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Total Suspended Solids Dynamics in Tin Mining Exploitation Areas in Northeastern Coastal Waters of Bangka Island: A Remote Sensing Approach

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Abstract: The dynamics of total Suspended Solids (TSS) are a characteristic of water quality that can be observed over time, especially in areas where water is used for extractive purposes, such as tin mining areas in Northeastern Coastal Waters of Bangka Island. This study describes the TSS dynamics that occurred in those areas which are covered by Landsat 8 Imagery (Path123/Row 061). This is interesting because the research location is a tin mining site whose exploitation activities have an impact on Total Suspended Solids in the surrounding area. The method used in this study was multispectral analysis of satellite imagery. The algorithm used was developed by Laili *et al*. (2015). The results show that during the 10-year study period, the dynamics of Total Suspended Solids on the Northeastern Coast of Bangka Island from 2015 to 2024 did not experience significant changes. The annual average values of Total Suspended Solids ranged from 18.48 mg/L to 18.74 mg/L. However, there is a significant difference (p-value of 0.00 on T-Test) between Total Suspended Solids levels within the tin mining area (19.15 mg/L) and those outside the tin mining area (18.64 mg/L).

Keywords: coastal dynamics; distribution mapping; multi-spectral analysis; multi-temporal analysis; satellite imagery; tin mining area; total suspended solids; water quality

1. Introduction

Tin mining has been one of the sectors supporting Indonesia's economy for decades. In recent years, the value of tin exports has been no less than US$ 1 million per year, and in 2021, the value reached US$ 2.3 million (BPS, 2026). In the waters, this activity is carried out using dredging vessels that extract sand from the seabed, wash it, and then extract the tin ore in the same vessel as shown in Figure 1.

Figure 1. Dredgers operating in the coastal waters of the Northeastern Coast of Bangka Island dredge sand from the seabed, washing the material using a jigging system, and extracting the tin ore contained within

The washing process is carried out mechanically (without additional chemicals), which also produces fine sediments that are returned to the water. This process increases total suspended solids concentrations and can disrupt the balance of aquatic ecosystems. This issue is crucial because it has the potential to damage the quality of seawater, threaten biodiversity, and affect the livelihoods of coastal communities, such as fishermen (Syamdhora *et al*. 2025; Pamungkas and Husri, 2020). However, for particles of a certain size, the impact of this increase in TSS levels does not extend beyond a 50-meter radius from the center of the material discharge into the water. Under these conditions, existing water quality standards will not exceed the thresholds established by the Government of the Republic of Indonesia through Government Regulation Number 22 of 2021 (Wardhana and Santoso, 2023).

In the waters around Bangka Island, tin mining tends to degrade the quality of coastal ecosystems, especially in shallow waters less than 10 meters deep. The results of modeling analysis conducted by Syamdhora *et al*. (2025) show that total suspended solids in the tin mining area of Matras Beach, Sungailiat, Bangka Regency range from 20 mg/L to 24 mg/L in the east season of monsoon and 26 mg/L to 28 mg/L in the west season of monsoon. Meanwhile, Kurniawan *et al*. (2019) conducted observations at 7 locations where tin mining waste was discharged into the waters of Bangka Regency and found that the total suspended solids content ranged from 63 to 208 mg/l. This value is far above the seawater quality standards for marine life set by the Indonesian government, which is 20 mg/L for seagrass and coral reef ecosystems and 80 mg/L for mangrove ecosystems (PP22, 2021).

High levels of total suspended solids have the potential to degrade coastal ecosystems by decreasing water transparency and reducing the penetration of sunlight into the water column, which inhibits photosynthesis by phytoplankton and algae. If this occurs, the primary productivity of the ecosystem will be disrupted, which will ultimately disrupt the balance of the food chain. Research also shows that high total suspended solids disrupt biogeochemical processes, such as the nutrient cycle, which ultimately degrades overall water quality and makes ecosystems more vulnerable (Bianchi and Allison, 2009).

Environments that are vulnerable to continuous exploitation certainly require a means of sustainable monitoring, one of which is through a multi-spectral analysis approach using remote sensing data. The use of remote sensing data is crucial because it enables extensive spatial and temporal monitoring without direct contact. Satellite imagery data can be utilized because it is publicly available online through Global Vision Portal, records continuously over a certain period of time, and has sufficient spatial resolution (Pradana and Semedi, 2025).

Although there have been previous studies on total suspended solids modelling, most studies have focused on mathematical models only and when using spatial models in the eastern coastal area of Bangka Island have been based on seawater sample data collected at a specific point in time. Recognizing this gap, this study attempts to describe the dynamics of total suspended solids over the long term (10 years) using a remote sensing approach.

This research is necessary to support sustainable policies, such as mining permit regulations, ecosystem restoration, and coastal environmental damage mitigation. This research also identifies the dynamics of total suspended solids, which can help minimize environmental impacts while maintaining the economic benefits of tin mining.

2. Materials and Methods

The use of Landsat 8 data to obtain total suspended solids distribution is possible. One way to do this is by using band 2 (visible blue) and band 4 (visible red) on the Operational Land Imager (OLI) sensor as developed by Laili *et al.* (2015). Unfortunately, this development uses an algorithm that is not yet capable of separating the influence of land and atmospheric objects. To separate them, the Land Surface Water Index (LSWI) value can be used, which is then followed by histogram cutting at a certain value range (Arif and Toersilowati, 2024; Declaro *et al.* 2025).

The results of the calculations and histogram cuts obtained from each recording time over 10 years (ideally 228 scenes, as explained later) were then averaged to obtain a composite image of the annual average value. If negative values are still found in the pixel values after this series of processes, then those negative values are considered invalid and must be discarded from the final image calculation before compositing the imagery. Negative values are considered errors and must be deleted because in reality, the total suspended solids cannot be negative. Zero is the lowest value that can be found in the field. This process simply removes pixels without reducing the number of scenes being processed. The next step is to mask the areas in the water to remove the values on land to analyse the dynamics of total suspended solids.

Furthermore, the distribution data of *KKPR Laut* (Marine Spatial Utilization Permits) issued by the Ministry of Marine Affairs and Fisheries regarding tin mining exploitation activities at the study area was used for comparison. This comparison was conducted to determine the correlation between TSS levels at the tin mining area and TSS levels outside the tin mining area.

2.1. Data Source and Collection

Landsat 8 imagery data was collected by downloading it from an online portal at the domain address *https://glovis.usgs.gov/app*. This portal is managed by the United States Geological Survey (USGS) and data is freely available upon registration for research and scientific development purposes. Data were downloaded in early 2025 with the aim of obtaining imagery data from the last 10 years, namely Landsat 8 imagery data scanned from January 2015 to December 2024 in Northeastern Coastal Waters of Bangka Island (Path123/Row 061).

According to the USGS (2019), the Sun-Synchronous orbit of the Landsat 8 satellite causes repeated record of scenes at the same location at specific intervals called temporal resolution of satellite imagery. Landsat 8 imagery has a temporal resolution of 16 days, meaning that within that time frame, the satellite records scenes at the same location (same path/row), so that over a period of 10 years, it ideally produces 228 images at the same location. Thus, the observed data were collected or obtained every 16 days over 10 years (2015-2024).

Not only satellite imagery but also distribution of marine protected areas used in this study were obtained from eSEA Map Portal. The eSEA Map Portal is a spatial data portal managed by the Ministry of Marine Affairs and Fisheries that displays the distribution of issued *KKPR Laut* (Marine Spatial Utilization Permits).

2.2. Data Analysis

The Landsat 8 imagery obtained was then extracted to retrieve data only from band 2 and band 4 for analysis using the algorithm developed by Laili *et al.* (2015). This algorithm was developed to identify the relationship between reflectance values in each band on Landsat 8 images and TSS values in the waters of Poteran Island, Sumenep Regency, East Java. The results show that the total suspended solids value is closely related to the reflectance value of bands 2 and 4 of OLI Sensor in Landsat 8 satellite with the following mathematical equation:

$$TSS = 31{,}42 \times ((\mathrm{Log}(\rho B2) / \mathrm{Log}(\rho B4)) - 12{,}719$$

where $\rho B2$ is the reflectance value of band 2 and $\rho B4$ is the reflectance value of band 4 with total suspended solids value is expressed in milligram per litre (mg/L).

This algorithm was tried and tested in Madura Strait, and showed a correlation of 80.68% with an $R^2 = 0.67$ **compared** to the total suspended solids value in the field during dry season and a correlation of 82.06% with an $R^2 = 0.65$ during rainy season. Therefore, this equation can be considered to represent the total value of suspended solids calculated according to field conditions (Cahyo, 2024).

The pixel values in a satellite imagery scene represent the objects captured (Lillesand and Kiefer, 1990). Therefore, in the analysis of this study, pixels with values that predominantly represent objects in the water must be used. These pixels can be filtered using the Land Surface Water Index (LSWI) values (Tesfaye and Bruer, 2024). The results of this index range from -1 to +1. Pixels with LSWI values less than or equal to zero are pixels that are predominantly formed from water bodies, so if there are pixels with LSWI values greater than zero, these pixels are not used in this study. LSWI is calculated using band 5 (near infrared) and band 6 (shortwave infrared) of Landsat 8 imagery with the following mathematical equation:

$$LSWI = (\rho B5 - \rho B6) / (\rho B5 + \rho B6)$$

where ρB5 is the reflectance value of band 5 and ρB6 is the reflectance value of band 6 from Landsat 8 imagery. It is important to note that this step is also taken to eliminate pixels whose values are predominantly affected by clouds.

The final part of the analysis is to eliminate pixels on the land surface. These pixels exist because there may be water on the land surface. Water bodies on the land surface are not included in the scope of this study. This elimination is carried out using land area data from the *Peta Rupa Bumi Indonesia Digital* (Indonesian Digital Basemap) published by the *Badan Informasi Geospasial* (Indonesian Geospatial Information Agency). This is the final result of the total suspended solids dynamics that this study aims to describe.

The distribution of average TSS levels over a 10-year period, derived from the analysis of satellite imagery, was then compared between areas outside the tin mining zone and TSS levels within the tin mining zone based on the *KKPR Laut* (Marine Spatial Utilization Permits) issued by the Ministry of Marine Affairs and Fisheries. The relationship between the two groups was examined using a t-test.

The t-test is a parametric inferential statistical method and is used to determine the difference in means between two sample groups. In addition, the T-test is used to determine the significance of differences between two conditions or groups of data. This is useful for determining the statistical significance of differences between groups. Furthermore, the T-test is a commonly used method in quantitative research for comparing data groups and evaluating the difference between observed values and expected values (Mustafa, 2022; Rahmani *et al*. 2025; Ramadhani *et al*. 2022). The T-test is formulated as follows:

$$t = (\bar{X}_1 - \bar{X}_2) \Big/ \sqrt{\frac{s_1^2}{\bar{n}_1} + \frac{s_2^2}{\bar{n}_2}}$$

where $\bar{X}_1$ and $\bar{X}_2$ are the average for each group, s_1 and s_2 is the standard deviation for each group, and *n* is the sample size. The TSS values to be included in this T-test analysis consist of all pixel values within the *KKPR Laut* (Marine Spatial Utilization Permits) area (approximately 2,600 pixels) and an equal number of pixel values outside the mining area, selected at random using mapping software.

2.3. Region of Interest

This study focuses on the region scanned by the Operational Land Imager sensor of Landsat 8 satellite in path 123 and row 061 on the USGS's World Reference System 2 (WRS-2). This scene covers an area measuring approximately 185 x 185 km and constitutes the study area for this research. A more general overview of the location of this study can be seen in Figure 2.

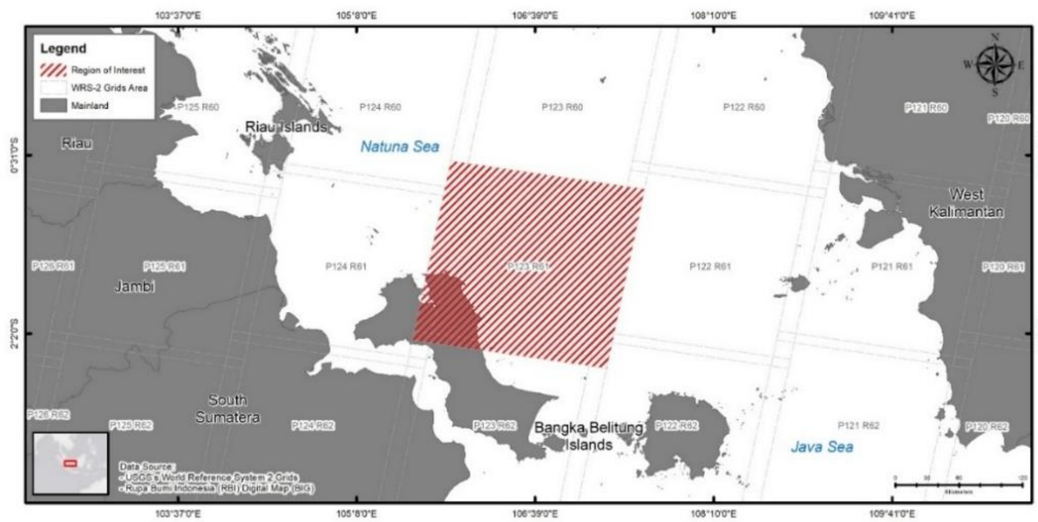

Figure 2. The region of interest on the study of dynamics of total suspended solids in the tin mining area in the Northeastern Coast of Bangka Island using a remote sensing approach (Landsat 8 OLI path 123 and row 061)

3. Results

This study produced maps of the average annual total suspended solids distribution from year 2015 to 2024 (10 years) for the coverage area of the northeastern coast of Bangka Island. These maps were derived from Landsat 8 image data using specific algorithms for subsequent analysis of total suspended solids dynamics.

3.1. Annual Change in Total Suspended Solids

Tin mining activities in the waters affect the total suspended solids value in the surrounding area. The distribution of the annual average total suspended solids successfully analysed using Landsat 8 multi-spectral image analysis shows values ranging from 19.82 mg/L to 21.60 mg/L at the annual maximum, 18.48 mg/L to 18.74 mg/L at the annual average, and 0.00 mg/L to 1.56 mg/L at the annual minimum value. The dynamics of changes in total suspended solids for each year can be seen in the graph presented in Figure 3.

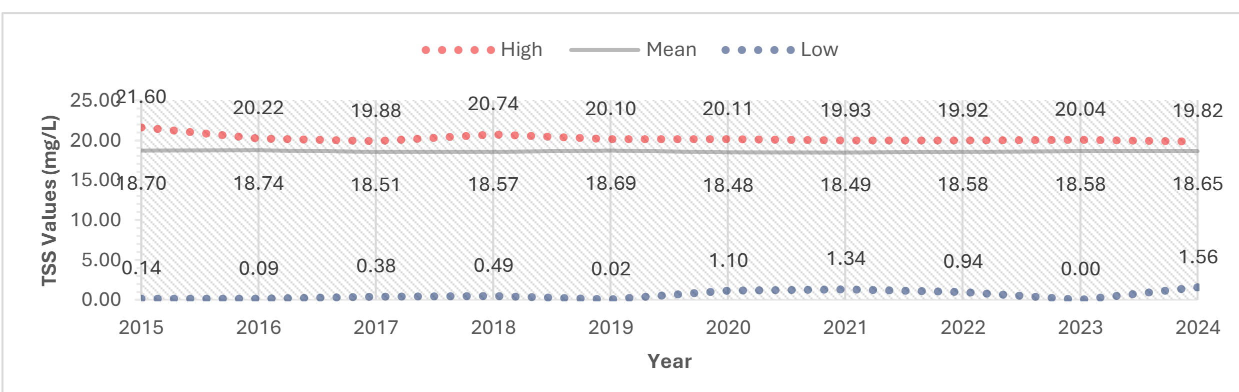

Figure 3. The dynamics of total suspended solids at the study site in the Northeastern Coast of Bangka Island

3.2. Distribution Maps of Total Suspended Solids

Mapping was conducted to facilitate the visualization of the distribution of total suspended solids. The resulting map is derived from Landsat 8 imagery data obtained using specific algorithms with multispectral analysis. Using this method, the total suspended solid value for a specific area/coordinate on the earth's surface is obtained and then represented in a map of the total suspended solid values.

Low total suspended solid values will be represented by green, values closer to the middle will gradually change to yellow, and values closer to red will gradually change to red. These colour gradients will make it easier to see the pattern of average annual total suspended solids distribution value on the Northeastern Coast of Bangka Island. This map is bounded by the land boundaries of the Digital Topographic Map of Indonesia (Rupa Bumi Indonesia Digital) and the boundaries of the USGS's World Reference System 2 (WRS-2) image scene on path 123 dan row 061. The map of the annual total suspended solids distribution (2015-2024) on the northeastern coast of Bangka Island can be seen in Figure 4.

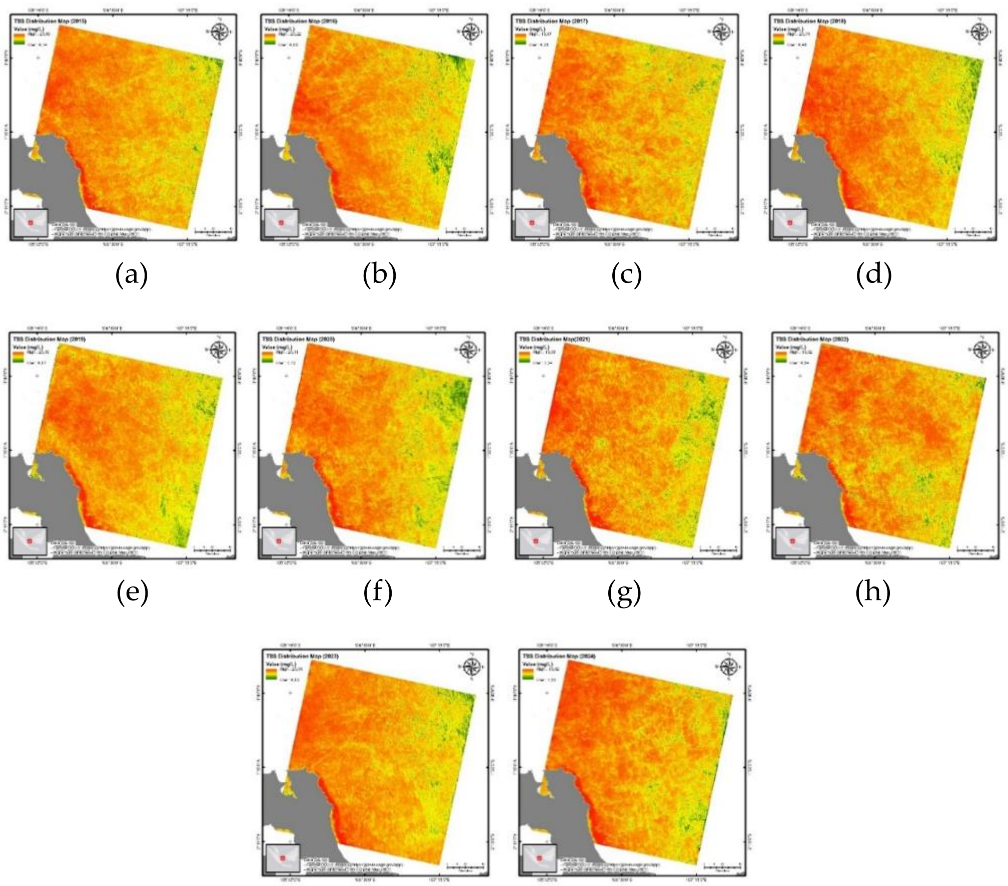

Figure 4. Differences of processed Landsat 8 OLI images (path 123 and row 061) in Northeastern Coast of Bangka Island for the annual distribution of total suspended solids (TSS) in the year (a) 2015; (b) 2016; (c) 2017; (d) 2018; (e) 2019; (f) 2020; (g) 2021; (h) 2022; (i) 2023; and (j) 2024. Color scale: green to red = low to high TSS

This study successfully processed 216 scenes of the 228 Landsat 8 image scenes that should be available (94.74%). By combining all processed images, it was possible to obtain an average picture of the total suspended solids over 10 years in a single map, as shown in Figure 5.

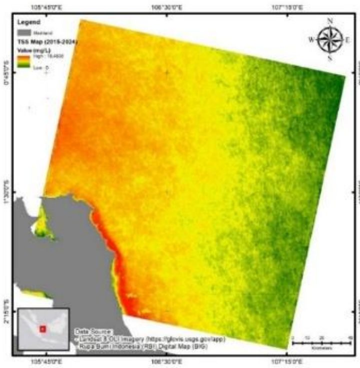

Figure 5. Composite visualization of processed Landsat 8 OLI imagery (path 123 and row 061) on the Northeastern Coast of Bangka Island showing the annual distribution of total suspended solids recorded from 2015 to 2024 (10-year average data). Color scale: green to red = low to high TSS

3.3. Relationship Between TSS Levels in Tin Mining Areas and Outside

A T-test was conducted to examine the relationship between TSS levels within the KKPR Laut area and the outside. The results of the T-test conducted are shown in Table 1.

Table 1. The results of the t-test illustrating the relationship between the presence of tin mining areas on the Northeastern Coast of Bangka Island and the annual total suspended solids levels recorded at the study sites

Parameter	TSS Value	
	Inside Tin Mining Area	**Outside Tin Mining Area**
Mean	19,15	18,64
Variance	0,03	0,06
Observations	2633	2633
Pooled Variance	0,05	
Hypothesized Mean Difference	0,00	
Df	5264	
t Stat	85,68	
P(T<=t) one-tail	0,00	
t Critical one-tail	1,65	
P(T<=t) two-tail	0,00	
t Critical two-tail	1,96	

4. Discussion

The calculation results show that the highest average value tends to be stable in the range of 19.82 mg/L in 2024 to 21.60 mg/L in 2015 (a difference of 1.78 mg/L with a decreasing pattern with a linear regression equation of y = -0.1178x + 258.03 with R^2 = 0,427). Meanwhile, the low average value is also relatively stable, ranging from 0.00 mg/L in 2023 to 1.56 mg/L in 2024 (a difference of 1.56 mg/L with an increasing pattern with a linear regression equation of y = 0.1127x - 226.92 with R^2 = 0,3428). The annual average values from 2015 to 2024 also show stable values. The total suspended solids value ranged from 18.48 mg/L in 2020 to 18.74 mg/L (a difference of 0.26 mg/L with a slight decreasing pattern with a linear regression equation of y = -0.0099x +38.627 with R^2 = 0,1074). The trend over the past 10 years (2015–2024) in mean values is shown in Figure 6.

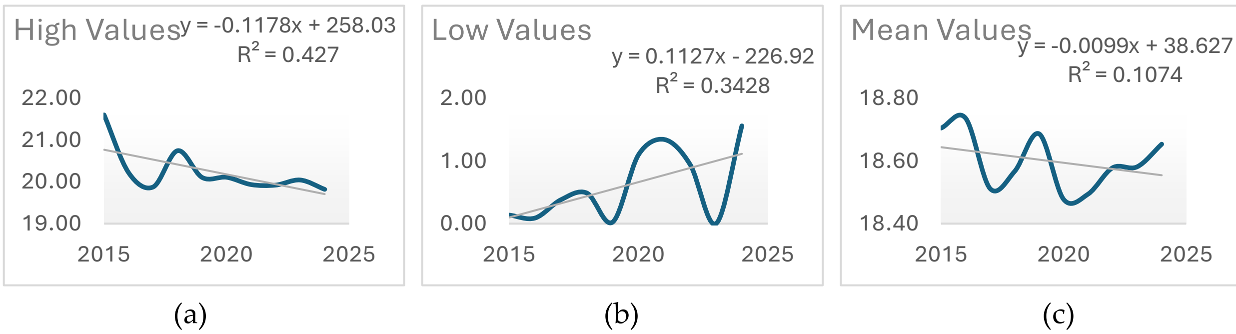

Figure 6. The annual total suspended solids values derived from the processing of Landsat 8 OLI imagery (path 123 and row 061) in Northeastern Coast of Bangka Island, along with the 10-year average (2015–2024) in the row (a) high values; (b) low values; (c) mean values

Looking at the annual TSS distribution maps in Figure 4, we can see a pattern indicating that water conditions are improving in 2020, as marked by the appearance of green colours on the map that are spreading. Green areas indicate low total suspended solids values. Unfortunately, in 2021 and the following years, the distribution of low total suspended solids values has decreased.

In 2020, Indonesia's tin production declined significantly. Indonesia is usually capable of producing up to 80,000 metric tons of tin annually, but throughout 2020, it only managed to produce 52,467 metric tons of tin. The main cause was the global COVID-19 pandemic (SMM 2020). TIB (2022) also reported that various policies implemented by the government, such as lockdowns (restrictions on exports and imports), caused disruptions to the supply chain and logistics of tin commodities. In addition, as a result of the COVID-19 pandemic, various factories around the world, particularly in Europe and America, which use tin as a raw material for their production, stopped production.

According to SMM (2022), Indonesia's tin production in 2021 increased significantly, reaching 70,000 metric tons, up about 33% from 52,467 metric tons in 2020, which was severely affected by the COVID-19 pandemic. This increase was mainly driven by the relaxation of restrictions on global commodity exports and imports, which restored the supply chain to normal conditions after the lockdown. In Indonesia, government policies such as the partial lifting of Large-Scale Social Restrictions (PSBB) in Bangka, the main production centre of tin to optimize legal mining operations, reducing the impact of illegal mining, which had been halted.

Looking at the comparison between these two parameters certainly creates a dilemma, whereby higher tin production will increase the total suspended solids in the field, which will certainly lead to poor environmental quality. This certainly poses a challenge for the government as the regulator of tin mining in the region. To overcome this dilemma, a sustainable approach is needed. Collaboration with local communities is also important for monitoring activities in the field. Without government intervention, increased production will accelerate environmental degradation. Ultimately, the balance between economic growth and environmental preservation is key to the sustainability of the tin sector in Indonesia.

The T-test results in Table 1 indicate that there is a significant difference between TSS values within tin mining areas and those outside such areas. This is based on the mean values of the two groups, where TSS in the tin mining areas was 19.15 mg/L, which is higher than the TSS outside the tin mining areas, which was 18.64 mg/L. Although the difference in means appears very small (only 0.51 mg/L), statistical tests indicate that the difference is statistically significant. The calculated t-Stat of 85.68 is far greater than the t-Critical two tail value of 1.96. Furthermore, the p-value of 0.00 (which is less than 0.05) indicates that there is a significant difference between TSS levels in the tin mining area and those outside the tin mining area. The large sample size in each group (2,633) also strengthens the reliability of these T-test results. The relatively small variance in both groups indicates that the data are sufficiently homogeneous, thus fulfilling the assumption of equal variances.

The relatively lower TSS values observed in this study compared to previous studies can be attributed to several methodological and operational factors. The first possibility is that tin mining activities involving vessels are dynamic in nature, with operations moving from one location to another over a specific period of time. Meanwhile, the TSS values obtained from satellite imagery are pixel values that have undergone an aggregation process, thus better reflecting average conditions at a specific spatial and temporal scale, which may potentially reduce the TSS values obtained. The second possibility is that satellite imagery is typically acquired in the morning through early afternoon (around 9:00 AM to 11:00 AM Local Time), which does not always coincide with the peak period of tin mining production activity in the afternoon. This condition causes the sediment suspension intensity recorded by the satellite sensor to tend to be lower compared to actual conditions when mining activity reaches maximum intensity. As is well known, satellite imagery is a snapshot of the Earth's surface captured by sensors over a very brief period of time. This inevitably means that the information derived from image processing reflects only the conditions present during that very brief moment of capture. This is one of the limitations of research employing a remote sensing approach.

On the other hand, it should also be noted that previous studies on TSS levels in tin mining wastewater have primarily focused on water discharged directly from production vessels. For instance, Kurniawan *et al*. (2019) collected water samples from the bottom of the water column at seven locations where vessels were actively discharging mining effluents. This approach captures localized and instantaneous TSS concentrations, which may differ substantially from satellite-derived estimates that represent spatially averaged conditions over a broader temporal scale.

5. Conclusions

Based on the results of this study, the dynamics of total suspended solids in tin mining exploitation areas in northeastern coastal waters of Bangka Island experienced a decreasing pattern in high and mean values, but an increasing pattern in low values. All of this pattern has emerged, though the relationship between the two variables is not strong. In addition, a pattern was found that when tin production declined due to the COVID-19 pandemic, there was a decrease in the total value of suspended solids in the field. Based on the results of the t-test, it can also be concluded that the presence of tin mining in the waters results in a significant difference in the average 10-year total suspended solids values observed from Landsat 8 satellite imagery. Although the difference in average values is very small (only 0.51 mg/L).

Author Contributions: Conceptualization by Filialdi Nur Hidayat, Taryono and Fery Kurniawan; methodology by Filialdi Nur Hidayat, Taryono and Fery Kurniawan; software by Filialdi Nur Hidayat and Fery Kurniawan; validation by Filialdi Nur Hidayat, Taryono and Fery Kurniawan; formal analysis by Filialdi Nur Hidayat and Fery Kurniawan; investigation by Filialdi Nur Hidayat; resources by Filialdi Nur Hidayat; data curation by Filialdi Nur Hidayat, Taryono and Fery Kurniawan; writing original draft preparation by Filialdi Nur Hidayat; writing review and editing by Taryono and Fery Kurniawan; visualization by Filialdi Nur Hidayat; supervision by Taryono and Fery Kurniawan; project administration by Filialdi Nur Hidayat; funding acquisition by Filialdi Nur Hidayat. All authors have read and agreed to the published version of the manuscript.

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References

Arif, N., Toersilowati, L., 2024. Using artificial neural networks and spectral indices to predict water availability in New Capital (IKN) and its' surroundings. Journal of the Indian Society of Remote Sensing. 52, 1549-1560. https://doi.org/10.1007/s12524-024-01889-z

Badan Pusat Statistik Provinsi Kepulauan Bangka Belitung, 2026. Ekspor timah dan nontimah Kepulauan Bangka Belitung berdasarkan HS 2022 (US$). Badan Pusat Statistik Provinsi Kepulauan Bangka Belitung. Diakses 8 Maret 2026. https://babel.bps.go.id/id/statistics-table/2/MTEyNyMy/ekspor-timah-dan-nontimah-kepulauan-bangka-belitung-berdasarkan-hs-2022.html

Bianchi, T.S., Allison, M.A., 2009. Large-river delta-front estuaries as natural "recorders" of global environmental change. Proceedings of the National Academy of Sciences. 106(20), 8085-8092. https://doi.org/10.1073/pnas.0812878106

Cahyo, A.M.D., 2024. Dinamika musiman sebaran total suspended solid (TSS) dan analisis risiko terhadap habitat terumbu karang di Perairan Selat Madura [Tesis]. IPB University, Bogor.

Declaro, A., Brown, Z., Kanae, S., 2025. VAWIlog: a log-transformed LSWI-EVI index for improved surface water mapping in agricultural environments. Remote Sensing. 17(16), 2771. https://doi.org/10.3390/rs17162771

Kurniawan, K., Supriharyono, S., Sasongko, D.P., 2019. Pengaruh kegiatan penambangan timah terhadap kualitas air laut di wilayah pesisir Kabupaten Bangka Provinsi Kepulauan Bangka Belitung. Akuatik: Jurnal Sumberdaya Perairan. 8(1), 13-21.

Laili, N., Arafah, F., Jaelani, L.M., Subehi, L., Pamungkas, A., Koenhardono, E.S., Sulisetyono, A., 2015. Development of water quality parameter retrieval algorithms for estimating total suspended solids and chlorophyll-a concentration using Landsat-8 imagery at Poteran Island water. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences. II-2/W2, 55-62. https://doi.org/10.5194/isprsannals-II-2-W2-55-2015

Lillesand, T.M., Kiefer, R.W., 1990. Penginderaan jauh dan interpretasi citra. Dulbahri, P. Suharsono, Hartono, Suharyadi, penerjemah. Gadjah Mada University Press, Yogyakarta.

Mustafa, P.S., 2022. Statistika inferensial meliputi uji beda dalam pendidikan jasmani: sebuah tinjauan. Didaktika: Jurnal Pemikiran Pendidikan. 28(2(1)), 71-86. https://doi.org/10.30587/didaktika.v28i2(1).4166

Pamungkas, A., Husrin, S., 2020. Pemodelan sebaran sedimen tersuspensi dampak penambangan timah di Perairan Bangka. Jurnal Ilmu dan Teknologi Kelautan Tropis. 12(2), 353-366. https://doi.org/10.29244/jitkt.v12i2.27875

Pemerintah Republik Indonesia, 2021. Peraturan Pemerintah Republik Indonesia Nomor 22 Tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup.

Pradana, M.R., Semedi, J.M., 2025. Effortless coastal monitoring: unsupervised detection of shoreline alterations due to tin mining in Bangka Belitung. IOP Conference Series: Earth and Environmental Science. 1462(1), 012004. https://doi.org/10.1088/1755-1315/1462/1/012004

Rahmani, D.A., Risnawati, R., Hamdani, M.F., 2025. Uji T-Student dua sampel saling berpasangan/dependend (paired sample t-test). Jurnal Penelitian Ilmu Pendidikan Indonesia. 4(2), 568-576.

Ramadhani, A., Polem, A.M., Miranda, M., Zahra, S.S., 2022. Konsep dasar uji T dalam statistika pendidikan. Al Itihadu Jurnal Pendidikan. 1(1), 94-102. https://doi.org/10.63736/ai.v1i1.23

Shanghai Metals Market, 2020. Indonesia's PT Timah cuts tin production and delays exports on COVID-19 impact. Shanghai Metals Market, 19 March 2020. Diakses 8 Maret 2026. https://news.metal.com/pt/newscontent/101045230-indonesias-pt-timah-cuts-tin-production-and-delays-exports-on-covid-19-impact

Shanghai Metals Market, 2022. Global tin production increases due to rebound in consumer demand in 2021. Shanghai Metals Market, 22 February 2022. Diakses 8 Maret 2026. https://news.metal.com/vn/newscontent/101756944-global-tin-production-increases-due-to-rebound-in-consumer-demand-in-2021

Syamdhora, R., Juniah, R., Rozirwan, 2025. Kajian metode penambangan timah di laut untuk mengurangi dampak penyebaran sedimen pada perairan laut di Laut Matras Kabupaten Bangka. Jurnal Locus: Penelitian dan Pengabdian. 4(6), 2672-2688. https://doi.org/10.58344/locus.v4i6.4391

Tesfaye, M., Breuer, L., 2024. Performance of water indices for large-scale water resources monitoring using Sentinel-2 data in Ethiopia. Environmental Monitoring and Assessment. 196, 467. https://doi.org/10.1007/s10661-024-12630-1

The International Banker, 2022. Why have tin prices struggled in 2022? The International Banker, 6 December 2022. Diakses 8 Maret 2026. https://internationalbanker.com/brokerage/why-have-tin-prices-struggled-in-2022/

United States Geological Survey, 2019. Landsat 8 (L8) data users handbook. Version 5.0. U.S. Geological Survey, Earth Resources Observation and Science Center, Sioux Falls, South Dakota.

Wardhana, A.G., Santoso, 2023. Pemodelan sebaran total suspended solid (TSS) dari pembuangan limbah pengeboran di Laut Natuna Utara. Coastal and Ocean Journal. 7(1), 1-16. https://doi.org/10.29244/coj.v7i1.44738