a necessary effort to return land to its original form or useful function according to its intended use (Prassetia & Isniarno, 2023);(Fitrawan et al., 2021);(Kivinen, 2017). Post-mining land use strategies should consider sustainable development principles, integrating natural habitats and landscape functions into reclamation planning (Mborah et al., 2016);(Hendrychová et al., 2020);(Putra et al., 2017). Various reclamation models have been developed and implemented globally, including engineering concepts for abandoned alluvial tin mines and soil-based reclamation strategies using appropriate vegetation (Chamid et al., 2020);(Anda et al., 2022);(Wyrzykowska & Janiszek, 2025). The socio-economic impacts of tin mining and the importance of proper closure planning must also be considered in developing comprehensive post-mining land management strategies (Nurtjahya & Fournita Agustina, 2015);(Hadi et al., 2025).

The study area is located within a mining permit area in Kemingking Village, Sungaiselan District, Central Bangka Regency, Bangka Belitung Islands Province, covering an area of 654.6 hectares. Geographically, it lies at coordinates 2°28'22.06" South Latitude and 106°11'52.35" East Longitude, extending to 2°29'22.06" South Latitude and 106°12'32.48" East Longitude. The area is classified as a Production Forest (*Hutan Produksi*, HP) area and has received a Forest Area Borrow-to-Use Permit as per the Decree of the Minister of Forestry of the Republic of Indonesia in 2025. This approval allows for the use of 328.56 hectares for tin ore production operations and supporting facilities in Central Bangka Regency. Access to the mining area is possible by air or sea, with a flight from Jakarta (CGK) to Depati Amir Airport (PGK) taking approximately 1 hour 15 minutes. From Pangkalpinang City, land transportation is required, with the travel time to the research site in Kemingking Village spanning approximately 1 hour 20 minutes, covering a distance of about 55.6 km.

METHOD

This research methodology explains the stages systematically passed in the process of identifying and differentiating legal and illegal mining land openings and developing a reclamation planning concept for former alluvial tin mining land in the Kemingking area using a spatial-descriptive analysis approach based on multitemporal data.

The research phase began with an in-depth literature review of national regulations, land cover classification standards, good mining practice principles, and reclamation and post-mining technical guidelines, which served as the conceptual basis for determining technical parameters. Data collection was conducted through the compilation of secondary data in the form of satellite imagery from 2004–2021 and drone/UAV-based aerial photography from 2022–2024. This was then reinforced with the acquisition of supporting primary data from drone recordings in 2025 for field validation.

The image pre-processing stage includes geometric correction before interpretation, delineation, and cropping of the Area of Interest (AOI). The Object-Based Image Analysis (OBIA) stage is the process of segmenting and analyzing objects based on their spatial, spectral, and temporal scale characteristics, resulting in image objects or segments that are then used for classification (Wang et al., 2004);(Blaschke, 2010), as cited in (Hao et al., 2021). The next stage, namely the classification of land cover and openings, is carried out using a supervised classification method based on physiognomic and spectral characteristics of the cover, to distinguish dominant vegetation classes, water bodies, open land, and mining areas. The classification results are analyzed spatially through overlays with official permit boundary maps (IUP and PPKH) and permanent production forest area maps (HPT) to detect areas outside the permit agreement as a spatial representation of illegal mining activities.

RESULTS AND DISCUSSION

Result

Illegal Land Clearing Activities from 2004 to 2019

The extent of existing or illegal land clearing in the study area can be identified through satellite image analysis from 2004 to 2019 (Table 1). Land cover in the study area, based on satellite image maps from 2004, 2006, 2008, 2010, 2011, and 2015–2019, is generally classified as secondary swamp forest, swamp scrub, and water bodies. Analysis could not be conducted in 2005, 2007, and 2009 due to the lack of imagery. The 2006 imagery was only partially available, thus limiting the study to the western part of the study area.

Mining activity began to be recorded in 2013 in the south-southwest, before the legality of the 2019 Mining Business Permit, thus categorizing it as illegal mining with 0.08 ha of disturbed land outside the forest area permit boundary. From 2014–2016, illegal mining expanded rapidly in areas within the forest area, increasing from 0.81 ha to 3.35 ha (2014); 7.85 ha (2015); and 47.11 ha (2016). Disturbed land outside the permit boundary also expanded to 10.46 ha (2016) and reached a peak of 24.94 ha (2017).

In 2017, the mining area appeared to shrink from 47.11 ha to 34.15 ha due to rising surface water and tailings inundation recorded as water bodies (65.7 ha) due to high rainfall. The development of illegal mining peaked again in 2018 at 73.89 ha, then decreased in 2019 to 57.73 ha. Mining land inundation increased again and was recorded as water bodies up to 96.47 ha in 2019. Throughout 2014–2019, land disturbance by illegal mining without permits continued to increase and at the end of the period was recorded at around 34 ha, spread across the south–southwest, central, and north–northeast–west of the study area. Overall, the 2013–2019 period showed a strong trend of expansion and fluctuation in illegal mining areas influenced by data availability, surface hydrological dynamics, and satellite imagery recording resolution.

Realization of Legal Land Openings in 2020-2024

Mining Business Permit (*IUP*) holders in the research area received approval for the transfer of the Production Operation *IUP* from the holding company on December 17, 2019, then obtained approval for the extension of the *IUP* for the metal mineral production operation stage on November 7, 2024. Mining operational activities began after obtaining approval for the 2020 Work Plan and Budget (*RKAB*) on July 10, 2020, with the scope including construction and infrastructure development, mining, sales, environmental management and monitoring, mining safety, and community development and empowerment. Mining activities in 2020 were legal because the Production Operation *IUP* had been previously established on December 19, 2019.

Land clearing dynamics analysis was conducted using satellite imagery for the 2020–2024 period, with classification referring to SNI 7645-1:2014 (Table 2). The interpretation results show fluctuations in the mining area in the forest use area, namely decreasing in 2020 from 57.73 ha to 36.20 ha, then expanding again in 2021 to 58.69 ha, in 2022 decreasing in 2023 to 40.57 ha, and then expanding again in 2024 to 51.74 ha.

The land cover component in the form of open land representing mining supporting infrastructure also gradually increased from 0.46 ha in 2020 to 1.48 ha in 2024. Meanwhile, the area of disturbance due to illegal mining/mining without permits located outside the *IUP* boundaries and forest areas showed a downward trend based on imagery results from 34.18 ha in 2019 to 31.37 ha in 2023–2024. However, this decrease does not fully indicate permanent recovery because it is strongly influenced by external factors, especially high rainfall that causes tailings sand material to be inundated so that it is recorded as a body of water in the imagery, or inactive mining areas that undergo revegetation and produce a spectral response resembling shrubs or swamp bushes. Thus, the dynamics of the area of mining land clearings in forest areas tend to reflect the phase of operational activity, while changes around illegal mining in satellite imagery more represent temporary changes in the spectral response due to inundation or partial revegetation, not always indicating permanent ecological recovery.

Land Cover Classification

The physical characteristics of the research area in 2004–2024 based on satellite image interpretation using land cover class classification at a scale of 1:50,000/1:25,000 SNI 7645-1:2014 consist of secondary swamp forest, scrub swamp, water bodies, and mining, which can be described as follows:

1. Secondary swamp/peat forests are forests that grow and develop in wetland habitats, including brackish and peat swamps. Wetland areas have unique characteristics: low elevation, seasonal areas located far from the coast, peat, and, for the most part, the enclosed areas have experienced human intervention.
2. Swamp scrub: vegetation formation or structure in the form of a collection of shrubs with a height of between 50 cm to 2 m, which is dominated by woody vegetation, interspersed with very short trees with a height of more than 5 m. Or: wetland areas that have been overgrown with various heterogeneous and homogeneous natural vegetation with a sparse to dense density level. The area is dominated by low (natural) vegetation. Shrubs in Indonesia are usually former forest areas and usually no longer show traces of logging spots. Swamp scrub in SNI 7645-1:2014 does not exist; the description above is a class of shrub land cover that distinguishes only between dry and wet land conditions. In the research area, the physical characteristics of the description are the same as shrubs only in wetlands, so the shrub class is modified to swamp shrubs.
3. Water bodies: all naturally formed water bodies other than shallow sea waters, deep sea waters, natural lakes/ponds, inland swamps, vegetated coastal swamps, non-vegetated coastal swamps, and rivers. Water bodies in SNI 7645-1:2014 are referred to as Other Water Bodies (not specified).
4. Mining: open land excavated for mining activities that are not included in the descriptions of existing classes. Mining in SNI 7645-1:2014 is referred to as Other Open Mining.
5. Open land: not included in the land cover classification of SNI 7645-1:2014. The open land referred to in the research area is land that has been cleared by humans for the construction of facilities and infrastructure.

Table 1. Recapitulation of land cover classification and area 2004 – 2019

Land cover	**Year**												
	2004	**2006**	**2008**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Secondary swamp forest (Hrs)													
Area (ha)	303.46	300.42	290.8	287.22	287.22	326.84	319.23	320.9	312.62	224.83	224.57	187.58	172.17
Percentage	92.36%	91.44%	88.51%	87.42%	87.42%	99.48%	97.16%	97.67%	95.15%	68.43%	68.35%	57.09%	52.40%
Swamp thicket (Br)													
Area (ha)	22.80	25.84	13.52	38.92	38.92	0.00	6.28	0.13	0.80	15.07	4.14	4.46	2.20
Percentage	6.94%	7.86%	4.11%	11.85%	11.85%	0.00%	1.91%	0.04%	0.24%	4.59%	1.26%	1.36%	0.67%
Illegal mining (Pb)													
Area (ha)	0	0	0	0	0	0	0.81	3.35	7.85	47.11	34.15	73.89	57.73
Percentage	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.25%	1.02%	2.39%	14.34%	10.39%	22.49%	17.57%
Water body (A)													
Area (ha)	2.30	2.30	24.24	2.42	2.42	1.72	2.24	4.18	7.29	41.55	65.70	62.63	96.47
Percentage	0.70%	0.70%	7.38%	0.74%	0.74%	0.52%	0.68%	1.27%	2.22%	12.65%	20.00%	19.06%	29.36%
Total area (Ha)	328.56	328.56	328.56	328.56	328.56	328.56	328.56	328.56	328.56	328.56	328.56	328.56	328.57
Percentage	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 1 shows the changes in land cover classification from 2004 to 2019 in the research area. During this period, secondary swamp forest remained the dominant land cover, although its percentage decreased from 92.36% in 2004 to 52.40% in 2019. Meanwhile, swamp scrubland showed a significant decline, with the identified area shrinking drastically, reaching the lowest percentage of 0.67% in 2019. A significant increase was observed in illegal mining activities, which were first recorded in 2013, rising sharply to 17.57% by 2019. Additionally, water bodies fluctuated considerably, peaking at 29.36% in 2019, likely due to mining activities and other ecosystem changes.

Table 2. Recapitulation of land cover classification and area 2020 - 2024

Land cover	Year				
	2020	2021	2022	2023	2024
Secondary swamp forest (Hrs)					
Area (ha)	189.99	170.19	182.41	197.56	184.75
Percentage	57.83%	51.80%	55.52%	60.13%	56.23%
Swamp thicket (Br)					
Area (ha)	2.26	6.36	16.68	24.02	5.38
Percentage	0.69%	1.94%	5.08%	7.31%	1.64%
Mining (Pb)					
Area (ha)	36.2	51.68	58.69	40.57	51.74
Percentage	11.02%	15.73%	17.86%	12.35%	15.75%
Water body (A)					
Area (ha)	100.11	99.87	70.26	65.17	85.22
Percentage	30.47%	30.40%	21.38%	19.83%	25.94%
Open land (T)					
Area (ha)	0.00	0.46	0.52	1.25	1.48
Percentage	0.00%	0.14%	0.16%	0.38%	0.45%
Total area (Ha)	328.56	328.56	328.56	328.56	328.56
Presentation	100%	100%	100%	100%	100%

Table 2 illustrates the land cover classification from 2020 to 2024, showing significant changes in land use patterns in the research area. Secondary swamp forest continued to decline, although it still covered 56.23% of the total area in 2024. Swamp scrub land exhibited considerable fluctuation, reaching 7.31% in 2023 before dropping to 1.64% in 2024. Mining activities continued to expand, covering 15.75% in 2024, a notable increase compared to 11.02% in 2020. Water bodies decreased from 30.47% in 2020 to 25.94% in 2024, while open land began to appear, though it only accounted for 0.45% of the total area in 2024, reflecting the impact of infrastructure and mining expansion in the area.

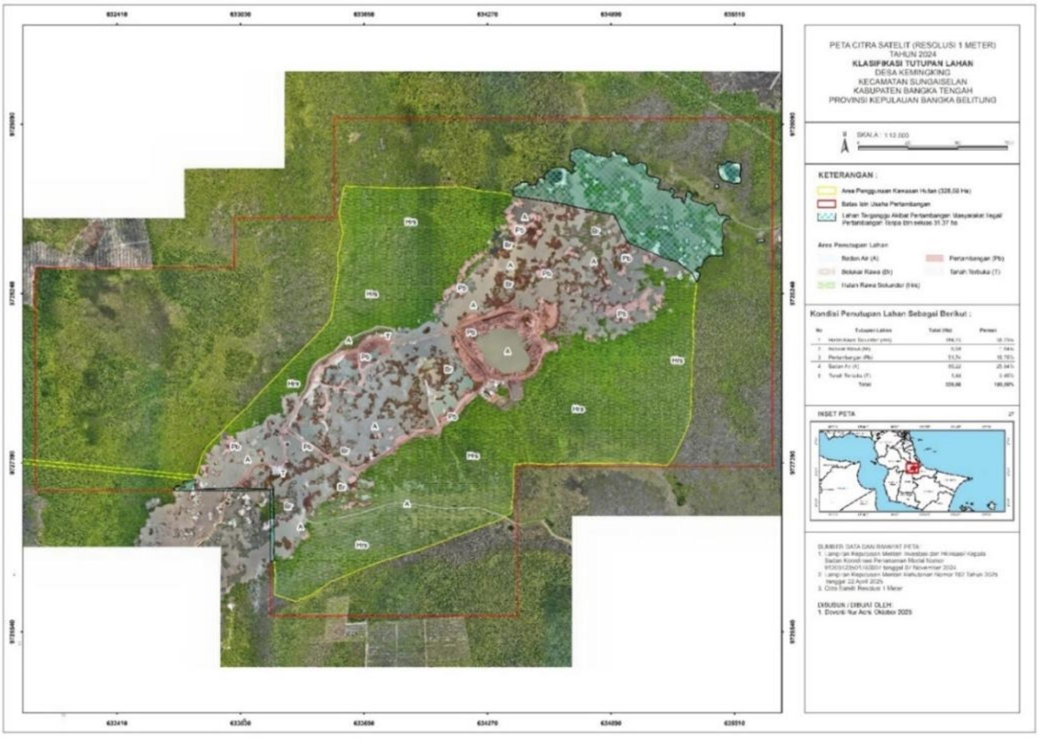

Figure 1. Land cover classification based on drone data in 2024

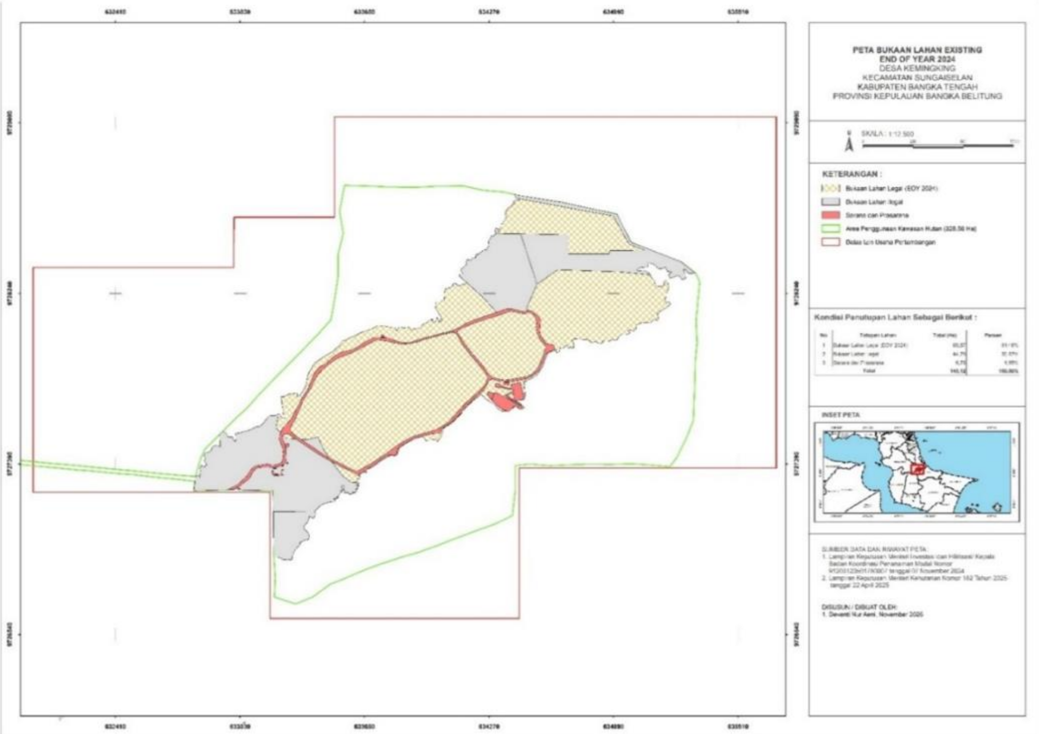

Figure 2. *Existing* land openings as of December 31, 2024

6. The 44.79 hectares of illegal mining land were not cleared by the company. These land clearings were used by the community for illegal mining in previous years, but conditions have now improved, and there are no illegal community mines within the Mining Business Permit area of the study area.

Table 3. Recapitulation of legal and illegal mining openings in the research area

No	Description	Land clearing realization in 2024
Illegal mining land openings		**44.79**
1	Land for Active Mining (ha)	93,570
2	OB/cover rock piles in former mines (backfilling) (ha)	0,000
3	OB/overburden pile outside the mine pit (ha)	0,000
4	Topsoil stockpile (ha)	0,000
5	Commodity Stockpile (Ore Stockpile) (ha)	0,000
6	Mine Roads & Access Roads (ha)	5,300
7	Sediment pond/erosion control (ha)	1,170
8	Supporting Facilities	
	a. Water Channels/Ditches (ha)	0,000
	b. Workshop and Support (ha)	0.017
	c. Temporary B3 Waste Warehouse (ha)	0.004
	d. Employee Mess (ha)	0.037
	e. Security Post (ha)	0.008
	f. Production Office (ha)	0.012
	g. Logistics and Concentrate Warehouse	0.008
	h. Nursery/Seedling Area (ha)	0.028
	i. Processing Area (ha)	0.152
	j. Employee Parking	0.008
	k. BBC Tank	0.003
	Subtotal Supporting Facilities	0.278
	Total	**145,108**

Table 3 presents data on the land clearing realization for mining activities in 2024, including areas used for illegal mining land openings. The total land area for all activities amounts to 145,108 hectares. The table categorizes the land usage into several types, such as active mining land (93,570 ha), backfilling of former mines (0 ha), and various supporting facilities like water channels, workshops, temporary hazardous waste storage, and employee parking. Additionally, the table includes land for erosion control (1,170 ha) and mining/access roads (5,300 ha), showing the distribution of land for different operational activities within the mining site.

Realization of Legal Land Opening in 2025

Based on the UAV photogrammetry map taken at the end of October 2025, the interpretation of land use in the forest area in the research area includes a development area of 178.75 ha, active mining openings of 139.34 ha, and a total of 10.5 ha of supporting facilities.

A summary of known mine openings as of December 31, 2024, will serve as a reference for developing annual reclamation plans based on the mine's lifespan during the production operations phase and a three-year post-mining reclamation plan. Priority reclamation areas and locations are determined based on the production plan and mining progress, which are evaluated monthly and annually during the production period.

Reclamation will be applied to former mining areas and overburden stockpiles, except for supporting facility areas such as employee canteens, production offices, employee *messes*, nursery areas, security posts, warehouses, workshops, generator houses, water channels/ditches, temporary storage warehouses for B3 waste, and processing areas (washing plants). Supporting facility areas will undergo reclamation and revegetation processes in the post-mining program for 3 years.

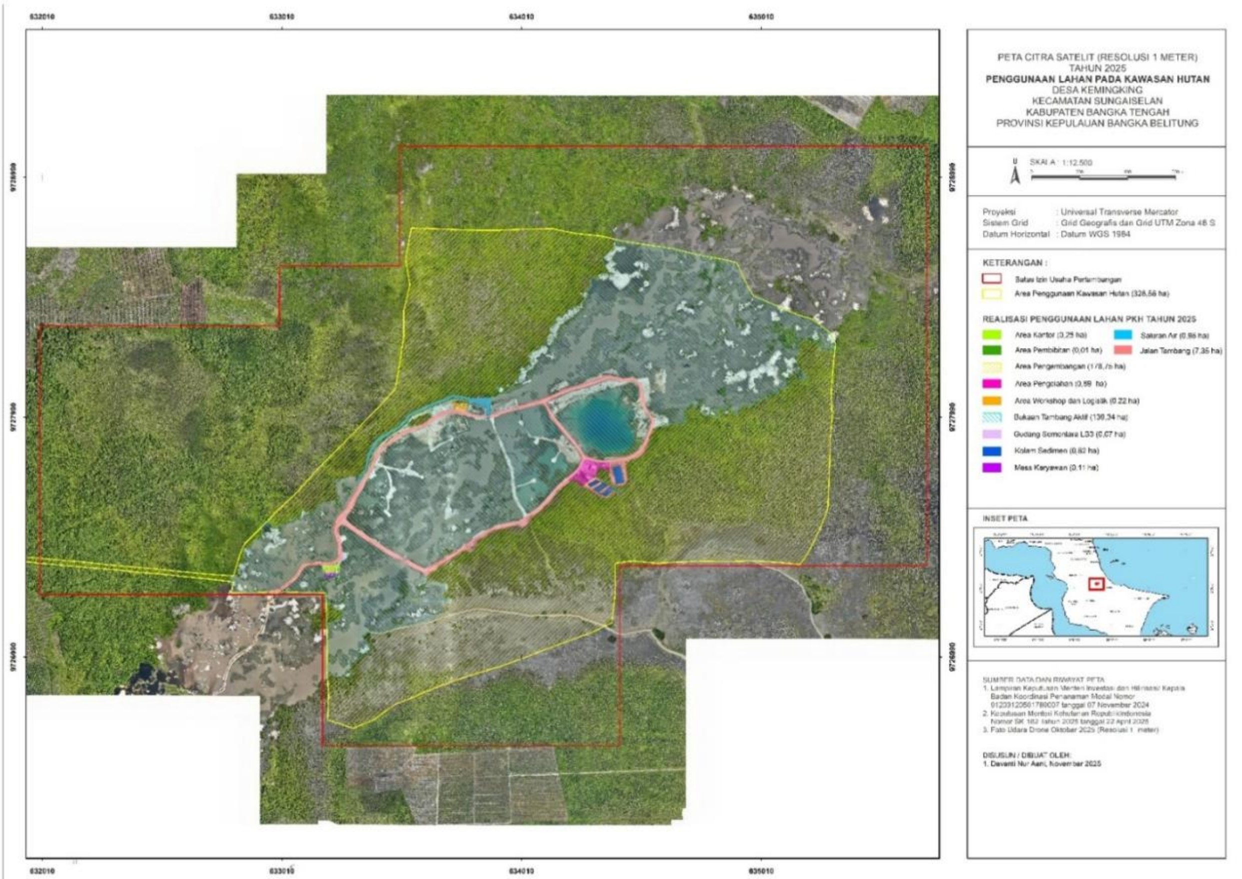

Figure 3. Land use in forest areas as of October 2025

Discussion

The results from the satellite image analysis and land cover classification over the years reveal significant changes in the land use and illegal mining activities in the study area. Between 2004 and 2019, illegal mining land cover fluctuated significantly, peaking in 2018 at 73.89 ha, driven by factors such as insufficient monitoring and legal oversight. This expansion aligns with the findings of previous studies Asuamah (2023) that point to the rapid growth of illegal mining due to weak enforcement of regulations and growing demand for mineral resources. The peak in illegal mining observed in 2018 was followed by a slight decline in 2019, likely due to the combined effect of natural factors such as rainfall causing inundation, as well as governmental efforts to curb illegal activities. This fluctuating trend suggests that the dynamics of land use in the mining sector are not only driven by regulatory factors but also by external environmental influences, as highlighted in prior research (Zhang et al., 2022). Moreover, the rise in water bodies (96.47 ha in 2019) could be linked to increased mining tailings and runoff, indicating an ongoing challenge in managing the environmental impact of mining activities.

In the period from 2020 to 2024, legal mining activities under the Mining Business Permit (*IUP*) began to dominate the land use in the area, with a steady expansion in the mining area reaching 51.74 ha by 2024. While this shift marks a transition from illegal to legal mining, the persistence of illegal mining, albeit at a lower level (31.37 ha in 2023–2024), highlights the continued challenges in achieving full compliance with mining regulations. The fluctuations observed in the mining areas, especially the decrease in 2023, suggest that operational activities, such as the monitoring of tailings and water management, significantly affect land clearing patterns. As noted in previous studies Prassetia (2023); Fitrawan (2021), reclamation and revegetation efforts are vital in mitigating the environmental damage caused by mining. The gradual increase in open land (0.45% in 2024) and the associated rise in mining infrastructure development reflect ongoing efforts to support mining operations while addressing environmental concerns through strategic land use. However, the need for consistent monitoring, annual evaluations, and adaptive reclamation strategies, as outlined in this study, remains critical in ensuring the long-term sustainability of mining operations and the restoration of affected ecosystems. These findings support the broader theoretical implications of sustainable mining practices, emphasizing the necessity for integrated monitoring systems and adaptive management frameworks in the mining sector (Etdria et al., 2022).

CONCLUSION

Differences in the area of legal and illegal land clearing for alluvial tin mining permits in the Kemingking area based on satellite image interpretation show natural conditions from 2004 to 2012 with land cover classifications in the form of secondary swamp forest, swamp scrub, and water bodies. In 2013 to 2019, illegal activities in the form of conventional mining were found and the physical conditions included secondary swamp forest, swamp scrub, water bodies, and illegal mining. From 2020 to the present, mining activities were carried out legally. Recapitulation of land clearing until the end of 2024 was an area of 44.79 ha of illegal mining land clearing and an area of 100.318 ha of legal mining openings. Land use in forest areas as of 2025 in the research area includes a development area of 178.75 ha, active mining openings of 139.34 ha, and a total of 10.5 ha of supporting facilities. Based on the recapitulation of land openings up to 2024 and the use of existing land in 2025, it can be used as a reference for preparing a reclamation plan at the production and post-mining operations stage with a total land area that must be reclaimed of 145.108 hectares.

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AUTHOR CONTRIBUTION STATEMENT

Deventi Nur Aeni contributed to the conceptualization of the research, formulation of objectives, and development of the methodological framework. She conducted data collection, including multitemporal satellite imagery analysis and UAV photogrammetry, performed spatial data processing and GIS-based analysis, interpreted the results, and drafted the original manuscript. She was also responsible for visualization, data validation, and integration of findings into post-mining reclamation strategies.

Harmin Sulistiyaning Titah contributed to research supervision, methodological validation, and critical review of the analytical approach. He provided guidance on environmental management perspectives, interpretation of reclamation implications, and substantially revised the manuscript through critical review and editing to enhance scientific rigor and coherence.

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