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Legal Analysis of Marine Space Utilization for Tin Mining Based on Total Suspended Solids at Rebo Beach, Bangka

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Abstract
Tin mining on Rebo Beach, Bangka Regency, has triggered conflicts over marine space use and caused significant degradation of the coastal ecosystem. This unauthorized tin mining (PETI) encroaches on an area legally designated for marine tourism development under Bangka Belitung Islands Provincial Regulation No. 3 of 2020. This study was conducted to analyze spatial use inconsistencies and measure their impact on coral reef degradation. The method used is an interdisciplinary normative-empirical approach that integrates legal approaches (Statute, Case, and Conceptual Approaches) with oceanographic analysis (Spatial Evidence Approach), based on spatiotemporal satellite data and field surveys, as scientific evidence of the impacts of tin mining on Rebo Beach. The research results indicate multidimensional inconsistencies in marine spatial use,

encompassing spatial function, zoning, legality, and ecological aspects due to the absence of a Marine Spatial Planning Permit (KKPRL), Mining Business License (IUP), and Environmental Impact Assessment (AMDAL). Sedimentation from mining tailings has driven TSS levels to 63 mg/L in 2024, exceeding the 20 mg/L threshold for coral reef waters under Government Regulation No. 22 of 2021. Monsoon dynamics trap suspended sediments in the nearshore zone, reducing light penetration and contributing to coral mortality in 2024. Addressing coastal degradation requires strengthening ecosystem-based marine spatial planning through KKPRL review, technology-based spatial monitoring, diversification of the blue economy, strict law enforcement, and environmental restoration obligations.

KEYWORDS
Tin Mining, Marine Areas, Coral Reefs, Total Suspended Solids, Spatial Planning.

Introduction

Coastal and marine areas are strategic spaces that underpin sustainable development through their interrelated ecological, economic, and social functions. Coastal ecosystems, such as coral reefs, seagrass beds, and mangroves, not only serve as habitats for various marine species but also support fisheries productivity, coastal protection, carbon sequestration, and the development of marine tourism. On the other hand, coastal areas are also used for various economic activities, including mineral mining. The increasing intensity of marine space utilization heightens the potential for conflicts among users if not balanced by a well-planned and sustainable management system. This situation calls for a marine spatial planning system capable of harmonizing the interests of natural resource utilization with the protection of ecological functions.In the context of Indonesian law, this principle is rooted in Article 33, paragraph (3) of the 1945 Constitution of the Republic of Indonesia ("1945 Constitution"), which affirms that the state controls the Earth, water, and the natural resources contained therein and shall be utilized to the greatest extent possible for the prosperity of the people.[1] This constitutional mandate implies that the use

[1] Undang-Undang Dasar Negara Republik Indonesia Tahun 1945, Pasal 33 ayat (3).

of maritime space must be carried out in accordance with the principles of sustainability, legal certainty, and environmental protection.

The urgency of managing these marine areas is not only a concern within national legal systems but has also emerged as a global agenda in international maritime governance. Increasing pressure on marine ecosystems due to the exploitation of natural resources, pollution, climate change, and the loss of biodiversity has prompted the international community to establish more integrated mechanisms for marine protection. One significant development is the adoption of the Agreement on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ Agreement),which emphasizes the importance of integrated marine space management by integrating legal, scientific, and environmental protection aspects.[2] This agreement demonstrates that modern ocean governance is no longer focused solely on the exploitation of natural resources, but also on a country's ability to ensure the sustainability of the ocean's ecological functions through an ecosystem-based management approach. Thus, the protection of marine areas is a key prerequisite for achieving sustainable development and implementing the Sustainable Development Goals (SDGs), particularly Goal 14 (Life Below Water).[3]

These principles of marine governance were subsequently incorporated into the Indonesian legal system through various instruments for coastal zone management. Law No. 27 of 2007 on the Management of Coastal Zones and Small Islands as, amended by Law No. 1 of 2014 ("**Law No. 1/2014**"), which is subsequently implemented through the Zoning Plan

[2] Kristina M. Gjerde et al., "Getting Beyond Yes: Fast-Tracking Implementation of the United Nations Agreement for Marine Biodiversity Beyond National Jurisdiction," *npj Ocean Sustainability* 1, no. 6 (2022): 1–12, https://doi.org/10.1038/s44183-022-00006-2.

[3] United Nations, "The 17 Goals," *Sustainable Development Goals*, diakses 23 Juli 2026. https://sdgs.un.org/goals.

for Coastal Areas and Small Islands ("**RZWP3K**").[4] The RZWP3K serves as the basis for the allocation of marine space based on ecological, social, and economic characteristics, ensuring that all activities involving the use of marine space align with the designated functions of the area. In addition to serving as the basis for issuing the Marine Spatial Utilization Activity Compliance Certificate **("KKPRL")**, the RZWP3K also functions as an instrument for controlling spatial utilization, resolving intersectoral conflicts, and protecting areas of high ecological value. Therefore, any form of marine spatial use that does not conform to the established zoning has the potential to cause conflicts over spatial use while simultaneously reducing the effectiveness of coastal ecosystem protection.

The urgency of implementing marine spatial planning instruments in Indonesia is increasing due to the country's vast mineral potential, particularly tin. According to Fitch Solutions, Indonesia produced approximately 83,000 metric tons of tin in 2021, equivalent to 26% of global tin production, making it the world's second-largest tin producer. In the same year, the United States Geological Survey (USGS) estimated Indonesia's tin reserves at approximately 800,000 metric tons. Approximately 91% of these reserves are located in Bangka Belitung Islands Province, which also accounts for about 90% of the country's tin production[5]. This dominance is reflected in the existence of 482 Mining Business Permits (IUP) covering an area of 862,761 hectares, making the mining sector one of the main drivers of the regional economy. The high concentration of mineral reserves and mining activities makes the Bangka

[4] Undang-undang (UU) Nomor 1 Tahun 2014 tentang Perubahan atas Undang-Undang Nomor 27 Tahun 2007 Tentang Pengelolaan Wilayah Pesisir dan Pulau-Pulau Kecil.

[5] Kementerian Sekretariat Negara Republik Indonesia, "Saatnya Hilirisasi Produk Timah," Indonesia.go.id, 14 Februari 2022, diakses 23 Juli 2026, https://indonesia.go.id/kategori/editorial/6050/saatnya-hilirisasi-produk-timah.

Belitung Islands Province a region that holds a strategic position in supporting national mineral security.[6]

The magnitude of this economic potential has driven an increase in mining activity, both legal and through unlicensed tin mining (**"PETI"**). According to 2018 data from the Bangka Belitung Islands Provincial Government, there are an estimated 18,000 illegal mining sites scattered across both land and water areas. On the other hand, the mining sector contributed approximately 50% to Local Own-Source Revenue (**"PAD"**) in 2023, meaning that efforts to crack down on PETI are often caught in a dilemma between economic interests and environmental protection.[7] As a result, mining activities continue unabated, including in coastal areas designated for specific land-use functions. These conditions have a significant impact on the environment. According to data from the Regional Planning Agency of the Bangka Belitung Islands Province, approximately 124,838 hectares of land have been damaged by tin mining, along with degradation of forest areas, critical lands, and coastal ecosystems such as mangroves, seagrass beds, and coral reefs.This fact demonstrates that mining activities are not merely a matter of mineral resource utilization but also of environmental governance and the appropriate use of marine space.[8]

One of the most significant ecological impacts of offshore tin mining is the increase in Total Suspended Solids ("TSS") concentrations resulting from seabed dredging and sediment resuspension. In the long term, suspended sediments will settle on coral surfaces, inhibiting colony growth, reducing live coral cover, and ultimately degrading coral reef ecosystems.

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[6] Kompas, "Tambang Timah Bangka Belitung: Sejarah, Dampak, dan Asa untuk Masa Depan," diakses 18 Juli 2026, https://jeo.kompas.com/tambang-timah-bangka-belitung-sejarah-dampak-dan-asa-untuk-masa-depan

[7] Imanuel La Antragi, Yanti Tesalonika Situmaeng, Suci Arinda, dan Aditya Aulia Rochim, "Penegakan Hukum Pertambangan Timah Ilegal Pasca Kasus Korupsi Tata Niaga Timah di Bangka Belitung," *BULLET: Jurnal Multidisiplin Ilmu* 3, no. 2 (2024): 184–191, https://journal.mediapublikasi.id/index.php/bullet/article/view/4206/2718.

[8] La Antragi et al., "Penegakan Hukum Pertambangan Timah Ilegal," 185.

Therefore, TSS is not only an indicator of water quality but also scientific evidence explaining the relationship between mining activities and the degradation of coastal ecosystems.

The relationship between rising TSS concentrations and the degradation of coastal ecosystems is clearly evident at Rebo Beach in Bangka Regency. As an area that serves both as a community fishing ground and a coastal tourist destination, Rebo Beach has experienced a decline in environmental quality due to tin mining activities in the surrounding waters, which have triggered sedimentation, altered the characteristics of the seabed, and reduced both fishery productivity and the area's appeal to tourists. These conditions have sparked a prolonged conflict between fishermen and mining operators since the mid-1990s[9]. From a legal perspective, this situation conflicts with Bangka Belitung Islands Province Regional Regulation No. 3 of 2020 ("Babel Regional Regulation No. 3/2020") on the RZWP3K, which designates Rebo Beach as a Coastal/Beach Nature Tourism Subzone. In contrast, mineral mining activities are permitted only in specific water areas in Sungailiat. Thus, mining activities at Rebo Beach not only cause ecological and socioeconomic impacts but also demonstrate a mismatch between the use of marine space and applicable spatial planning policies.[10]

Various previous studies have examined the relationship between water quality, marine ecosystem degradation, and the socioeconomic dynamics of coastal communities resulting from anthropogenic activities and mining. In the context of water quality monitoring, a study by Adjovu et al. (2023) demonstrates the use of remote sensing technology to monitor

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[9] H. Purnaweni, Kismartini, B. Prabawani, D. P. Rahayu, dan A. Putra, "Conflict of Fishermen vs Tin Miners in Rebo Beach, Bangka Island: Dispute in the Sungailiat Special Economic Zone," *AIP Conference Proceedings* 3001 (2024): 080036, https://doi.org/10.1063/5.0184251

[10] *Provinsi Kepulauan Bangka Belitung, Peraturan Daerah Provinsi Kepulauan Bangka Belitung Nomor 3 Tahun 2020 tentang Rencana Zonasi Wilayah Pesisir dan Pulau-Pulau Kecil Provinsi Kepulauan Bangka Belitung Tahun 2020–2040, Lampiran II, "Rencana Alokasi Ruang Wilayah Pesisir dan Pulau-Pulau Kecil Provinsi Kepulauan Bangka Belitung," diakses melalui* https://peraturan.bpk.go.id/Details/156383/perda-prov-bangka-belitung-no-3-tahun-2020

changes in TSS concentrations.[11] Aprilianti, Yusuf, and Wulandari (2023) found that unconventional tin mining increases TSS and nitrate concentrations to the point of causing moderate water pollution.[12] In line with this, Syari (2016) reports that mining-induced sedimentation has resulted in up to 100% coral reef mortality at several locations.[13] Meanwhile, Purnaweni et al. (2024) and Apriansyah et al. (2025) found that damage to coastal ecosystems also contributes to conflicts over the use of marine space between fishermen and mining operators.[14] Nevertheless, these studies still examine environmental, social, and legal aspects only in part. Therefore, this study offers a novel approach by integrating a legal analysis of marine spatial planning and mining permits with a spatiotemporal analysis of the relationship between TSS and coral reef degradation to identify inconsistencies in marine spatial use along Rebo Beach, Bangka Regency, and to provide a basis for developing evidence-based policy.

Based on the above discussion, this study aims to analyze the use of marine space resulting from tin mining at Rebo Beach in accordance with spatial planning and permitting regulations, through the lens of Spatial Planning Theory, which views spatial planning as a legal instrument for the planned allocation of land uses, the prevention of conflicts over land use, and the realization of sustainable development. This study also examines the relationship between TSS and coral reef degradation as an ecological

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[11] Godson Ebenezer Adjovu, Haroon Stephen, David James, and Sajjad Ahmad, "Measurement of Total Dissolved Solids and Total Suspended Solids in Water Systems: A Review of the Issues, Conventional, and Remote Sensing Techniques," *Remote Sensing* 15, no. 14 (2023): 3534, https://doi.org/10.3390/rs15143534.

[12] Wadiya Aprilianti, Muh. Yusuf, dan Sri Yulina Wulandari, "Analisis Total Padatan Tersuspensi (TSS) dan Nitrat (NO3-N), serta Penentuan Indeks Pencemaran di Perairan Pantai Rebo, Kabupaten Bangka," *Indonesian Journal of Oceanography* 5, no. 4 (2023): 230–238, https://doi.org/10.14710/ijoce.v5i4.16846.

[13] Indra Ambalika Syari, "Kondisi Terumbu Karang di Perairan Rebo Sungailiat Bangka Akibat Pertambangan Timah," *Akuatik: Jurnal Sumberdaya Perairan* 10, no. 1 (2016): 13–20, https://journal.ubb.ac.id/index.php/akuatik/article/view/327

[14] H. Purnaweni, Kismartini, B. Prabawani, D. P. Rahayu, dan A. Putra, "Conflict of Fishermen vs Tin Miners in Rebo Beach, Bangka Island: Dispute in the Sungailiat Special Economic Zone," *AIP Conference Proceedings* 3001 (2024): 080036, https://doi.org/10.1063/5.0184251;

consequence of mining activities. It places this scientific evidence within the framework of the Precautionary Principle to strengthen environmental control and protection. The research findings are expected to contribute to the development of marine spatial planning law, strengthen the scientific basis for environmental law enforcement, and serve as recommendations for the formulation of coastal zone management policies aligned with the principles of sustainable development and the Blue Economy.

Methods

This study is a normative-empirical legal study employing an interdisciplinary approach integrating law and oceanography. The normative approach is used to examine the compliance of offshore tin mining activities with legal regulations concerning mineral and coal mining, marine spatial planning, coastal zone management, and environmental protection. Meanwhile, the empirical approach uses spatiotemporal data from remote sensing and field surveys to provide scientific evidence to identify the environmental impacts of offshore tin mining on the coastal area of Rebo Beach.

The research approaches used include: the Statute Approach, to analyze the alignment and implementation of laws and regulations regarding mining, marine spatial planning, and the environment; the Case Approach, to examine offshore tin mining practices at Rebo Beach as a case study of unlicensed mining and non-compliance with marine spatial planning; and the Conceptual Approach, to analyze the concepts of marine spatial planning, coastal governance, sustainable development, and coastal ecosystem protection. Spatial-Evidence Approach, an interdisciplinary approach that uses spatiotemporal evidence in the form of changes in TSS concentration, wind dynamics, and changes in coral reef cover to strengthen legal analysis regarding the appropriateness of marine spatial planning. In this study, spatial data is used as scientific evidence to evaluate the effectiveness of implementing legal norms, rather than as the primary object of analysis.

The study was conducted in the waters off Rebo Beach, on the eastern coast of Bangka Island, Bangka Belitung Islands Province, which borders the Natuna Sea to the north and the Karimata Strait to the east.

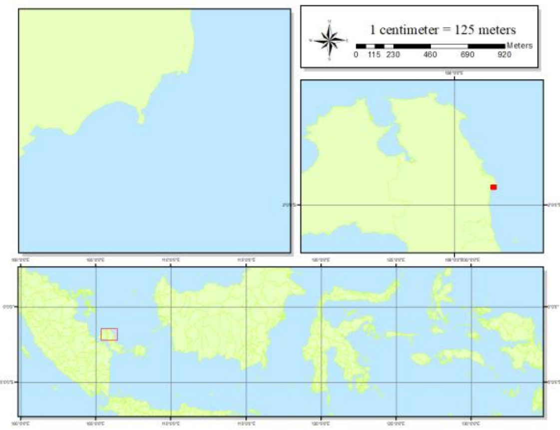

Figure 1. Research Study Area

The study employed a multitemporal approach with data acquisition periods tailored to each parameter. Field surveys were conducted in July 2026. Coral reef cover analysis was performed by comparing images from 2016 and 2024, while TSS analysis covered temporal trends from 2016 to 2024 and spatial distribution in 2024. Surface wind data from January and August 2024 were used to represent the peaks of the West and East Monsoons, respectively, to examine the circulation patterns that affect sediment transport. All of this data was then integrated to analyze the relationship between oceanographic dynamics and coral reef degradation in the waters off Rebo Beach. The types of data used in the study are presented in Table 1.

Table 1. Research Data

No	Data	Source	Description
1.	Wind	ECMWF (*European Center for Medium-Range Weather Forecasts*).	ERA5 Global Climate Reanalysis Data
2.	*Total Suspended Solid* (TSS)	*Copernicus Open Access Hub* dan *Google Earth Engine*	Sentinel-2 Level-2A Image
3.	Coral Reef	*USGS Earth Explorer*	Landsat-8 satellite data

Surface wind data were processed using Surfer software to calculate wind speed magnitudes and visualized as vector maps to identify the direction of air mass movement, the potential for the formation of wind-driven currents, and coastal currents that play a role in sediment transport in the waters off Rebo Beach. Next, spatial processing of TSS was performed using SNAP (Sentinel Application Platform) software, beginning with the separation of water bodies using the Modified Normalized Difference Water Index (MNDWI) (Xu, 2006), where *Green* represents Band 3, and *SWIR1* represents Band 11 in Sentinel-2 imagery, through the equation[15]:

$$MNDWI = \frac{Green - SWIR\,1}{Green + SWIR\,1} \tag{1}$$

Surface turbidity levels were then qualitatively mapped using the Normalized Difference Turbidity Index (NDTI), which utilizes the spectral

[15] H. Xu, "Modification of Normalized Difference Water Index (NDWI) to Enhance Open Water Features in Remotely Sensed Imagery," *International Journal of Remote Sensing* 27, no. 14 (2006): 3026, https://doi.org/10.1080/01431160600589179.

ratio of Band 3 (*green*) to Band 4 (*red*) (Lacaux *et al.*, 2007) via the equation[16] ,

$$NDTI = \frac{B3-B4}{B3+B4} \quad (2)$$

Next, the TSS concentration was quantitatively calculated using the empirical algorithm of Liu et al. (2017) based on Band 7 (SWIR2) for water pixels with an NDWI threshold > 0.1, as given by the equation.[17] :

$$TSS = 2{,}950 \times B7^{1{,}357} \quad (3)$$

A temporal analysis of TSS concentrations for the 2019–2024 period was conducted using the Google Earth Engine (GEE) platform. Data were obtained by processing a collection of cloud-free Sentinel-2 images, extracted using the annual-average spatial reducer function, at the study's sample points. TSS values were extracted using a linear algorithm based on red-band reflectance, integrated with the NDWI index to eliminate land features. All processed data were then integrated into the QGIS software for map visualization and layout.

Coral reef cover mapping was processed using SAGA GIS, QGIS, and ArcGIS. The processing steps included radiometric correction, land and cloud separation, and correction for water depth effects using the Lyzenga algorithm through the calculation of attenuation coefficients[18]:

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[16] Jean-Paul Lacaux, Yves M. Tourre, Christian Vignolles, Jean-Alfred Ndione, and Mireille Lafaye, "Classification of Ponds from High-Spatial Resolution Remote Sensing: Application to Rift Valley Fever Epidemics in Senegal," *Remote Sensing of Environment* 106, no. 1 (2007): 66–74, https://doi.org/10.1016/j.rse.2006.07.012

[17] H. Liu, Q. Li, T. Shi, S. Hu, G. Wu, and Q. Zhou, "Application of Sentinel-2 MSI Images to Retrieve Suspended Particulate Matter Concentrations in Poyang Lake," *Remote Sensing* 9, no. 7 (2017): 761, https://doi.org/10.3390/rs9070761

[18] David R. Lyzenga, "Remote Sensing of Bottom Reflectance and Water Attenuation Parameters in Shallow Water Using Aircraft and Landsat Data," *International Journal of Remote Sensing* 2, no. 1 (1981): 71–82, https://doi.org/10.1080/01431168108948342.

$$a = \frac{var(band2) - var(band3)}{2 + covar(band2,band3)} \tag{4}$$

$$(\frac{k_i}{k_j}) = a + \sqrt{a^2 + 1} \tag{5}$$

This coefficient is then used to calculate the Depth Invariant Index (DII) using the equation:

$$Y = \ln(g1) + (\frac{k_i}{k_j}) * \ln(g2) \tag{6}$$

The results of the Depth Invariant Index were then classified using the K-Means Clustering method to distinguish the classes of seabed cover, and subsequently interpreted visually to obtain information on the distribution and changes in coral reef cover in the waters off Rebo Beach. Data analysis techniques were conducted in an integrated manner through legal-normative, descriptive-qualitative, quantitative, and environmental-legal correlative analyses. All analysis results were then integrated to assess the relationships among increases in TSS, coral reef degradation, and the suitability of marine spatial use, using the RZWP3K as the basis for formulating recommendations for sustainable spatial planning and coastal zone management.

Result and Discussion

1. Use of Marine Space in Unlicensed Tin Mining Activities at Rebo Beach

The utilization of marine space is an integral part of the national spatial planning system, which aims to allocate each marine area in accordance with its ecological, social, and economic characteristics so that its use proceeds in an orderly and sustainable manner and provides legal certainty. From a legal perspective, marine spatial planning serves not only as an instrument for development planning but also as the basis for regulating land use, issuing permits, resolving conflicts among land users, and protecting environmental functions. Andreas Faludi, in his book "*The Planning Environment: A Theory of Planning*," explains that spatial planning is a policy instrument that guides the allocation of land uses based on regional characteristics to avoid conflicts over land use and achieve sustainable development. In the context of coastal areas, this theory positions the RZWP3K as a legal instrument that determines the compliance of every marine spatial use activity. Therefore, the analysis of tin mining activities at Rebo Beach was conducted by assessing their compliance with the spatial functions established in the zoning policy.[19]

In the Bangka Belitung Islands Province, the use of marine space is regulated under Provincial Regulation No. 3 of 2020. This regulation implements Article 9 paragraph (5) of Law No. 1 of 2014, which designates the Coastal and Small Islands Zoning Plan (RZWP3K) as an instrument for marine spatial planning, a basis for determining spatial allocations, and a guideline for monitoring and controlling the use of marine space. Consequently, all activities involving the use of marine space, including mining, must comply with the spatial functions established in the zoning plan.

In the context of Rebo Beach, inconsistencies in the use of marine space can be identified by comparing the spatial functions designated in the RZWP3K with the actual conditions on the ground. Based on Appendix II of Regional Regulation No. 3 of 2020, Rebo Beach is designated as part of the Coastal/Beach and Small Islands Nature Tourism Subzone (KPU-W-P3K-016) along with Matras Beach, Rambak, Uber Bay, Tanjung Pesona, Tanjung Tikus, Tanjung Ratu, Batu Bedaun Island, and other coastal areas.[20] This designation indicates that land-use planning in the Rebo Beach

[19] Faludi, Andreas. *The Planning Environment: A Theory of Planning*. Oxford: Pergamon Press, 1973.

[20] Peraturan Daerah Provinsi Kepulauan Bangka Belitung Nomor 3 Tahun 2020 tentang RZWP3K Tahun 2020–2040.

area is oriented toward supporting coastal tourism development that prioritizes preserving the coastal landscape, water quality, and the sustainability of marine ecosystems as the area's primary attractions. This designation indicates that land-use planning in the Rebo Beach area is oriented toward supporting coastal tourism development that prioritizes preserving the coastal landscape, water quality, and the sustainability of marine ecosystems as the area's primary attractions.

Figure 2. in Mining Pontoon Vessels in the Waters off Rebo Beach (Source: Author's Documentation, 2026)

However, the actual findings of the survey reveal deviations from the planned land-use functions. In areas designated as coastal tourism zones, tin mining is carried out using small- to medium-scale pontoons and suction rafts operating in coastal waters. These activities are carried out without the required legal documentation, such as an IUP, KKPRL, or AMDAL. This phenomenon is not an isolated case. WALHI Bangka Belitung has documented at least 298 offshore IUPs spread across nearly the entire coastal region of Bangka and Belitung Islands, covering an area of 595,381 hectares, which demonstrates the high pressure that mining activities are exerting on the marine environment.[21] This situation also shows that mining

[21] Wahana Lingkungan Hidup Indonesia (WALHI). "RZWP3K Babel Harus Steril dari IUP." Accessed July 25, 2026. https://www.walhi.or.id/rzwp3k-babel-harus-steril-dari-iup

activities, both licensed and unlicensed, overlap with various other land-use functions, such as tourist areas, conservation areas, and commercial fishing zones.

Based on a comparison between the normative regulations and these actual conditions, this study identifies four forms of inconsistency in the use of marine space: spatial function inconsistency, zoning inconsistency, legal inconsistency, and ecological inconsistency. The first form is spatial function incompatibility. Normatively, Rebo Beach has been designated as a coastal tourism area intended to support tourism activities based on environmental sustainability. However, in reality, the area is being used as an unlicensed tin mining site. This change in land use from a tourism area to a mineral exploitation area contradicts the fundamental principle of spatial planning, which requires that every area be utilized in accordance with the functions established in the zoning plan. Thus, the issue at hand is not only the lack of a mining permit but also a change in land use that undermines the area's intended purpose as a tourism destination and a site for protecting the coastal ecosystem.

This analysis must be understood in context, given that Local Regulation No. 3/2020 also designates part of the Sungailiat waters as a Mineral Mining Zone (KPU-TB-MN). The existence of this zone indicates that the local government continues to allow for offshore mining activities in specific locations. However, the existence of the mining zone cannot be interpreted as legitimizing mining activities throughout the waters of Sungailiat. Under the spatial planning regime, the principle of "spatial specificity" applies—that is, each zone has distinct functions, boundaries, and utilization regulations in accordance with the characteristics of its respective area. Therefore, the mining activities conducted at Rebo Beach still constitute a form of non-compliant land use because they are located outside the zone designated for mining activities.

The next inconsistency relates to the legality of marine space utilization. Under a risk-based permitting system, any activity that uses marine space must obtain a KKPRL to ensure that its location complies with the zoning plan. The KKPRL serves not only as an administrative requirement but also as a preventive measure to avoid conflicts over space utilization and to ensure that economic activities do not disrupt the ecological or social functions of an area. The failure to fulfill the obligation to obtain a KKPRL indicates that mining activities at Rebo Beach never underwent the spatial compliance verification process as required by law.

In addition to lacking a KKPRL, these activities also constitute PETI activities as defined in Law No. 3/2020. The mining legal framework requires that all mining activities be conducted solely under an IUP issued by the government within its authority. The lack of an IUP indicates that these activities never underwent the administrative, technical, environmental, or spatial planning evaluation processes that are legal prerequisites for the use of marine space. Thus, the violations occurring at Rebo Beach not only concern the mining regime but also demonstrate a failure to comply with the legal mechanisms within the marine spatial planning regime.

This inconsistency must also be viewed from a constitutional perspective. In Constitutional Court Decision No. 3/PUU-VIII/2010.[22] The Court affirmed that the management of coastal areas and small islands must remain under state control and be carried out for the greatest possible prosperity of the people while ensuring environmental sustainability. The ruling does not preclude economic use of marine spaces, including mining activities. However, it emphasizes that such use must be carried out through mechanisms that safeguard the public interest, protect the environment, and ensure state oversight. Therefore, unauthorized tin mining activities at Rebo Beach not only violate sectoral regulations regarding mining and

[22] Lihat Dalam Putusan Mahkamah Konstitusi Nomor 3/PUU-VIII/2010.

spatial planning but also deviate from constitutional principles concerning state control over natural resources and environmental protection.

The final form of incompatibility relates to the ecological function of the marine environment. The designation of Rebo Beach as a coastal tourism area is fundamentally based on the presence of the coastal landscape, water quality, and marine ecosystems, which are the area’s main attractions. However, tin mining activities involving seabed dredging generate sediment that increases the total suspended solids (TSS) concentration in the water column. Consequently, this mismatch in land use not only conflicts with the area's normative functions but also undermines the ecological functions that underpinned the designation of Rebo Beach as a coastal tourism area.

Based on the above discussion, the mismanagement of marine space at Rebo Beach is multidimensional, as it involves violations of spatial function, zoning regulations, legal requirements, and the ecological function of the area. The issues at hand cannot be understood merely as unlicensed mining practices; rather, they reflect a failure in marine spatial governance that has prevented the spatial planning regime, the mining regime, and the environmental protection regime from operating in an integrated manner. These conditions further serve as the basis for analyzing how the increased concentration of TSS resulting from mining activities contributes to coral reef degradation as an ecological consequence of the mismanagement of marine space at Rebo Beach.

2. The Relationship Between Increased TSS (Total Suspended Solids) Caused by Unlicensed Tin Mining and Coral Reef Degradation

Findings regarding the relationship between increased TSS and coral reef degradation indicate that the use of marine space cannot be evaluated only after environmental damage has occurred, but must be directed toward preventive measures through effective legal instruments. From an environmental law perspective, this approach aligns with the Precautionary Principle as articulated in Principle 15 of the 1992 Rio Declaration on Environment and Development, which states that where there is a threat of serious or irreversible environmental damage, the absence of full scientific certainty should not be used as a reason to delay the implementation of effective preventive measures. This principle establishes prevention as a state obligation in every decision-making process that could pose a risk to the environment.[23]

The application of the precautionary principle becomes increasingly relevant when an activity shows strong indications of environmental risk. In this study, this risk is reflected in the increasing concentration of Total Suspended Solids (TSS) originating from tin mining activities in the coastal area of Rebo Beach. Small-scale mining activities (PETI), particularly those using floating unconventional mining (TI) pontoons in coastal areas, are the primary contributors to physical pollution, namely suspended solids in the water column. These activities generate tailings slurry that is discharged directly into the sea, triggering a drastic spike in TSS concentrations and turning the waters off Rebo Beach murky.[24] These anthropogenic activities directly control the distribution patterns and fluctuations of suspended solids in the water column over time.

[23] Rio Declaration on Environment and Development, Principle 15, United Nations, 1992.

[24] Aprilianti, W., Yusuf, M., dan Wulandari, S. R. (2023). *Analisis Total Padatan Tersuspensi (TSS) dan Nitrat (NO3-N), serta Penentuan Indeks Pencemaran di Perairan Pantai Rebo, Kabupaten Bangka*. Indonesian Journal of Oceanography (IJOCE), Vol. 05 No. 04 : 230 - 238, https://doi.org/10.14710/ijoce.v5i4.16846.

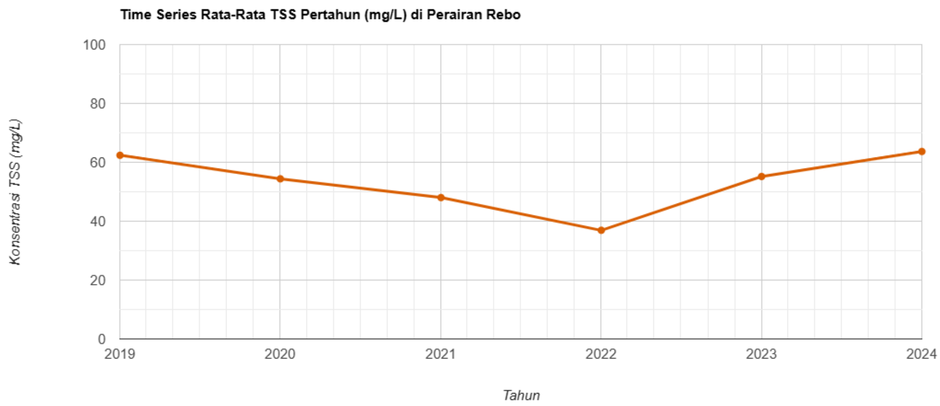

Figure 3. Temporal TSS Graph for Rebo Beach
(**Source:** Author's Analysis, 2026)

Dynamics of Total Suspended Solids (TSS) concentration distribution in the waters off Rebo Beach from 2019 to 2024. At the start of the observation period in 2019, the average TSS was around 62 mg/L and gradually decreased to its lowest point in 2022 at approximately 37 mg/L, in line with the decline in coastal tin mining operations during the pandemic. However, after 2022, the TSS concentration trend surged again, exceeding 55 mg/L in 2023 and rising to 63 mg/L in 2024 as sediment dredging, mining, and maritime transportation activities resumed.

Furthermore, the high supply of suspended solids resulting from these mining activities is exacerbated by seasonal wind patterns and regional surface ocean current circulation. These hydrodynamic factors are the primary drivers that determine the direction of surface water transport and control the dispersion patterns of turbidity along the eastern coast of Bangka Island. These dynamic interseasonal interactions periodically create hydrodynamic barriers in shallow waters, causing fine sediment and tailings slurry to continue accumulating near the mainland.

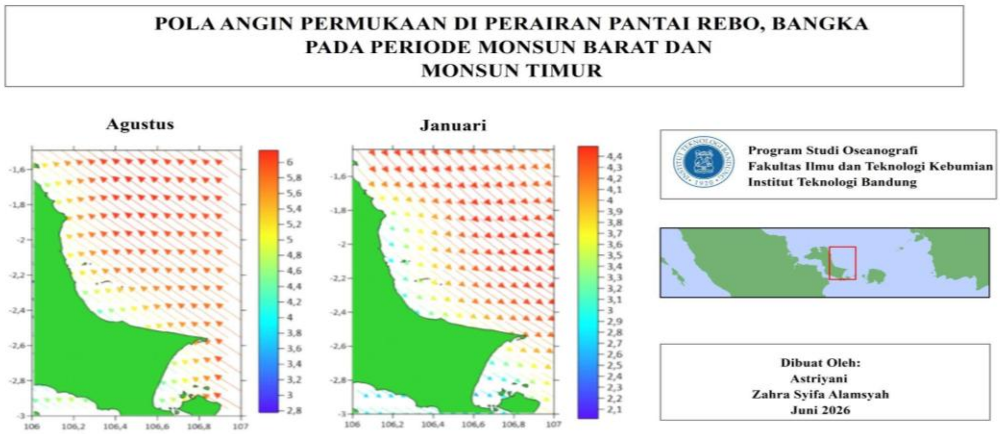

Figure 4. Map of Monsoon Surface Wind Patterns
(**Source:** Author's Analysis, 2026)

During the East Monsoon period, which occurs in August, surface winds blow strongly from the southeast toward the northwest at speeds of 5,2 m/s to 6,0 m/s. From a physical standpoint, these strong and constant southeasterly winds have great potential to generate surface currents moving in the same direction toward the coast. The continuous transfer of kinetic energy from these winds reaches Rebo Beach, which is geographically oriented toward the east-northeast, thereby driving the nearshore water mass and generating an active longshore current along the coastal zone. Conversely, the opposite conditions occur in January, which marks the peak of the Western Monsoon; the direction of air mass movement reverses drastically from the north-northwest to the southeast, with weaker wind speeds (3,4 m/s – 4,4 m/s). These characteristics of the generally weaker West Monsoon winds indicate that the wind-driven surface currents in January are weaker than those in August, and that the wind direction tends to push surface water away from the coastline (*offshore transport*).

The seasonal variations of these two monsoons provide an important physical basis for analyzing Total Suspended Solids (TSS) concentrations. The alternating monsoon cycles, which blow in opposite directions throughout the year, influence the transport and dispersion of suspended material generated by offshore tin mining activities. As a result, the suspended material is not completely dispersed into deeper waters but may remain concentrated in the shallow waters off Rebo Beach. This dynamic influences the spatial distribution of Total Suspended Solids (TSS) and contributes to the formation of a hydrodynamic trapping system in the shallow waters off Rebo Beach.

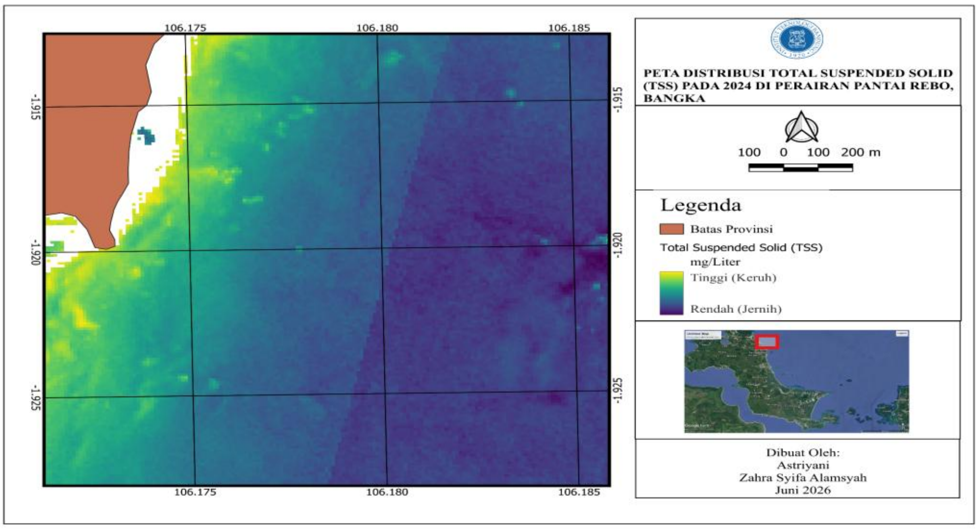

Figure 5. Map of Total Suspended Solids (TSS) Distribution at Rebo Beach in 2024 (Source: Author's Analysis, 2026)

The spatial distribution pattern of turbidity, which converges along the coastline from the southeast toward the northwest, demonstrates the strong mechanical influence of the Eastern Monsoon. Dominant surface winds from the southeast, with speeds of up to 6,0 m/s, transfer massive amounts of kinetic energy to the sea surface. This continuous friction generates a longshore current that carries sediment-rich water masses along the shallow coastal corridor of Rebo Beach. As a result, suspended material originating from terrestrial runoff and waste from anthropogenic activities around the coast undergoes intensive spatial accumulation and becomes trapped in the ultra-coastal zone, rather than being diluted or carried out to deeper offshore zones.

The transport of sediment trapped in these shallow waters has triggered extremely high sediment accumulation in the land-sea interface zone. From a technical remote sensing cartography perspective, these white areas result from filtering using the Normalized Difference Water Index (NDWI) algorithm, which misidentifies these shallow water areas as pure land. This can occur due to the loss of the physical characteristics of pure water and the high reflectance of solid materials. The high rate of continuous sedimentation has altered the local topography by shallowing the water bottom and raising the elevation of the sediment surface to the point where it approaches or even protrudes above sea level during certain tidal conditions.

On the other hand, the gradual decrease in turbidity levels, which gradually clear to a deep blue hue toward the open sea, indicates the boundary of the influence of these coastal physical dynamics. As the spatial orientation moves away from the coast toward the deep sea, the effects of wave breaking and alongshore currents triggered by southeasterly winds begin to weaken. The physical characteristics of offshore seawater, dominated by great depth and more stable regional water mass circulation, facilitate the natural deposition of fine-grained material. The confinement of dense sediment dispersion to this ultra-coastal zone underscores that the combination of the Rebo Beach coastline's orientation and the forcing of the East Monsoon winds acts as a hydrodynamic shield that localizes high turbidity levels, keeping them confined to the nearshore environment.

The conditions of intensive sediment transport trapped in this coastal zone show a negative correlation with coral reef cover conditions at Rebo Beach in recent years. The characteristics of this inverse relationship are clearly evident when comparing environmental spatial data from two different time periods. Based on the 2016 spatial distribution map of coral reefs, the waters off Rebo Beach featured linear coral cover that grew and extended extensively along the coastline. However, the year-round exposure to suspended solid material caused significant ecosystem damage. This environmental pressure ultimately drastically altered the ecological landscape of Rebo Beach by 2024, with the coral colonies that once dominated the area now having died off across nearly the entire region.

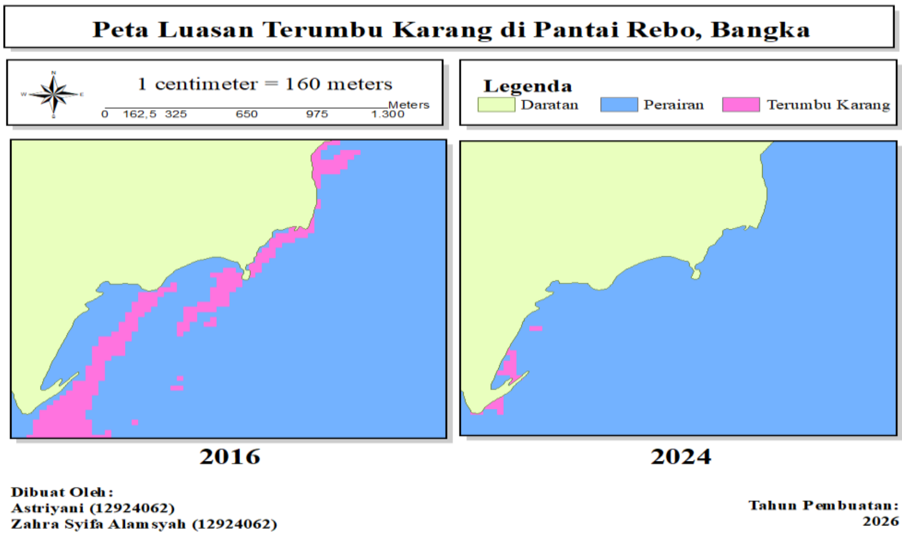

Figure 6. Maps the extent of the coral reefs at Rebo Beach in 2016 (left) and 2024 (right) (Source: Author's analysis, 2026)

Local hydrodynamic forces drive the rate of accumulation of this suspended solid material; during the East Monsoon season, strong winds blow from the southeast toward the Rebo Coast, generating significant waves that trigger the resuspension of bottom sediments, which trap the mining tailings and keep them near the coast. Meanwhile, during the West Monsoon season, winds from the north-northwest push water masses along the coastline toward the south. The interaction of these two monsoon cycles causes fine sediments resulting from anthropogenic activities to become trapped and continuously circulated along the coastal corridor. The long-term impact is clearly visible on the 2024 map, where coral reef colonies have suffered mass mortality, leaving only a few small fragments in the southwestern section.

Mass coral reef die-offs can occur through destructive physical and biological mechanisms resulting from severe sedimentation (*siltation*), given that coral reefs are highly vulnerable to declines in aquatic environmental quality. The chronic presence of high concentrations of TSS in the water column chronically reduces light penetration (light attenuation). High concentrations of suspended solids in the water column act as a physical barrier, preventing sunlight from reaching the seafloor, thereby inhibiting photosynthesis in the *Zooxanthellae* microalgae that live in symbiosis within the coral tissue[25]. This obstacle has devastating consequences because the products of microalgal photosynthesis are the primary energy source corals use to grow, regenerate, and build their calcium carbonate skeletons.

In addition to hindering energy supply, high concentrations of TSS trigger direct sedimentation in nearshore environments. This fine material, which constantly settles, covers the coral polyps (smothering), thereby blocking their respiratory systems and preventing the corals from capturing food from the water column. This sediment-buried condition forces coral colonies to secrete excessive amounts of mucus to clear their surfaces of the fine sediment layer. This constant self-cleaning process drains the corals' energy on a massive scale until they eventually run out of energy and undergo coral bleaching, which ultimately leads to their death[26].

These ecological impacts may be permanent because coral reefs that die as a result of *siltation* are extremely difficult to restore (*recovery*).

[25] Nikita, L. Paulangan, Y. P., dan Hamuna, B. (2021). *Laju Sedimentasi Di Perairan Ekosistem Terumbu Karang Kampung Yakore Distrik Demta Kabupaten Jayapura*. ACROPORA: Jurnal Ilmu Kelautan dan Perikanan Papua, Vol. 4 No. 1, Hal. 28-35, https://doi.org/10.31957/acr.v4i1.1752.

[26] Brunner, C. A., Uthicke, S., Ricardo, G. F., Hoogenboom, M. O.,dan Negri, A. P. (2021). *Climate change doubles sedimentation-induced coral recruit mortality*. Science of the Total Environment, 768, Article 143897, https://doi.org/10.1016/j.scitotenv.2020.143897.

Intensive sedimentation transforms the physical characteristics and texture of the seabed substrate from hard carbonate rock into an unstable layer of fine silt. This fragile, nutrient-rich substrate is quickly invaded and overgrown by *turf algae* (macroalgae)[27]. As a result, new coral larvae lack a hard, clean surface to attach to, disrupting the natural regeneration cycle of the coral reef ecosystem at Rebo Beach.

These illegal mining operations also violate the provisions of Law No. 32 of 2009 on Environmental Protection and Management (PPLH Law) due to the absence of required documents, such as an Environmental Impact Assessment (AMDAL), which is mandated to minimize the risk of ecological damage at Rebo Beach. Furthermore, the material act (actus reus), specifically the direct discharge of tailings slurry, has been proven to exceed the regulatory standards outlined in Government Regulation (PP) No. 22 of 2021 (Annex VIII), which establishes a maximum threshold of 20 mg/L for the Total Suspended Solids (TSS) parameter in sensitive ecosystems under the Seawater Quality Standards. In reality, the presence of this unlicensed mining operation has triggered a surge in the TSS parameter, reaching 63 mg/L in 2024. This increase, which exceeds the legally defined safe limit, legally fulfills the legal elements of environmental pollution as stipulated in Article 1, point 14 of the Environmental Protection and Management Law (UU PPLH), as it has damaged the physical characteristics of natural seawater.

[27] Syari, I. A., Nugraha, M. A., & Hudatwi, M. (2022). *Dampak Penambangan Timah di Laut terhadap Ekosistem Terumbu Karang di Pulau Pemuja dan Karang Malang Duyung, Kabupaten Bangka Barat, Provinsi Kepulauan Bangka Belitung*. Journal of Tropical Marine Science Vol 5(1): 63-69, https://doi.org/10.33019/jour.trop.mar.sci.v5i1.2965.

3. A Zoning-Based Model for Aquatic Spatial Planning to Ensure the Sustainability of Coastal Ecosystems

The research findings indicate that the main problem at Rebo Beach lies not only in the presence of illegal, unlicensed, and unregulated mining (PETI) activities, but also in the suboptimal implementation of marine spatial planning in regulating land use in accordance with its designated functions. Although the Bangka Belitung Islands Province has enacted Provincial Regulation No. 3/2020, mining activities continue in areas designated as coastal tourism zones and possessing important ecological functions. This situation indicates that the available legal instruments are not yet fully supported by an effective system of monitoring, control, and law enforcement. Therefore, a model of marine spatial planning is needed that is not only administratively oriented but also capable of ensuring the sustainability of coastal ecosystems and the well-being of local communities.

From a spatial planning perspective, coastal zone management must be guided by an ecosystem-based marine spatial planning approach, which is a spatial planning system that prioritizes the environment's carrying capacity and resilience as the primary basis for determining spatial allocation and granting permits for the use of marine areas. Through this approach, ecosystem protection is prioritized over economic interests, so that every form of land use must account for the resulting ecological impacts, including increased TSS concentrations that could threaten the sustainability of coral reefs.

Table 2. Spatial Planning Strategy for the Rebo Coastal Waters

Aspect	Indicators	Policies/Strategies
Ecology	- Coral reef protection. - Sedimentation and TSS control	1) Establishment of coastal ecosystem protection zones based on environmental sensitivity levels.

	- Coastal ecosystem health.	2) Use of satellite technology and remote sensing for TSS monitoring. 3) Rehabilitation and restoration of coastal ecosystems.
Economy	- Diversification of income sources. - Coastal economic sustainability. - Implementation of the principles of the *blue economy*.	1) Development of the coastal economic sector through marine tourism, MSMEs, aquaculture, and sustainable fisheries. 2) Implementation of the *blue economy* concept as the foundation for the sustainable use of marine resources. 3) Provision of training, mentoring, and business assistance for coastal communities.
Social	- Community participation. - Multistakeholder collaboration.	1) .Community-based coastal management 2) Collaboration between communities, the government, and academia.
Legal Governance	- Appropriateness of land use. - Effectiveness of permitting and oversight - Enforcement of environmental laws.	1) Strengthening spatial planning and permitting instruments through the optimization of the KKPRL and evaluation of the RZWP3K. 2) Integrating scientific data and remote sensing technology into the monitoring of marine space utilization. 3) Enforcing the law against illegal mining operators and

		restoring the environment through reclamation and ecosystem rehabilitation.

(**Source:** Compiled by the Author, 2026)

Based on the spatial planning strategy shown in Table 2, the implemented zoning model must integrate ecological, social, and legal aspects by dividing space according to levels of environmental sensitivity. In this regard, areas with high coral reef cover that serve as fish habitats must be designated as core protection zones that are off-limits to all mining activities. The designation of these protection zones must also take into account the overall health of the coastal ecosystem, including water quality, the presence of marine habitats, and the area's ecological role in maintaining the balance of the coastal environment. Additionally, these areas should be supplemented with buffer zones designed to mitigate the impacts of sedimentation from activities that increase total suspended solids (TSS) concentrations. Furthermore, areas with economic potential can be designated as limited-use zones for sustainable fisheries, aquaculture, and marine tourism, while still taking into account the environment's carrying capacity. Mining zones, meanwhile, may only be established in ecologically non-sensitive areas, located outside coral reef zones, and that meet technical, environmental, and spatial suitability requirements.

This concept aligns with Australia's marine spatial management practices, which employ an ecosystem-based marine spatial planning approach to balance conservation goals and the use of marine resources. This approach emphasizes the importance of integrating environmental protection, stakeholder participation, and scientific data into the policymaking process. Through the implementation of adaptive and collaborative governance, marine spatial management in Australia seeks to maintain ecosystem sustainability while accommodating various economic interests in coastal and marine areas[28]. Although there are differences in social and institutional characteristics between Australia and Indonesia, these principles can serve as a reference for strengthening coastal governance in Pantai Rebo, particularly through the implementation of ecosystem-based zoning, the strengthening of collaboration among stakeholders, and ongoing monitoring.

However, the establishment of zoning will not be effective unless it is accompanied by strengthened instruments to regulate land use. Therefore, the Mechanism for the Conformity of Marine Space Utilization Activities (KKPRL) needs to be strengthened as a preventive instrument that ensures every activity utilizing marine space is consistent with the area's designated function before an operational permit is granted. The evaluation of KKPRL issuance should not be based solely on administrative requirements. However, it must also take into account the results of scientific studies on the impact of the planned activities on marine conditions. Thus, scientific data becomes an integral part of the legal decision-making process regarding marine spatial planning.

Surveillance efforts also need to be strengthened through the integration of remote sensing technology into marine spatial management policies. Remote sensing technology is a method of collecting information about the conditions of the Earth's surface and water bodies without direct contact with the observed objects, through the use of satellite sensors. The use of remote sensing data can support evidence-based surveillance systems in monitoring changes in environmental conditions resulting from mining activities. However, the effectiveness of technology-based monitoring still requires support from coastal communities as direct users of marine space.

[28] Charlene Sharee-Ann Charles dan Yi Chang, "Cross-National Analysis of Marine Spatial Planning (MSP) Frameworks: Collaboration, Conservation, and the Role of NGOs in Australia, Germany, Seychelles, and England," *Sustainability* 17, no. 18 (2025): 8306, https://doi.org/10.3390/su17188306.

Therefore, the implementation of community-based coastal management can be developed by involving communities in monitoring environmental conditions, reporting inappropriate land-use activities, and participating in ecosystem rehabilitation efforts. Collaboration among communities, the government, and academia is necessary to ensure that the monitoring system does not rely solely on spatial monitoring but is also supported by direct observations at the local level. The integration of remote sensing data and community participation enables the government to conduct periodic evaluations of the effectiveness of the RZWP3K, verify compliance by holders of KKPRL and IUP permits, and identify mining activities conducted outside designated zones.

Strengthening marine spatial governance must also be accompanied by policies that can reduce communities' economic dependence on the tin mining sector. To date, the high level of community involvement in illegal mining activities cannot be separated from the limited availability of alternative livelihoods. Therefore, local governments need to promote economic diversification through the development of the marine tourism sector, sustainable capture fisheries, aquaculture, coastal-based micro and small enterprises, and the development of a blue economy that utilizes marine resources sustainably. The implementation of this economic diversification must be supported by community capacity-building programs, including skills training, business management mentoring, access to capital, and assistance for developing sustainable coastal resource-based enterprises. These efforts are necessary to provide communities with viable alternative livelihoods and gradually reduce their dependence on tin mining activities.

In addition to a preventive approach, marine spatial planning policies must also be supported by consistent and sustained law enforcement. Law enforcement must not focus solely on small-scale miners but must also target masterminds, receivers of stolen goods, licensed companies, and smelters that accept illegally mined tin. This approach aligns with the concept of law enforcement at both the macro and micro levels, where the eradication of illegal mining is achieved by severing the entire illegal tin trade chain rather than merely halting mining activities in the field. To achieve this, stronger coordination is needed among the Ministry of Marine Affairs and Fisheries, the Ministry of Energy and Mineral Resources (ESDM), the police, the Attorney General’s Office, local governments, and maritime enforcement agencies so that monitoring, enforcement, and prosecution can proceed in a coordinated manner.

In addition to being supported by interagency coordination, effective control over the use of marine space also requires instruments capable of ensuring compliance with applicable regulations. In this context, a sanctions system plays a crucial role as the state's response to any violations that could threaten the sustainability of ecosystems and the orderly use of coastal areas. From an administrative law perspective, violations of marine space utilization must be subject to progressive sanctions, ranging from written warnings, temporary suspension of activities, the freezing or revocation of KKPRLs and business licenses, to orders for environmental restoration. If a violation is committed intentionally or results in serious ecosystem damage, enforcement may be escalated by imposing criminal sanctions as stipulated in Law No. 3/2020. Consistent enforcement of sanctions is necessary to serve as a deterrent while ensuring that violations of marine spatial planning are viewed as serious breaches of the public interest and environmental sustainability.

In addition to imposing sanctions, spatial planning policies must strengthen the implementation of environmental restoration mechanisms as a form of accountability for damage caused by the use of marine space that does not comply with regulations. Every business operator that causes ecosystem degradation is required to carry out area rehabilitation, such as the reclamation of former mining sites, coral reef transplantation, and coastal ecosystem rehabilitation. In this context, the polluter pays principle must be applied so that all restoration costs are borne by the party causing the damage, not by the state or the affected coastal communities.

Thus, the proposed zoning-based marine spatial planning model serves not only as a planning tool but also as a preventive, repressive, and restorative legal instrument. Through the strengthening of ecology-based zoning, the optimization of the KKPRL, the use of remote sensing data in monitoring systems, the development of alternative economic sectors, consistent law enforcement across the entire illegal mining chain, and environmental restoration obligations, it is hoped that the increase in TSS concentration can be controlled so that the ecological functions of the coral reefs at Rebo Beach remain preserved. This model can also serve as a reference for coastal zone management in other regions of Indonesia facing similar conflicts between mining activities, conservation, and the use of marine space.

4. Coral Reef Conservation Strategies to Support the Sustainability of Coastal Ecosystems

Coral reef rehabilitation efforts are a key strategy for restoring degraded coastal ecosystems. Restoration can be carried out through both physical and biological approaches, one of which is coral transplantation, which involves grafting live coral fragments onto artificial substrates in degraded areas to accelerate reef regeneration.[29] The application of a transplantation method using spider-shaped frameworks in the waters off Tanjung Sekeben, Banyuwangi, for example, has demonstrated high survival rates among coral seedlings over one year, along with increased marine biodiversity around the restoration site. This method has therefore

[29] Sagala, D., Lautetu, L. M., Prayoga, M. B. R., dan Afla, R. A. (2024): Restorasi Terumbu Karang: Upaya Mempertahankan Kesehatan Ekosistem Laut. Journal of Marine Problems and Threats, 1(1), 1–9, https://doi.org/10.61511/jmarpt.v1i1.2024.465.

proven effective in supporting ecosystem recovery while strengthening the community's role in marine conservation efforts.[30]

The success of coral reef rehabilitation is inextricably linked to the active involvement of coastal communities and their local wisdom. A conservation program based on simple technological innovations combined with local wisdom, as implemented in the coastal area of Kupang City, demonstrates that the active role of tourism-driven communities is a key element of the program's success through local innovation and cross-sectoral collaboration involving communities, academics, government, and the private sector. This holistic approach, which integrates simple technology with local wisdom, ultimately supports the sustainability of coral reef ecosystems.[31]

Multistakeholder collaboration is also key to the success of other conservation strategies. The application of coral nursery technology in coral reef restoration demonstrates that synergy between academics and coastal communities can produce more sustainable conservation models, in which academics play a role in transferring knowledge and technology. In contrast, coastal communities serve as the implementers and long-term managers of restoration programs in the field[32]. Collaborations such as this underscore that the sustainability of coral reef conservation depends on the integrated roles of government agencies, educational institutions, nongovernmental

[30] Syarifah, R. D., Zahroh, M., Handayani, S., Sara, I. W. W., Mawarti, J. I., dan Cahya, M. I. D. (2026): Restorasi Terumbu Karang untuk Mendukung Keberlanjutan Ekosistem Laut dan Peningkatan Populasi Ikan di Perairan Tanjung Sekeben. JMM (Jurnal Masyarakat Mandiri), 10(2), 1673–1682, https://doi.org/10.35912/yumary.v6i3.5762.

[31] Riwu, Y. F., Nenabu, J. C., Bunga, M., dan Marliani, S. (2026): Pemberdayaan Masyarakat Penggerak Wisata Berbasis Inovasi BioReefTek dalam Konservasi Terumbu. Yumary: Jurnal Pengabdian kepada Masyarakat, 6(3), 209–220, https://doi.org/10.35912/yumary.v6i3.5762.

[32] Putra, M. G. A., Lahay, A. F., dan Efendi, E. (2026): Penerapan Teknologi Coral Nursery dalam Restorasi Terumbu Karang: Kolaborasi Akademisi dan Masyarakat Pesisir untuk Konservasi Berkelanjutan. Jurnal Pengabdian Perikanan Indonesia, 6(1), https://doi.org/10.29303/jppi.v6i1.9775.

organizations, the private sector, and local communities as a unified ecosystem governance system.

In addition to technical and social aspects, the sustainability of coral reef conservation also requires integration with marine spatial planning policies and consistent law enforcement. A study on the suitability of marine space utilization for marine tourism activities in the Raja Ampat Islands Marine Conservation Area shows that business operators' compliance with conservation area zoning guidelines contributes to increased coral reef fish abundance and supports the sustainability of the coral reef ecosystem[33]. Therefore, an effective coral reef conservation strategy must combine physical rehabilitation efforts, community engagement, and the incorporation of local knowledge, multistakeholder collaboration, and compliance with marine spatial planning instruments such as the RZWP3K and KKPRL so that coastal ecosystem management can be carried out in an integrated and sustainable manner over the long term.

Conclusion

Unlicensed tin mining (PETI) at Rebo Beach has triggered multidimensional conflicts over the use of marine space. These conflicts explicitly violate Bangka Belitung Regional Regulation No. 3 of 2020, which designates the Rebo Beach area as a Coastal Nature Tourism Sub-Zone (KPU-W-P3K-016). Furthermore, these mineral extraction activities also violate legal requirements because they operate without the necessary administrative documents and valid permits, such as the Marine Space Utilization Compliance Certificate (KKPRL), the Mining Business Permit (IUP), and the Environmental Impact Analysis (AMDAL) report, all of which are essential for ensuring compliance with environmental and spatial planning requirements and protecting the ecological functions of the coastal area.

[33] Arafat, M. (2024): Analisis Kesesuaian Pemanfaatan Ruang Laut Kegiatan Wisata Bahari di Raja Ampat, Papua Barat Daya. Jurnal Penataan Ruang, 19(1). 34–39, http://dx.doi.org/10.12962/j2716179X.v19i1.20202.

On the other hand, this failure to enforce the law has a direct impact on physical ecological degradation. The discharge of *tailing* sludge from floating mining operations has been shown to trigger a surge in *Total Suspended Solids* (TSS) concentrations, reaching 63 mg/L by 2024—a level that significantly exceeds the seawater quality standard threshold for coral ecosystems (20 mg/L) as stipulated in Annex VIII of Government Regulation No. 22 of 2021, thereby reducing sunlight penetration for *Zooxanthellae* photosynthesis and smothering coral polyps, which triggered coral bleaching and mass coral reef mortality throughout the years 2016–2024.

To halt this increasingly widespread ecological degradation, it is necessary to strengthen the ecosystem-based marine spatial planning model . This strengthening of preventive measures is carried out through the evaluation of KKPRL permits, integrated remote-sensing-based monitoring, and community participation (community-based management). The diversification of the blue economy reinforces this legal framework, law enforcement from upstream to downstream, and the application of the polluter pays principle to impose rehabilitation costs on business operators. During the restoration phase, efforts to restore the coral reef ecosystem of Rebo Beach, such as coral transplantation and coral nurseries, must be aligned with local wisdom and supported by cross-sectoral collaboration to ensure the sustainability of the Rebo Beach ecosystem and compliance with marine spatial planning regulations.

References

Adjovu, Godson Ebenezer, Haroon Stephen, David James, and Sajjad Ahmad. "Measurement of Total Dissolved Solids and Total Suspended Solids in Water Systems: A Review of the Issues, Conventional, and Remote Sensing Techniques." Remote Sensing 15, no. 14 (2023): 3534. https://doi.org/10.3390/rs15143534.

Agustari, and A. Muslim. "Meminimalisasi Konflik Lingkungan Akibat Offshore Tin Mining (Studi terhadap Implementasi Peraturan Daerah RZWP3K di Bangka Belitung)." Jurnal Ekonomi & Kebijakan Publik 14, no. 2 (2023): 181–201.

Antragi, Imanuel La, Yanti Tesalonika Situmaeng, Suci Arinda, and Aditya Aulia Rochim. "Penegakan Hukum Pertambangan Timah Ilegal Pasca Kasus Korupsi Tata Niaga Timah di Bangka Belitung." BULLET: Jurnal Multidisiplin Ilmu 3, no. 2 (2024): 184–191. https://journal.mediapublikasi.id/index.php/bullet/article/view/4206/2718.

Aprilianti, Wadiya, Muh. Yusuf, and Sri Yulina Wulandari. "Analisis Total Padatan Tersuspensi (TSS) dan Nitrat (NO3-N), serta Penentuan Indeks Pencemaran di Perairan Pantai Rebo, Kabupaten Bangka." Indonesian Journal of Oceanography 5, no. 4 (2023): 230–238. https://doi.org/10.14710/ijoce.v5i4.16846.

Arafat, M. "Analisis Kesesuaian Pemanfaatan Ruang Laut Kegiatan Wisata Bahari di Raja Ampat, Papua Barat Daya." Jurnal Penataan Ruang 19, no. 1 (2024): 34–39. http://dx.doi.org/10.12962/j2716179X.v19i1.20202.

Brunner, C. A., S. Uthicke, G. F. Ricardo, M. O. Hoogenboom, and A. P. Negri. "Climate Change Doubles Sedimentation-Induced Coral Recruit Mortality." Science of the Total Environment 768 (2021): 143897. https://doi.org/10.1016/j.scitotenv.2020.143897.

Charles, Charlene Sharee-Ann, and Yi Chang. "Cross-National Analysis of Marine Spatial Planning (MSP) Frameworks: Collaboration, Conservation, and the Role of NGOs in Australia, Germany, Seychelles, and England." Sustainability 17, no. 18 (2025): 8306. https://doi.org/10.3390/su17188306.

Douvere, Fanny. "The Importance of Marine Spatial Planning in Advancing Ecosystem-Based Sea Use Management." Marine Policy 32, no. 5 (2008): 762–771. https://doi.org/10.1016/j.marpol.2008.03.021.

Ehler, Charles, and Fanny Douvere. Marine Spatial Planning: A Step-by-Step Approach toward Ecosystem-Based Management. Paris: UNESCO, 2009.

Frazão Santos, Catarina, et al. "Marine Spatial Planning." Marine Policy 132 (2021): 103428. https://doi.org/10.1016/j.marpol.2020.103428.

Gjerde, Kristina M., et al. "Getting Beyond Yes: Fast-Tracking Implementation of the United Nations Agreement for Marine Biodiversity Beyond National Jurisdiction." npj Ocean Sustainability 1, no. 6 (2022): 1–12. https://doi.org/10.1038/s44183-022-00006-2.

Haryadi, D., Ibrahim, and Darwance. "Environmental Improvement Policy through the Obligation of Post-Tin Mining Reclamation in the Islands of Bangka Belitung." IOP Conference Series: Earth and Environmental Science 1175 (2023): 012021. https://doi.org/10.1088/1755-1315/1175/1/012021.

Indonesia. Undang-Undang Dasar Negara Republik Indonesia Tahun 1945.

Indonesia. Undang-Undang Nomor 1 Tahun 2014 tentang Perubahan atas Undang-Undang Nomor 27 Tahun 2007 tentang Pengelolaan Wilayah Pesisir dan Pulau-Pulau Kecil.

Kamajaya, G. Y., I. D. N. N. Putra, and I. N. G. Putra. "Analisis Sebaran Total Suspended Solid (TSS) Berdasarkan Citra Landsat 8 Menggunakan Tiga Algoritma Berbeda di Perairan Teluk Benoa, Bali." Journal of Marine and Aquatic Sciences 7, no. 1 (2021): 18–24.

Kementerian Sekretariat Negara Republik Indonesia. "Saatnya Hilirisasi Produk Timah." Indonesia.go.id. February 14, 2022. Accessed July

23, 2026. https://indonesia.go.id/kategori/editorial/6050/saatnya-hilirisasi-produk-timah.

Kompas. "Tambang Timah Bangka Belitung: Sejarah, Dampak, dan Asa untuk Masa Depan." Accessed July 18, 2026. https://jeo.kompas.com/tambang-timah-bangka-belitung-sejarah-dampak-dan-asa-untuk-masa-depan.

Kurniawan, Kurniawan, Supriharyono, and Dwi P. Sasongko. "Pengaruh Kegiatan Penambangan Timah terhadap Kualitas Air Laut di Wilayah Pesisir Kabupaten Bangka Provinsi Kepulauan Bangka Belitung." Akuatik: Jurnal Sumberdaya Perairan 8, no. 1 (2014): 13–21.

Kusbiarsi, Aldora, Nadya Putri Fitriani, Albertus Erico Jerry Krisna Nugroho, and Ike Fitri Samsiyah. "Pendekatan Perencanaan Ruang Laut untuk Pengelolaan Sumber Daya Pesisir yang Berkelanjutan: Tinjauan Literatur." Jurnal Laot Ilmu Kelautan 7, no. 2 (2025): 226–242. https://doi.org/10.35308/jlik.v7i2.13892.

Lacaux, Jean-Paul, Yves M. Tourre, Christian Vignolles, Jean-Alfred Ndione, and Mireille Lafaye. "Classification of Ponds from High-Spatial Resolution Remote Sensing: Application to Rift Valley Fever Epidemics in Senegal." Remote Sensing of Environment 106, no. 1 (2007): 66–74. https://doi.org/10.1016/j.rse.2006.07.012.

Liu, H., Q. Li, T. Shi, S. Hu, G. Wu, and Q. Zhou. "Application of Sentinel-2 MSI Images to Retrieve Suspended Particulate Matter Concentrations in Poyang Lake." Remote Sensing 9, no. 7 (2017): 761. https://doi.org/10.3390/rs9070761.

Lyzenga, David R. "Remote Sensing of Bottom Reflectance and Water Attenuation Parameters in Shallow Water Using Aircraft and Landsat Data." International Journal of Remote Sensing 2, no. 1 (1981): 71–82. https://doi.org/10.1080/01431168108948342.

Mahkamah Konstitusi Republik Indonesia. Putusan Mahkamah Konstitusi Nomor 3/PUU-VIII/2010.

Nikita, L., Y. P. Paulangan, and B. Hamuna. "Laju Sedimentasi di Perairan Ekosistem Terumbu Karang Kampung Yakore Distrik Demta

Kabupaten Jayapura." ACROPORA: Jurnal Ilmu Kelautan dan Perikanan Papua 4, no. 1 (2021): 28–35. https://doi.org/10.31957/acr.v4i1.1752.

Parjito, Henrie Buchari, Endang Linirin Widiastuti, and Samsul Bakri. "Analisis Alokasi Ruang Laut dalam Rencana Zonasi Wilayah Pesisir dan Pulau-Pulau Kecil (RZWP3K) Provinsi Lampung." Jurnal Sumberdaya Akuatik Indopasifik 6, no. 1 (2022): 11–24.

Permatasari, Bunga, Reko Dwi Salfutra, Rahmat Robuwan, and Muhammad Yogie Adha. "Keadilan Lingkungan dan Prinsip Pencemar Membayar: Analisis Pemulihan Kerusakan Lingkungan Akibat Tambang Timah di Bangka Belitung." Jurnal To Ciung: Jurnal Ilmu Hukum 2 (2025). https://doi.org/10.64078/ws8hy822.

Provinsi Kepulauan Bangka Belitung. Peraturan Daerah Provinsi Kepulauan Bangka Belitung Nomor 3 Tahun 2020 tentang Rencana Zonasi Wilayah Pesisir dan Pulau-Pulau Kecil Provinsi Kepulauan Bangka Belitung Tahun 2020–2040. Accessed July 23, 2026. https://peraturan.bpk.go.id/Details/156383/perda-prov-bangka-belitung-no-3-tahun-2020.

Purnaweni, H., Kismartini, B. Prabawani, D. P. Rahayu, and A. Putra. "Conflict of Fishermen vs Tin Miners in Rebo Beach, Bangka Island: Dispute in the Sungailiat Special Economic Zone." AIP Conference Proceedings 3001 (2024): 080036. https://doi.org/10.1063/5.0184251.

Putra, M. G. A., A. F. Lahay, and E. Efendi. "Penerapan Teknologi Coral Nursery dalam Restorasi Terumbu Karang: Kolaborasi Akademisi dan Masyarakat Pesisir untuk Konservasi Berkelanjutan." Jurnal Pengabdian Perikanan Indonesia 6, no. 1 (2026). https://doi.org/10.29303/jppi.v6i1.9775.

Rahayu, Derita Prapti, Muhammad Rustamadji, Faisal, and Rafiqa Sari. "Illegal Tin Mining, Policy Gaps and the Plight of Small-Scale Tin

Miners in Indonesia." South East Asia Research 32, no. 4 (2025): 351–369. https://doi.org/10.1080/0967828X.2025.2462727.

Rio Declaration on Environment and Development. Rio Declaration on Environment and Development. Rio de Janeiro: United Nations, 1992.

Riwu, Y. F., J. C. Nenabu, M. Bunga, and S. Marliani. "Pemberdayaan Masyarakat Penggerak Wisata Berbasis Inovasi BioReefTek dalam Konservasi Terumbu." Yumary: Jurnal Pengabdian kepada Masyarakat 6, no. 3 (2026): 209–220. https://doi.org/10.35912/yumary.v6i3.5762.

Riwu, Y. F., Nenabu, J. C., Bunga, M., dan Marliani, S. (2026): Pemberdayaan Masyarakat Penggerak Wisata Berbasis Inovasi BioReefTek dalam Konservasi Terumbu. Yumary: Jurnal Pengabdian kepada Masyarakat, 6(3), 209–220, https://doi.org/10.35912/yumary.v6i3.5762.

Sagala, D., L. M. Lautetu, M. B. R. Prayoga, and R. A. Afla. "Restorasi Terumbu Karang: Upaya Mempertahankan Kesehatan Ekosistem Laut." Journal of Marine Problems and Threats 1, no. 1 (2024): 1–9. https://doi.org/10.61511/jmarpt.v1i1.2024.465.

Siringoringo, Rikoh Manogar, and Tri Aryono Hadi. "The Condition of Coral Reefs in West Bangka Water." Marine Research in Indonesia 39, no. 2 (2014): 69–75. https://doi.org/10.14203/mri.v39i2.86.

Sulaiman, Aimie, La Ode Muhamad Muliawan, Komang Jaka Ferdian, and Marwan Yaumal Akbar. "Fighting over the Bangka Sea: The Tin Mining Conflict in the Marine Area of Bangka Regency." Journal of Governance 8, no. 1 (2023): 61–75.

Suyadi, D., I. M. Yulianto, A. T. White, et al. "Coral Reef Restoration in Indonesia: A Review of Policies and Projects." Marine Policy 137 (2022): 104940. https://doi.org/10.1016/j.marpol.2021.104940.

Syari, I. A., M. A. Nugraha, and M. Hudatwi. "Dampak Penambangan Timah di Laut terhadap Ekosistem Terumbu Karang di Pulau Pemuja dan Karang Malang Duyung, Kabupaten Bangka Barat, Provinsi Kepulauan Bangka Belitung." Journal of Tropical Marine Science 5, no. 1 (2022): 63–69. https://doi.org/10.33019/jour.trop.mar.sci.v5i1.2965.

Syari, Indra Ambalika. "Kondisi Terumbu Karang di Perairan Rebo Sungailiat Bangka Akibat Pertambangan Timah." Akuatik: Jurnal Sumberdaya Perairan 10, no. 1 (2016): 13–20. https://journal.ubb.ac.id/index.php/akuatik/article/view/327.

Syarifah, R. D., M. Zahroh, S. Handayani, I. W. W. Sara, J. I. Mawarti, and M. I. D. Cahya. "Restorasi Terumbu Karang untuk Mendukung Keberlanjutan Ekosistem Laut dan Peningkatan Populasi Ikan di Perairan Tanjung Sekeben." JMM (Jurnal Masyarakat Mandiri) 10, no. 2 (2026): 1673–1682.

United Nations. "The 17 Goals." Sustainable Development Goals. Accessed July 23, 2026. https://sdgs.un.org/goals.

Wahana Lingkungan Hidup Indonesia (WALHI). "RZWP3K Babel Harus Steril dari IUP." Accessed July 25, 2026. https://www.walhi.or.id/rzwp3k-babel-harus-steril-dari-iup.

Xu, Hanqiu. "Modification of Normalized Difference Water Index (NDWI) to Enhance Open Water Features in Remotely Sensed Imagery." International Journal of Remote Sensing 27, no. 14 (2006): 3025–3033. https://doi.org/10.1080/01431160600589179.