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Abstract

Jakarta Bay is a bay supporting the economy of thousands of nearby fishermen. Therefore, the reclamation in Jakarta Bay raises many environmental, economic, and social problems. During this reclamation, dredging and stockpiling activities increase the turbidity of the waters. This research aims to determine the changes in the distribution of total suspended solids (TSS) after reclamation using Sentinel 2A satellite imagery from 2016 to 2022. This research implemented the previous algorithm to produce the distribution of TSS in Jakarta Bay for attaining TSS values from Sentinel 2A satellite imagery processed by Google Earth Engine with overlay analysis method in a geographic information system. Spatial data were obtained by extracting TSS values using the previous estimation algorithm, namely the Budhiman algorithm, with a correlation coefficient of -0.745 and NMAE of 0.167. Based on the data processing results, it was found that the distribution of TSS from 2016 to 2022 was at a moderate level, which had a relatively significant influence on fisheries, requiring the fishermen to go to the open sea farther from the coast. This shows that reclamation carries no impact on the life of marine biota in Jakarta Bay.

Keywords: Jakarta Bay; reclamation; sentinel 2A; total suspended solids

1. Introduction

The issues of reclamation is essential as it affects the environment, people's lives, and the economy of the surrounding area. Meanwhile, the bay area has a very complex ecosystem with high biodiversity. Therefore, reclamation in the bay area can disrupt the survival of various animal and plant species. Reclamation can also affect water and air quality, threaten the sustainability of coral reefs, and increase the risk of natural disasters, such as floods and landslides. Contrastingly, in economic terms, reclamation provides various benefits, such as boosting the local economy through property development. Simultaneously, it possibly carries a negative impact on the tourism and fishing sectors that depend on the environment of the bay. Meanwhile, it also influences the social aspect, such as the rights of local communities and their participation in decision-making related to reclamation, as well as the possible issue of conflicts of interest. Therefore, the issues of reclamation demand a comprehensive investigation that regards a balance between the environmental, social, and economic sectors.

In Indonesia, the Jakarta Bay reclamation has become a polemic for the past few years. Reclamation will undoubtedly affect the quality of Jakarta Bay waters. According to the Executive Director of the Wahana Lingkungan Hidup Indonesia (WALHI), Tubagus Soleh Ahmadi, reclamation will change the Jakarta Bay ecosystem's landscape and the location of the fishermen's management area (Tio, 2018). Furthermore, this reclamation will increase the fisherman's difficulties in getting fish because of environmental damage due to reclamation, which further declines the economy.

As highlighted in WALHI's statement, reclamation in Jakarta Bay tends to harm marine life. In some cases, reclamation accelerates the rate of coastal erosion and causes flooding (Edyanto, 2016). In addition, reclamation also triggers damage to marine ecosystems, such as coral reefs and mangroves. Further, reclamation increases the total suspended solid (TSS) concentration in water (Liu et al., 2011). Increases in TSS can occur naturally as part of the water and aquatic ecosystems' life cycle, such as in events such as natural floods or tides. However, in many cases, the increasing TSS in waters can be caused by human activities, such as urban development, agriculture, and industry (Sholihin, Perwira, & Ernawati, 2021). In these situations, increasing TSS can harm water quality and aquatic ecosystems, damaging the ecosystems and impacting human health (UN GEMS/Water Programme, 2008).

In addition, the sediment concentration can be monitored through the total suspended solid (TSS) value before and after reclamation. The high TSS concentrations will inhibit light penetration into the water and disrupt the photosynthesis process (Kamajaya, Putra, & Putra, 2021), so it will disrupt the food chain associated with phytoplankton (Hiwari, 2018). Further, the low phytoplankton levels reduce the fish populations, restricting fishermen's ability to catch fish. According to the Ministerial Decree of the Ministry of Environment No 51 The Year 2004 concerning seawater quality standards, the TSS threshold for fisheries and marine park conservation is <80 mg/L.

Observation of water quality conditions using conventional methods over a sufficiently large area will undoubtedly be costly and time-consuming. Therefore, remote sensing appears as the alternative for effective and efficient monitoring. Remote sensing, especially satellite imagery, can be used to observe and analyze water conditions in the marine sector. Satellite imagery can be divided into three categories based on its sensor type, namely multispectral, hyperspectral, and radar. This study utilized Sentinel 2A multispectral imagery with a spatial resolution of 10 meters and a temporal resolution of 5 days. We also used several previous TSS estimation algorithms, including the Budhiman, Parwati, and Lestari algorithms, for extracting the TSS value from the Sentinel 2A imagery with the help of Google Earth Engine (GEE), a cloud computing platform.

A number of TTS studies using satellite imagery data have been carried out in Indonesia, but they used Landsat satellite imagery which has a spatial resolution of 30 meters without data processing through a cloud computing platform (Fanela, Takarina, & Supriatna, 2019; Kamajaya et al., 2021; Wibisana, Soekotjo, & Lasminto, 2019). In this study, we used Sentinel 2A as it offers more accurate measurement because of its better spatial resolution than other free satellite imagery. Further, the GEE was also used since it can process data more quickly and efficiently due to its abundant amount of images depicting before and after the reclamation in Jakarta Bay. The results of this study provide the necessary data and information to evaluate the environmental impact of reclamation, identify risks and challenges, and provide solutions and recommendations to overcome problems as they arise. Thus, the studies concerning reclamation in Jakarta Bay must be a priority for stakeholders and the government to ensure the sustainable development of Jakarta Bay which takes into account the interests of all parties involved. Therefore, this study aims to determine the changes in the distribution of total suspended solids in Jakarta Bay after reclamation from 2016 to 2022.

2. Method

This study was conducted in Jakarta Bay, Jakarta Province, Indonesia, at 5° 48’ 29.88” S - 6° 10’ 30” S and 106° 33’ 00” E - 107° 03’ 00” E (Figure 1). Jakarta Bay has a coastline of ± 80 km with an average depth of 15 m and a sloping bottom, which grows deeper in its further north (Hidayah & Apriyanti, 2020). Jakarta Bay carries crucial roles for the surrounding society, especially in the economic and environmental sectors. From an ecological perspective, this bay supports marine life in the Java Sea. However, it is seriously threatened by pollution from human activities and waste from 13 rivers in Jakarta and its surroundings.

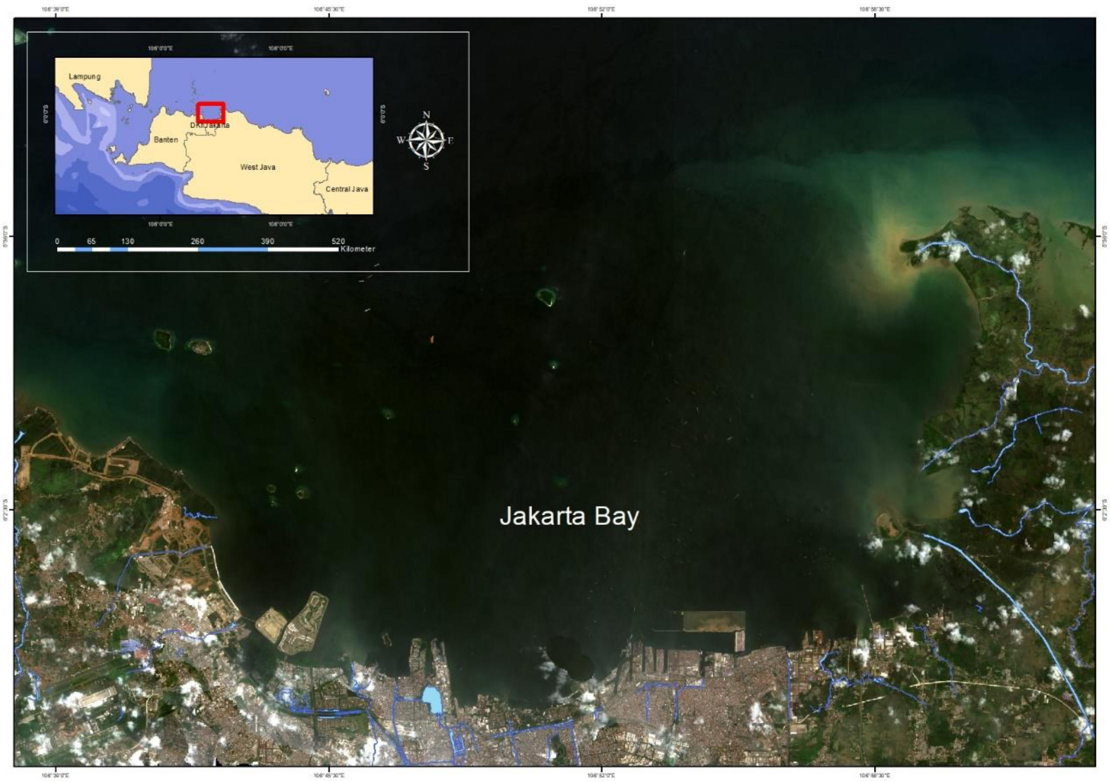

Figure 1. Research site

The essential data for this study was obtained from previous field surveys, which were carried out by taking 11 sample points on 18-21 May 2021 in the Kepulauan Seribu waters (Figure 2), which have a close location to Jakarta Bay. Therefore, it is reasonable to presume that the water quality in these two areas is comparable. Concurrently, our secondary data consist of two data set. First, the sentinel 2A multispectral image data was collected through the ESA database on the GEE (Google Earth Engine) platform and the administrative boundaries of the Province of DKI Jakarta that were collected from Inageoportal (Indonesian Geospatial Information Agency). Additionally, we also conducted interviews with several fishermen around Jakarta Bay to confirm the data on the reclamation impacts.

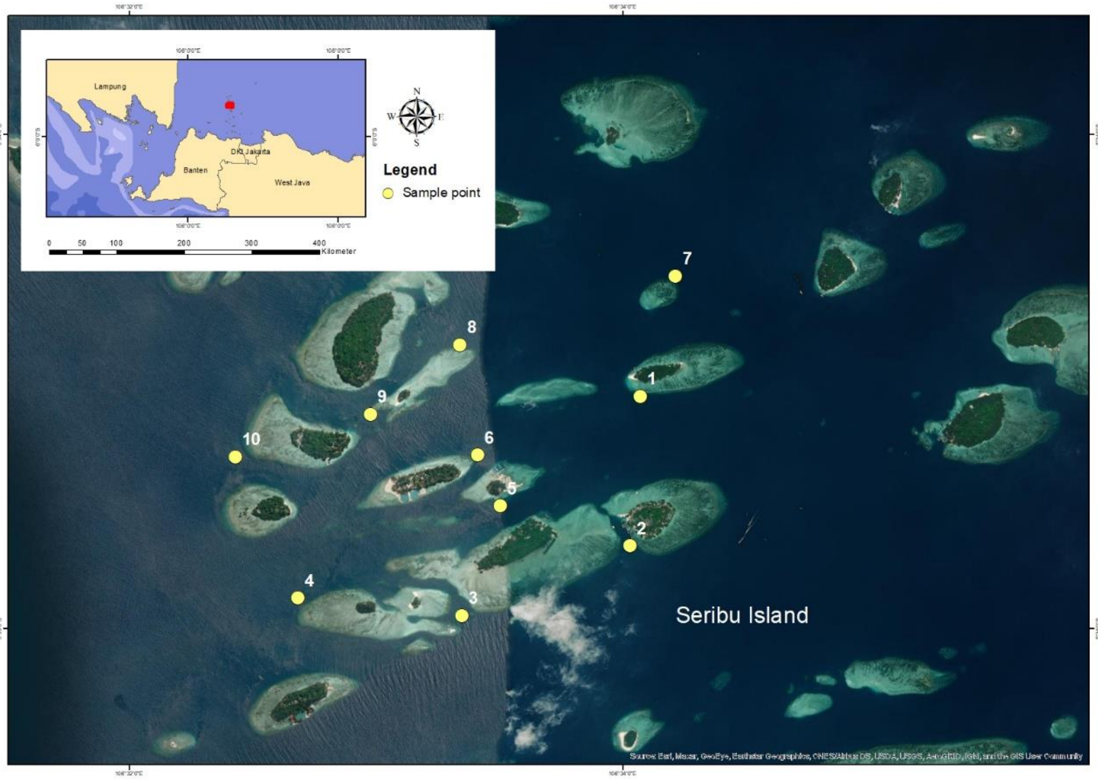

Figure 2. Sample Points of TSS

All data were processed through GEE, from image preprocessing to extracting TSS values. GEE is a cloud-based platform that provides easy access to high-performance computing resources for processing massive geospatial data sets with no IT issues (Gorelick et al., 2017). GEE offers several features compared to other data processing applications, such as free and easy access to global data, fast data processing on a large scale, high scalability, easy-to-learn programming languages, and accessibility via the internet. Therefore, an estimation algorithm (Table 1) is required to identify the distribution of TSS conditions in the study area. In this study, we used the available algorithm to estimate the TSS value, such as Parwati et al. (2006), Budhiman et al. (2004), and Lestari (2009), and in-situ values obtained through laboratory tests.

Table 1. TSS Algorithms

Parameter	Algorithms	Equation	Year
	Parwati	3.3238*exp (34.099*Red)	2006
	Budhiman	7.9038*exp (23.942*Red)	2004
TSS		24197x3-22050x2+6813x +664.98	
	Lestari	-26390x3+35823x2-16250x +2468	2009
		x = Blue chromaticity	

This algorithm was selected based on prior research with a comparable focus which shows that the performance of these algorithms has been tested in various locations in Surabaya Coast (Hariyanto, Krisna, Khomsin, Pribadi, & Anwar, 2017), Gadjah Mungkur reservoir (Sudarsono, Sukmono, & Santoso, 2018), Berau (Parwati & Purwanto, 2017), Lamongan (Akbari, 2016), etc. The correlation and accuracy of the in-situ value to the image value were carried out by calculating the correlation coefficient (R) and error value between the in-situ value. The image value is required for determining the applicability of a given algorithm in the study region (NMAE). The accuracy of the estimating algorithm implemented in satellite imagery can be tested using the Normalized Mean Absolute Error (NMAE) index and the correlation coefficient (R) (Jaelani et al., 2016). Therefore, the NMAE was used to determine the absolute error of the model algorithm estimation value with the field measurement results. At the same time, the correlation coefficient (R) was used to determine the best correlation between the estimated value of the model algorithm and the measurement results in the field. The NMAE and R formulas are shown in Formulas 1 and 2.

$$\text{NMAE } (\%) = \frac{1}{N} \text{ x } \sum \frac{|x\ estimated - x\ measured|}{x\ measured} \text{ x } 100 \qquad (1)$$

Which:

NMAE = Normalized Mean Absolute Error
N = amount of data
X estimated = Processed value
X measured = The value of the field measurement results that are considered correct

$$R = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n(\Sigma x2) - (\Sigma x)^2 [n(\Sigma y2) - (\Sigma y)^2]}} \qquad (2)$$

Which:

Y = Response variable or effect variable (dependent)
X = Predictor variable or causal factor variable (independent)
N = amount of data

Algorithms with R are in the range of moderate to strong (0.5-1) (Meghanathan, 2016), while the NMAE <30% can be used in estimating the TSS and SST values in the study area (Jaelani, Setiawan, & Matsushita, 2015). TSS value was extracted by uploading a sample point shapefile, appointing the image with the image collection function, setting the image date using the date filter function, and creating a script according to the calculations of each algorithm. After that, the extract from each sample point was obtained by exporting it to the table function. Furthermore, the estimation algorithm was implemented on the 2016-2022 image data by creating a script according to the Budhiman algorithm calculation and extracting the TSS median value in the study area with the Reducer.median() function. We used the median function because it offers fast computation, so it facilitates the quick creation of cloud-free images for an area (Digital Earth Africa, 2020). Finally, overlay analysis was carried out on depth maps and TSS distribution maps in Jakarta Bay from 2016 to 2022.

3. Results and Discussion

3.1. Accuracy Test for TSS Algorithm Selection in Jakarta Bay

Algorithm testing was carried out at the point in situ with the point extraction value from the Sentinel 2A image. This accuracy test was carried out to determine the algorithm suitable for estimating the TSS value in Jakarta Bay (Table 2). In testing the algorithm, three types of algorithms were used, namely the Parwati, Budhiman, and Lestari's algorithm (Budhiman et al., 2004; Lestari, 2009; Parwati et al., 2006).

Table 2. Accuracy Test of Several TSS Algorithms

Sample	Lat	Long	TSS	Algorithms			
				Budhiman	LestariH	LestariK	Parwati
1	-5.58431	106.5678	61	58.74311	2.539397	0.001369	35.18334
2	-5.59442	106.5671	50	61.93232	2.581105	0.001163	37.09347
3	-5.59912	106.5558	50	63.06397	2.557931	0.001272	37.77126
4	-5.59793	106.5447	81	52.67333	2.572858	0.001201	31.54794
5	-5.59173	106.5584	40.33	70.16253	2.539579	0.001368	42.02284
6	-5.58829	106.5568	61	63.57836	2.522805	0.001462	38.07935
7	-5.57621	106.5702	54.67	60.69779	2.563166	0.001247	36.35407
8	-5.58084	106.5557	62.67	59.15462	2.580352	0.001167	35.42981
9	-5.58553	106.5496	59.67	52.51902	2.586621	0.001139	31.45551
10	-5.58841	106.5404	62.33	49.89564	2.522393	0.001465	29.88428
R				-0.74448	-0.17547	-0.9992	0.156459
NMAE				0.167345	9.561223	9.999779	3.910415

Parwati's algorithm has a correlation coefficient (R) of 0.156, which indicates no significant correlation between the in-situ value and the image value. Although the obtained NMAE value was 3.910%, it is still within the 30% threshold. This correlation coefficient value shows a weak relationship, making this algorithm less suitable to be implemented in Jakarta Bay. Lestari's algorithm has two algorithms for the dry season and the rainy season; the algorithm in the dry season has a better correlation coefficient (R) than the algorithm in the rainy season of -0.999, which indicates a strong correlation between the in-situ value and the image value. The NMAE value of 9.999% suggests minimum errors and is still within the 30% threshold. Theoretically, the Lestari algorithm in the dry season can be used to estimate the TSS value in Jakarta Bay. However, as summarized in Table 2, Budhiman's algorithm has a correlation coefficient of -0.7444 and an NMAE of 0.167, indicating its smaller correlation coefficient and error value than the Lestari algorithm in the dry season. Thus, the most suitable algorithm to estimate the TSS value in Jakarta Bay is the Budhiman algorithm.

3.2. Spatial Distribution of TSS in 2016-2022 and Jakarta Bay Reclamation

According to the Ministerial Decree of the Ministry of Environment No 51 The Year 2004 concerning seawater quality standards, the TSS threshold for the fisheries and conservation marine parks is <80 mg/L (Ministry of Environment, 2004). Thus, in classifying the TSS, we referred to research by Permatasari et al. (2019), as described: a) Class I, with a TSS value of <25 mg/L, represents no significant influence in fisheries, b) Class II with a TSS value of 25-80 mg/L represents a moderate effect on fisheries interests, and c) Class III with a TSS value of > 80 mg/L shows unsuitability for fisheries.

The spatial distribution of TSS values in 2016 is dominated by 25-80 mg/L TTS value, which is classified as having a moderate effect on fisheries. However, in the middle of the bay, there is a small distribution of high TSS, which is possibly caused by the recently completed island reclamation. Thus, the detected TSS value remains exceptionally high in the middle of the bay, as illustrated in Figure 3. Meanwhile, in 2017-2021, the TSS values mainly ranged between 25-80 mg/L, classified as having a moderate effect on fisheries, as illustrated in Figure 3 (Permatasari et al., 2019). The spatial distribution of TSS values in 2022 (Figure 3) appears to be different from the spatial distribution in previous years. This can be caused by the satellite images captured in only eight months, from January–August, producing the median image that displays more data in the dry season.

The TSS value appears to increase on the coast because rivers carry TSS material from the Jakarta mainland to the estuaries in Jakarta Bay, which carry a high TSS value (>80 mg/l). Waters with a TSS value of >80 mg/L represent a high level of pollution that significantly impacts fisheries (Permatasari et al., 2019). The high concentration of TSS in the dry season can be caused by low rainfall, unabling the sedimentation to move towards the open seas, thus affecting TSS levels in estuaries in the waters of Jakarta Bay. If we exclude the 2022 data, the mean and maximum TSS value in 2016 is higher than the other year, which was 282.77 mg/L, and 40.64 mg/L (Table 3). This finding signifies that the higher TSS value is probably caused by any reclamation activities in Jakarta Bay. In general, the average TSS mean value from 2016 until 2022 was 35.48 mg/L, indicating that the waters were slightly polluted and affected the fisheries around the bay.

Table 3. TSS Mean Value in 2016-2022

Year	Min	Max	Mean (mg/L)
2016	24.07	282.37	40.64
2017	24.74	146.86	33.43
2018	28.9	136.64	35.74
2019	28.55	146.7	37.61
2020	24.37	155.58	33.24
2021	24.39	170.55	32.76
2022	73.61	206.24	80.13
2016-2022	28.88	145.29	35.48

Based on the remote sensing results, the TSS level from 2016 to 2021 did not demonstrate significant changes, as they are still at the same moderate level. A moderate level signifies the effects of TSS on the fisheries and the alarming rate of sedimentation. This high TSS value is an accumulation of various factors in the waters, from the mainland of Jakarta to the reclamation of Jakarta Bay (Figure 4). As reported in a previous study, coastal reclamation can change the ecosystem around the reclaimed area (Puspasari & Turni, 2017). The possible changes from this reclamation may include changes in current patterns, erosion, and sedimentation (Bambang, Sambodho, & Suntoyo, 2010), as well as the composition and abundance of biota living in the reclaimed aquatic environment. Meanwhile, increased sedimentation can change the morphology of the seabed which will cause siltation of the seabed (Suntoyo, Hidayah, & Ikhwani, 2017). In addition, increased turbidity and loss of mangrove forests due to reclamation can reduce the ecological role of Jakarta Bay as a spawning area and nursery area for various types of aquatic biotas, such as fish, shrimp, and mollusks, due to the decreased environmental carrying capacity (Puspasari & Turni, 2017). As reinforced by one of the fishermen participating in the interview that the reclamation of Jakarta Bay harmed fishing activities on the coast of North Jakarta, imposing the fishermen to go further into the open sea because of the lower amount of fish on the beach due to polluted waters. Similarly, the fishermen in the Kepulauan Seribu Utara also confirm the lowering population of fish after the reclamation in Jakarta Bay.

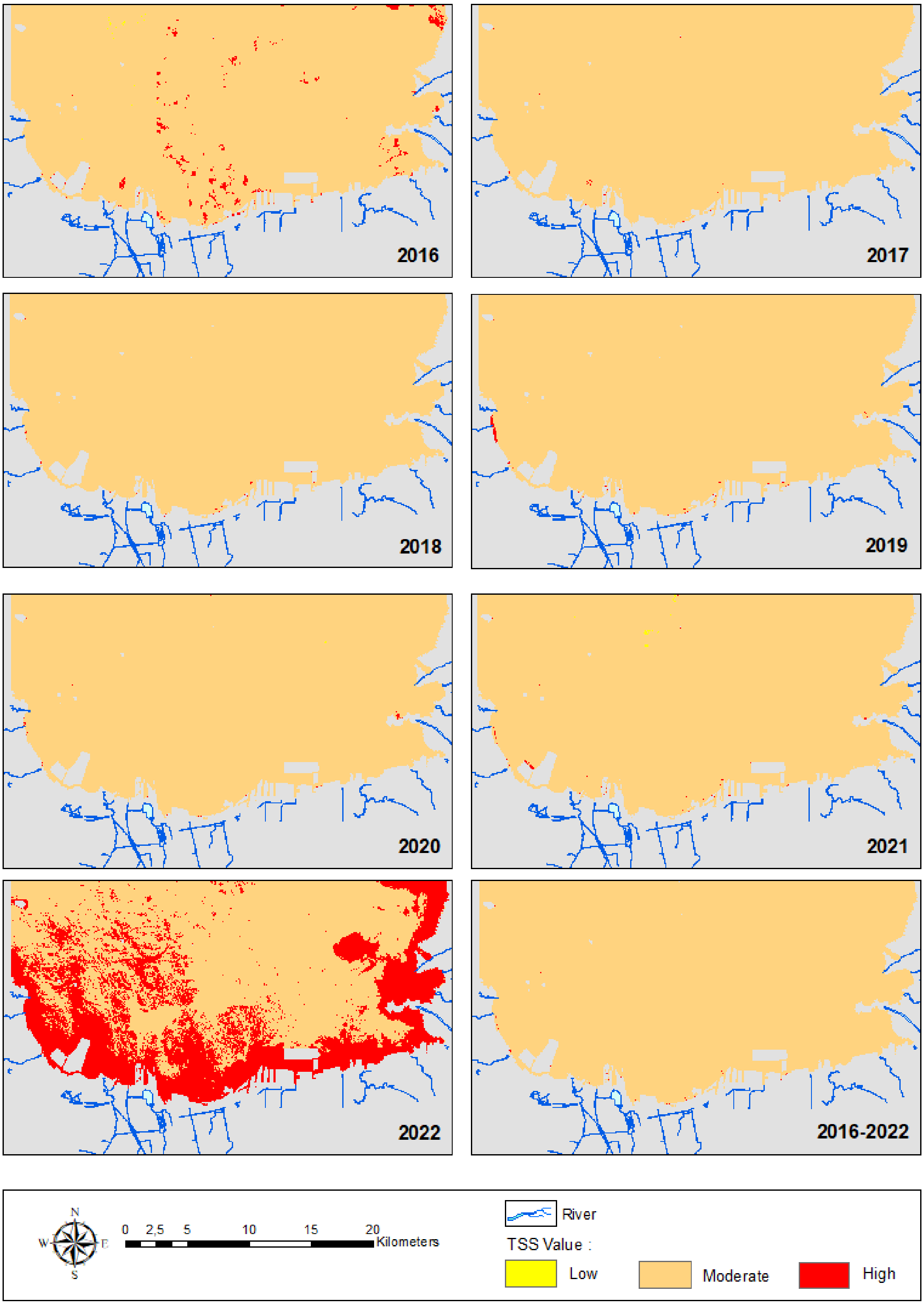

Figure 3. Distribution of TSS in 2016-2022

Figure 4. Reclamation Island

Interestingly, during our field monitoring, we found a large population of jellyfish on the coast (Figure 5). The overpopulation of jellyfish is one of the indications of overpolluted waters. Polluted seawater diminishes marine biota that acts as jellyfish predators, thereby reducing the number of jellyfish preyed upon and augmenting the jellyfish population. Due to their adaptability to contaminants, jellyfish are not adversely affected by substances and materials that pollute seawater and their surroundings (Pradana, 2016). Besides, in 2019, there was an explosion in the jellyfish population on Ancol Beach (which belongs to the Jakarta Bay area), which is similar to the phenomena in 2022 (Firmansyah & Arjanto, 2019).

However, further comprehensive research on jellyfish in Indonesia is still required. Thus, an explosion in the population of jellyfish or other uncommon types of jellyfish in the area could be a sign of trouble. Some of the factors that can cause a jellyfish population explosion are climate change, pollution, overfishing, or rapid human population growth. Therefore, the presence of jellyfish must be analyzed in more comprehensive environmental conditions.

Figure 5. Jellyfish Population

From our analysis results, that reclamation can have a negative impact on the aquatic environment and the sustainability of the fisheries sector in Jakarta Bay. Therefore, efforts are needed to reduce the impact of reclamation, such as by carrying out strict supervision of reclamation, paying attention to environmental aspects in reclamation planning, and carrying out a comprehensive impact assessment before carrying out reclamation. In addition, efforts are needed to accelerate the condition of the aquatic environment that has been affected by reclamation, such as by restoring natural habitats and reducing water pollution.

4. Conclusion

Google Earth Engine aids speeding up Sentinel 2A image data processing. The accuracy test for determining the suitable TSS estimator algorithm for Jakarta Bay showed that Budhiman's algorithm, with a correlation coefficient of -0.745 and NMAE 0.167, is the ideal algorithm for our study area. The spatial distribution of TSS from 2016 to 2022 suggested that Jakarta Bay waters have a moderate level of TSS, which affects marine biota and induces turbidity in the waters, so fishermen have to go out farther to the sea. In future studies, we recommend future studies take more sample data and examine the effects of the jellyfish population in Jakarta Bay due to an increase in TSS.

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