Satellite-Based Detection of Floating Plastic Debris in Jakarta Bay (2021–2024)

M S Wilda[1] and E Pasaribu[1,*]

[1] Politeknik Statistika STIS, Jl. Otto Iskandardinata No. 64C, Jakarta, Indonesia

*Corresponding author's email: ernapasaribu@stis.ac.id

Abstract. Plastic waste is a critical environmental issue in Jakarta Bay, causing ecosystem degradation and challenging coastal management. This study analyzes seasonal dynamics and spatial impacts of floating plastic debris using Sentinel-2 imagery from July 2021 to November 2024. The Floating Debris Index (FDI) and Normalized Difference Vegetation Index (NDVI) were applied, with optimum thresholds determined through ROC curve analysis. Monthly median composites were processed to minimize atmospheric noise. The results show a recurring seasonal pattern, with debris consistently peaking in June, likely influenced by monsoon-driven runoff and human activities. A clear increasing trend from 2021 to 2023 was followed by a decline in 2024, coinciding with the implementation of the National Ocean Love Month program. Buffer analysis indicated that most debris accumulates within 500 m of the shoreline, particularly near river mouths, ports, and settlements, while Thiessen Polygon analysis revealed hotspots concentrated along the eastern and western coasts. These findings highlight that floating plastic debris in Jakarta Bay is strongly shaped by seasonal cycles and land-based inputs, providing critical insights for designing targeted, evidence-based waste management policies.

Keyword : Floating Debris Index, Plastic Waste, Seasonal Pattern, Sentinel-2, Spatial Analysis.

1. Introduction

Indonesia is a maritime country with an archipelagic characteristic, where most of its territory consists of ocean. The total area of Indonesian waters reaches 6,315,222 km², while its land area is 1,922,570 km² [1]. Indonesia is currently facing a significant plastic waste crisis, particularly marine plastic debris. With an estimated 3.25 million km² of ocean area, the total amount of marine litter in Indonesia is projected to reach 5.75 million tons, with plastics as the dominant component, accounting for 627.80 g/m² or 35.4% of the total in 2020 [2]. This situation threatens marine ecosystems, biodiversity, and the health of coastal communities.

Jakarta Bay is one of the most severely impacted coastal zones in Indonesia. More than 7,000 tons of waste were generated daily in Jakarta in 2022, with disposal capacity limited to 82% [3]. Approximately 5% of unmanaged waste flows into rivers such as the Ciliwung and Cisadane, eventually reaching Jakarta Bay [4]. This semi-enclosed bay suffers from severe plastic debris accumulation, causing habitat degradation, ecological imbalance, and socio-economic consequences for local communities [5]. Studies have reported that plastic debris density in Jakarta Bay can reach 10,300 items/km² during the rainy season and 7,400 items/km² during the dry season [6]. The comparison of plastic debris density between the rainy and dry seasons is presented in figure 1.

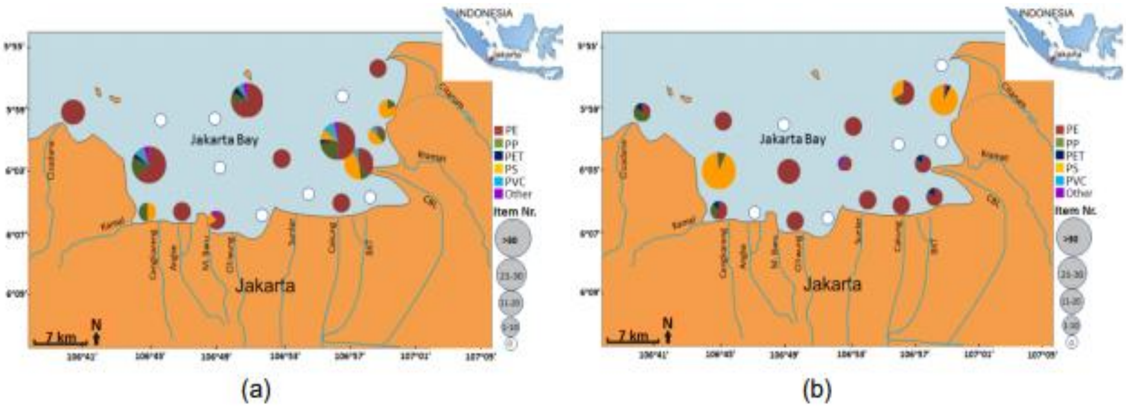

Figure 1. Plastic debris density during the rainy season (a) and dry season (b).

Source: Dwiyitno et al. (2020).

Conventional field-based monitoring of marine debris, while reliable, is resource-intensive and limited in spatial and temporal scope. As an alternative, remote sensing approaches have been increasingly applied. Sentinel-2, a multispectral imaging satellite by the European Space Agency (ESA), offers high spatial (10 m) and temporal (5–10 days) resolution suitable for monitoring floating debris. Biermann et al. [7] introduced the Floating Debris Index (FDI) for Sentinel-2, demonstrating its ability to identify macroplastic patches across four countries. Digital Earth Africa [8] applied FDI and NDVI to African waters, showing promising results in distinguishing plastics from vegetation. Themistocleous et al. [9] combined UAV and Sentinel-2 imagery, confirming that plastics exhibit strong spectral responses in the near-infrared range. Similarly, Danilov and Serdiukova [10] emphasized that NDVI is not sensitive to plastics but is useful in separating them from natural floating materials such as wood, pumice, and sea foam.

In addition to debris detection, several studies focused on spatial and temporal analysis. Cózar et al. [11] examined litter windrow density (LWD) using spatio-temporal models to understand plastic accumulation patterns influenced by environmental drivers. Other works highlighted the role of hydrodynamic and seasonal factors in redistributing plastic debris across coastal systems. However, the integration of spatial analytical techniques, such as buffer analysis to delineate impacted coastal zones and Thiessen Polygon analysis to identify dominant accumulation areas, remains limited in the context of marine plastic research.

Despite these advancements, research on floating plastic detection in Indonesia, particularly in Jakarta Bay, remains scarce. Most previous studies either relied on field sampling or lacked spatial-temporal integration with geospatial techniques. Therefore, this study seeks to address these gaps by (1) detecting floating plastic debris using Sentinel-2 imagery and spectral indices (FDI and NDVI), (2) identifying seasonal patterns between 2021 and 2024, and (3) evaluating the spatial impacts of debris accumulation using buffer and Thiessen Polygon methods. The outcomes are expected to provide evidence-based insights for marine waste management and coastal sustainability in Indonesia.

This study aims to detect and map floating plastic debris in Jakarta Bay using Sentinel-2 satellite imagery, an approach that has received limited attention in Indonesia. While previous research has demonstrated the feasibility of remote sensing for marine debris detection, most studies have not incorporated temporal monitoring, resulting in limited understanding of seasonal and interannual variability. In particular, the spatio-temporal dynamics of floating debris accumulation remain poorly documented in the Indonesian context.

Previous studies have demonstrated that FDI and NDVI are effective in differentiating floating plastic debris from other natural materials due to their distinct spectral responses in the near-infrared (NIR) and shortwave infrared (SWIR) regions. Biermann et al. and Topouzelis et al. showed that FDI enhances the spectral contrast between floating plastics and seawater, while NDVI effectively filters out vegetation or organic matter with higher reflectance in the red and NIR bands [7], [12]. Therefore, applying threshold optimization through ROC analysis allows this study to empirically determine the most suitable cutoff values for distinguishing plastic debris from other surface materials in the specific spectral context of Jakarta Bay.

Moreover, the integration of threshold-based classification using the Floating Debris Index (FDI) and the Normalized Difference Vegetation Index (NDVI) with spatial analyses such as buffer and Thiessen Polygon has not been widely implemented. This methodological framework provides a novel contribution by enabling both the detection of debris and the assessment of its spatial impacts on coastal areas. Through this integration, the study offers a more comprehensive perspective on the distribution, seasonal patterns, and potential impacts of floating plastic debris in Jakarta Bay.

2. Research Method

The methodological framework of this study follows the CRISP-DM standard, which serves as the conceptual framework of the research. The workflow begins with defining the research problem (business understanding), continues with exploring the characteristics of Sentinel-2 imagery and supporting data (data understanding), and proceeds with preprocessing and composite generation (data preparation) [13]. The modeling stage applies spectral indices, FDI and NDVI, combined with ROC-based thresholding, followed by spatial and temporal analyses. The results are then evaluated using balanced accuracy, and finally, the findings are deployed to provide actionable insights for policymakers. The overall research flow is illustrated in figure 2.

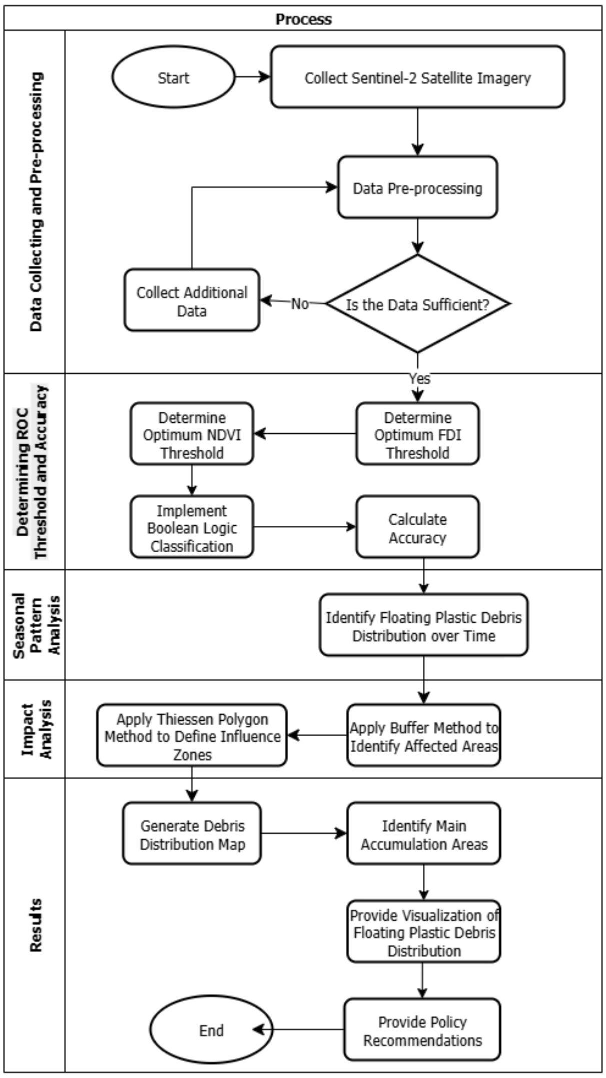

Figure 2. Research flowchart.

2.1. Business understanding

Marine plastic waste in Jakarta Bay represents a critical environmental issue with direct impacts on ecosystems and coastal livelihoods. Conventional monitoring methods rely on field observations that are costly and spatially limited. To address these limitations, this study aims to design an efficient and comprehensive method for detecting and mapping floating plastic debris. Sentinel-2 multispectral imagery combined with spectral indices, the Floating Debris Index (FDI) and the Normalized Difference Vegetation Index (NDVI), was adopted to improve detection accuracy and support evidence-based management of Jakarta Bay.

2.2. Data understanding

The study area covers approximately 514 km² of Jakarta Bay, located between 5°09′–6°02′S and 106°65′–107°05′E in figure 3. This semi-enclosed bay receives inputs from multiple rivers, including the Ciliwung and Cisadane, and is characterized by high urban and industrial influence [6], [14]. The primary dataset is Sentinel-2 MSI Level-2A imagery collected between July 2021 and November 2024, excluding December–February due to persistent cloud cover. Sentinel-2 provides 13 spectral bands at 10–60 m spatial resolution with a 5–10 day revisit cycle [15]. Two indices were applied: FDI, to detect floating debris, and NDVI, to separate plastics from vegetation. Reference data were obtained from the MARIDA dataset [16].

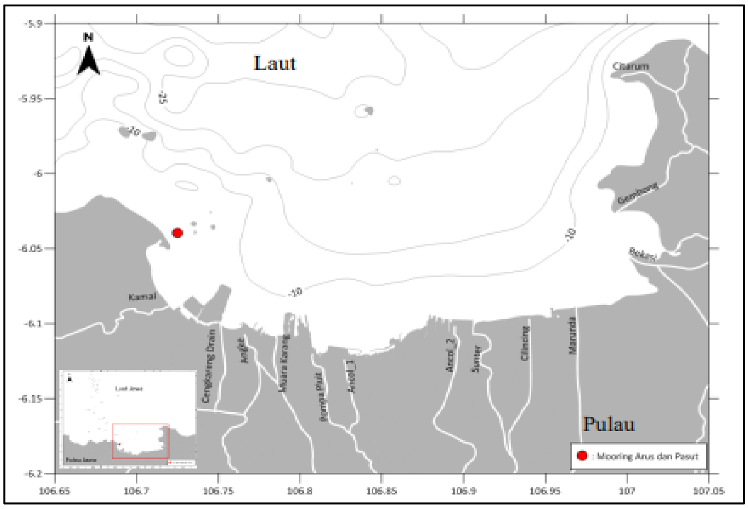

Figure 3. The study area.

Source: Yonvitner et al. (2023).

2.3. Data preparation

Preprocessing was conducted in the Google Earth Engine (GEE) environment. Sentinel-2 Level-2A images underwent atmospheric correction and cloud masking. Noise removal was applied to minimize irrelevant reflectance, such as sun glint. Monthly median composites were generated to reduce variability and improve temporal consistency. FDI and NDVI were computed for each composite. NDVI was calculated as [7]:

$$NDVI = \frac{NIR-Red}{NIR+Red} \tag{1}$$

where

- NIR (Near-Infrared) represents wavelengths that are highly reflected by healthy vegetation due to the internal structure of leaf cells.
- Red represents wavelengths that are strongly absorbed by chlorophyll during the process of photosynthesis.

FDI was calculated following [7]:

$$FDI = NIR - RE2 - (SWIR1 - RE2) \times \frac{(\lambda_{NIR} - \lambda_{RED})}{(\lambda_{SWIR1} - \lambda_{RED})} \times 10 \tag{2}$$

where

- NIR = Reflectance in the Near-Infrared (NIR) band
- RE2 = Reflectance in the Red (RE2) band
- SWIR1 = Reflectance in the Shortwave Infrared (SWIR1) band

- λ = Wavelength of each spectral band.

2.4. Modeling

The modeling stage was designed to address the three main research objectives: detection of floating plastic debris, analysis of seasonal patterns, and assessment of spatial impacts in Jakarta Bay.

2.4.1. Floating Debris Detection. Detection was performed through a pixel-based spectral classification approach using Sentinel-2 imagery. Two indices were applied: Floating Debris Index (FDI) to identify potential floating materials, and Normalized Difference Vegetation Index (NDVI) to differentiate non-vegetated from vegetated areas. Pixels were classified as floating plastic debris when FDI values exceeded the optimal threshold and NDVI values were below the vegetation threshold. The optimal thresholds were determined using Receiver Operating Characteristic (ROC) curve analysis, with Youden's J statistic used to maximize the trade-off between sensitivity and specificity [17].

2.4.2. Seasonal Pattern Analysis. To analyze temporal variations, a time-series decomposition approach was applied to the monthly median values of the Floating Debris Index (FDI) and Normalized Difference Vegetation Index (NDVI) from July 2021 to November 2024. This method separates the data into trend, seasonal, and residual components, allowing identification of recurring patterns (seasonality) and long-term tendencies (trend). The analysis was conducted using the additive decomposition model in R, which is suitable for environmental datasets exhibiting moderate seasonal variation. The results from this decomposition directly address the second research objective: identifying seasonal patterns of floating plastic debris in Jakarta Bay.

2.4.3. Spatial Impact Assessment. Spatial impact analysis aimed to determine the extent and influence zones of debris accumulation. Two spatial methods were used:

1. Buffer Analysis: 500-meter buffer zones were constructed around detected debris clusters to estimate the coastal areas at potential risk from debris accumulation [18].
2. Thiessen Polygon Analysis: Voronoi diagrams were generated to delineate zones of spatial influence around debris hotspots, allowing identification of areas with high potential contribution to pollution sources such as rivers, ports, and settlements [19].

This integrated modeling framework ensured that each analytical step, detection, temporal analysis, and spatial evaluation, directly addressed the corresponding research objectives, providing a comprehensive understanding of floating plastic debris dynamics in Jakarta Bay.

2.5. Evaluation

Model performance was evaluated by comparing the predicted debris classification results with reference data to assess detection accuracy. The predicted raster was generated from the Boolean classification rule applied in the modeling stage, where each pixel was labeled as debris (1) or non-debris (0) based on the optimal thresholds of FDI and NDVI.

Reference labels were obtained from two sources:

1. The MARIDA dataset, which provides validated annotations of marine debris presence for Sentinel-2 imagery; and
2. Visual interpretation of high-resolution Sentinel-2 images over Jakarta Bay for December 2019, used as a ground-truth reference for unlabelled areas.

Each pixel's predicted value was then compared with its corresponding reference label to construct a confusion matrix. From this matrix, performance metrics including accuracy, sensitivity (true positive rate), specificity (true negative rate), and balanced accuracy (BA) were computed. Balanced accuracy was chosen as the primary indicator because of the unequal number of debris and non-debris pixels, and it is defined as [20]:

$$Balanced\ Accuracy = \frac{\frac{TP}{TP+FN}+\frac{TN}{FP+TN}}{2} \tag{3}$$

Receiver Operating Characteristic (ROC) curves were further analyzed to evaluate the trade-off between sensitivity and specificity and to verify the robustness of the selected threshold values.

To ensure that the results were not affected by underfitting, the model's performance was validated using independent reference data from different acquisition periods (December 2019 for validation and 2021–2024 for analysis). The consistency of classification accuracy across multiple temporal subsets indicated that the selected thresholds generalized well to unseen data. Furthermore, the ROC analysis showed stable Area Under the Curve (AUC) values across validation samples, confirming adequate model generalization and the absence of underfitting.

2.6. Deployment

The deployment stage in this study does not involve continuous or real-time environmental monitoring. Instead, it focuses on the dissemination of analytical results derived from the spatial and temporal analyses. The primary objective of this stage is to organize and present the research findings in a structured and interpretable format through static and interactive visualizations, such as maps and dashboards.

This stage serves as a means to communicate the outcomes of debris detection, buffer analysis, and Thiessen polygon mapping in a user-friendly way, supporting data-driven insights into coastal waste management. The deployment was limited to the presentation of results for analytical and dissemination purposes only, in line with the final research objective.

3. Result and Discussion

The results and discussion are presented in three subsections corresponding to the research objectives, namely: detection of floating plastic debris, analysis of seasonal patterns of floating plastic debris, and impact analysis of plastic debris distribution.

3.1. Detection of floating plastic debris

In this study, floating plastic debris in Jakarta Bay was detected through spectral analysis of Sentinel-2 satellite imagery. Two spectral indices were utilized: Floating Debris Index (FDI) to identify objects with reflectance patterns characteristic of floating debris, and the Normalized Difference Vegetation Index (NDVI) to differentiate non-vegetated surfaces from open water. To minimize anomalies and atmospheric disturbances such as clouds or noise, monthly median composite images were generated for the period from July 2021 to November 2024, excluding January, February, and December due to data unavailability.

A crucial step prior to classification was the determination of the optimal threshold values for the two indices, as these thresholds were used to separate pixels classified as floating plastic debris from non-debris pixels. To establish representative thresholds, the Receiver Operating Characteristic (ROC) approach was employed. ROC is a widely used statistical method for evaluating the performance of binary classification systems by comparing the true positive rate (TPR) and the false positive rate (FPR) [17]. In this context, FDI and NDVI values were compared against labeled reference data to evaluate the ability of each index to discriminate between the "debris" and "non-debris" classes.

The labeling process was conducted using two complementary approaches. First, reference labels were derived from the MARIDA (Marine Debris Archive) dataset, which provides annotated pixels of floating debris for Sentinel-2 imagery. These data served as a reliable benchmark for training and threshold analysis. Second, visual interpretation was performed on high-resolution Sentinel-2 images from December 2019 over Jakarta Bay. Areas exhibiting distinctive spectral signatures consistent with floating debris were manually labeled as “debris,” while open-water areas free from visible debris were labeled as “non-debris.” This combination of dataset-based and manually interpreted labels ensured that the ROC analysis captured both verified and context-specific conditions of floating plastic debris in the study area.

From the ROC curve, the optimal cutoff point was determined using Youden’s J statistic, which maximizes the difference between TPR and FPR [21]. The resulting thresholds were then applied in the classification process, whereby a pixel was categorized as floating plastic debris if its FDI value exceeded the optimal threshold and its NDVI value was below the corresponding threshold. This Boolean logic approach enabled a simple yet effective classification of floating plastic presence on the sea surface.

The determination of threshold values in this study utilized the MARIDA dataset (December 2019) for the same region, though coverage was limited to certain areas. Additional raster data from Google Earth Engine for December 2019 were also used, adjusted to the available region for validation purposes. The results of debris classification, expressed in terms of pixel counts, are summarized in the classification table presented below.

Table 1. Debris classification table.

		Actual	
		Debris	Non debris
Predicted	Debris	148	0
	Non debris	340	21

The threshold values were determined using the coords function in R, with the results summarized in table 2.

Table 2. Optimal threshold values for each index.

Index	Threshold	Sensitivity	Specificity
FDI	-0.3586353	0.3668033	0.952381
NDVI	-0.11418	0.817623	0.7619048

The threshold values determined in table 2 were subsequently applied to all Sentinel-2 imagery within the study period. A pixel was classified as floating plastic debris if its FDI value exceeded the optimal threshold and its NDVI value was below the corresponding threshold. The classification was performed using QGIS, resulting in a binary map that was then subjected to further geoprocessing for spatial analysis. The processed Sentinel-2 imagery of Jakarta Bay, displayed with spectral index-based visualization using the Normalized Difference Vegetation Index (NDVI) and the Floating Debris Index (FDI), is presented in the map below.

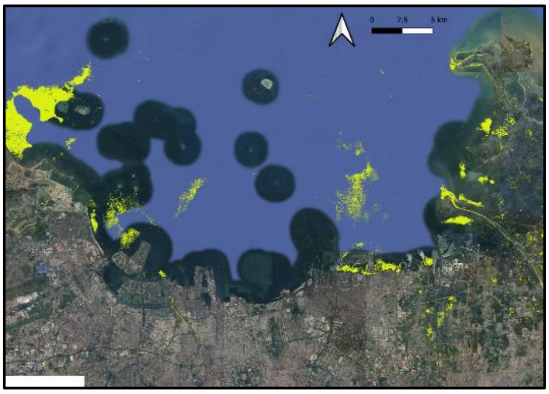

Figure 4. Detection results of floating debris using NDVI and FDI in April 2024.

Figure 5. Detection results of floating debris using NDVI and FDI in July 2024.

Figures 4 and 5 illustrate the differences observed following the implementation of the National Ocean Love Month (Gernas BCL) policy. This national movement, coordinated by the Ministry of Marine Affairs and Fisheries (KKP), is part of the government's commitment to reducing marine and coastal debris. The program, initiated in 2022, aims to support the national target of reducing marine debris by 70% by 2025, as mandated by Presidential Regulation No. 83 of 2018, and serves as a priority program for implementing Indonesia's blue economy policy [22]. In 2024, Gernas BCL was conducted from early May to the end of June. Accordingly, this study presents detection results before and after the program's implementation. In April 2024, the monitored area showed a wider and denser extent of detected debris, whereas in July 2024, the extent of detected debris was visibly reduced compared to April 2024.

This finding is consistent with data from the Environmental Agency of DKI Jakarta, which reported a decline in total waste generation from April 2024 to July 2024 [23]. These data were obtained through daily manual collection and sorting. The trend of waste generation in Jakarta Bay from 2023 to 2024 is presented in figure 6.

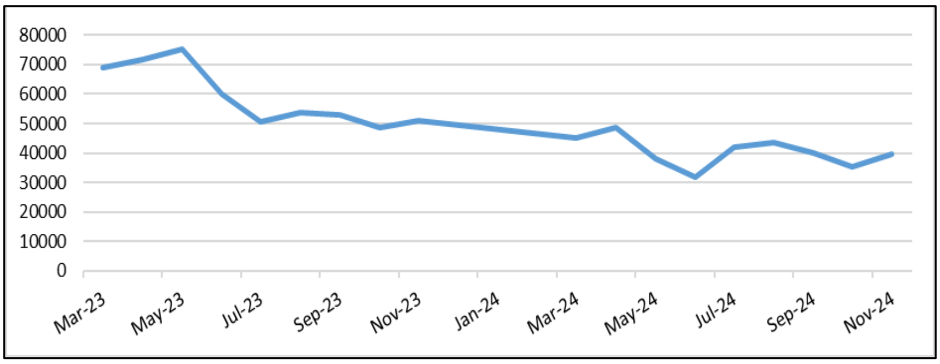

Figure 6. Waste generation in Jakarta Bay.

Source: Environmental Agency of DKI Jakarta (2025), processed.

In evaluating the performance of the classification model for detecting floating plastic debris, balanced accuracy was employed as the primary metric to provide a fair assessment under class imbalance between debris and non-debris categories. Balanced accuracy is calculated as the mean of sensitivity (true positive rate) and specificity (true negative rate). Sensitivity measures the ability of the model to correctly identify pixels that contain plastic debris, while specificity reflects the ability to correctly recognize areas without debris.

In this study, based on classification results using the optimal thresholds obtained from ROC analysis, a balanced accuracy of 0.652 was achieved. This value indicates that the model performs reasonably well in distinguishing between debris and non-debris areas and reduces potential bias caused by the disproportionate distribution of the two classes. Balanced accuracy was therefore considered a more representative evaluation metric compared to overall accuracy, particularly in spatial datasets dominated by non-debris pixels such as in the waters of Jakarta Bay.

The Sentinel-2 image processing also produced descriptive statistics of the monthly median values for the Floating Debris Index (FDI) and the Normalized Difference Vegetation Index (NDVI), which are summarized in table 3 below.

Table 3. Descriptive analysis of FDI and NDVI.

No.	Index	Min	Q1	Median	Mean	Q3	Max	SD
1.	FDI	-1.7700	-0.5873	-0.3595	-0.4781	-0.1735	0.0640	0.4596
2.	NDVI	-0.136	-0.056	-0.029	-0.03175	-0.0035	0.045	0.04147

Source: Google Earth Engine, processed

Based on the descriptive statistics presented in table 3, the most prominent index is the Floating Debris Index (FDI), as it shows a much higher degree of variation compared to the Normalized Difference Vegetation Index (NDVI). This can be observed from the minimum FDI value of –1.7700 and a maximum of 0.0640, indicating a wider range compared to NDVI, which only varies between –0.1360 and 0.0450. Furthermore, the standard deviation of FDI (0.4596) suggests a high level of variability in the data distribution, whereas NDVI shows a considerably lower standard deviation (0.04147).

The relatively low median and mean FDI values (–0.3595 and –0.4781) further indicate that most FDI data are below zero, which corresponds to a large number of areas detected as containing floating objects, such as plastic debris. Conversely, the NDVI central tendency values that are closer to zero suggest that the vegetation index contributes less significantly in the context of detecting floating debris in marine waters. Therefore, FDI can be considered the most representative index for detecting and analyzing floating plastic debris in the coastal waters of Jakarta Bay.

3.2. Seasonal pattern analysis of floating plastic debris

In this study, a time-series analysis was conducted to examine the temporal dynamics of the Floating Debris Index (FDI) in Jakarta Bay from July 2021 to November 2024. The FDI was employed as the primary indicator for detecting floating plastic debris using Sentinel-2 imagery. To reduce the effects of cloud cover, atmospheric noise, and outliers, a monthly median composite approach was applied, whereby multiple images within the same month were aggregated, and the median value of each pixel was computed. This ensured more stable estimates of FDI for long-term trend detection and seasonal pattern analysis.

3.2.1. Floating Debris Index (FDI)

The time-series decomposition of FDI, as shown in figure 7, produced four key components: the original series, seasonal component, long-term trend, and residuals. The original monthly series reflects temporal fluctuations in composite FDI values, which indicate significant variability across the study period. The seasonal component demonstrates recurring annual patterns, suggesting that peaks in FDI values during specific months are influenced by natural drivers such as ocean currents, monsoon rainfall, and river discharges, as well as anthropogenic activities around Jakarta Bay. The long-term trend reveals gradual changes in debris accumulation across years, while the residual component captures irregular variations not explained by seasonality or trend.

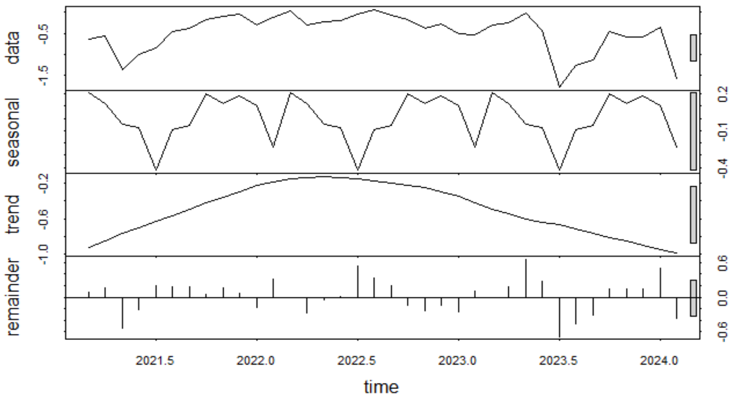

Figure 7. The time-series decomposition results of FDI data.

In addition, the trend component illustrates long-term changes in FDI, showing an increase from mid-2021 to 2023, followed by a decline towards the end of 2024. Meanwhile, the residual component represents random variations in the data that cannot be explained by either the trend or seasonal patterns.

The seasonal component indicates a recurring peak in plastic debris in Jakarta Bay during June of each year. This information can be used to design more targeted mitigation strategies focused on specific periods to reduce marine debris accumulation. The long-term upward trend observed from 2021 to 2023 underscores the urgent need for stronger waste management interventions. By contrast, the decline observed in 2024 may suggest the influence of other external factors, which warrants further investigation.

3.2.2. Normalized Difference Vegetation Index (NDVI). The time-series decomposition of the Normalized Difference Vegetation Index (NDVI) in Jakarta Bay, as illustrated in figure 8, shows the dynamics of vegetation or environmental conditions in the area from July 2021 to November 2024. The first panel presents the original NDVI values, which fluctuate over time and display a recurring annual cycle. The second panel, representing the seasonal component, indicates the presence of relatively consistent cyclical patterns each year.

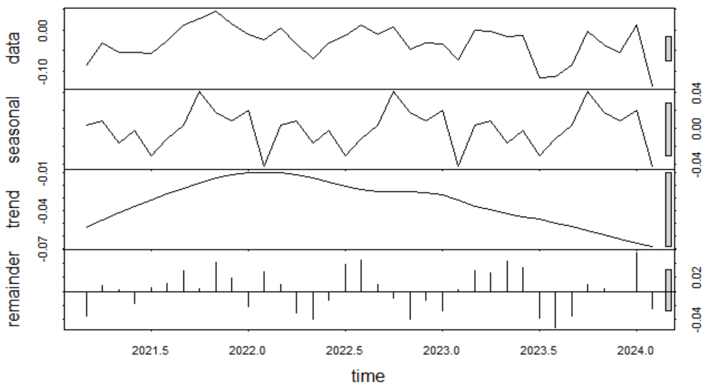

Figure 8. The time-series decomposition results of NDVI data.

The trend component demonstrates an increase in NDVI from mid-2021 to early 2023, followed by a gradual decline toward the end of the analysis period. This may reflect a temporary improvement in vegetation condition or environmental health, followed by subsequent degradation. The decline could be associated with anthropogenic factors such as settlement expansion or increasing water pollution, which negatively affect coastal vegetation growth. Meanwhile, the remainder component, which captures random variation, reveals small fluctuations that are not explained by either the seasonal or trend components. This analysis suggests that the vegetation condition in Jakarta Bay is influenced by both long-term and seasonal factors, highlighting the need for further investigation into the environmental and anthropogenic drivers behind NDVI dynamics.

In addition to the decomposition of both indices (FDI and NDVI), this study also quantified the total detected area of floating debris, which is presented in the following figure.

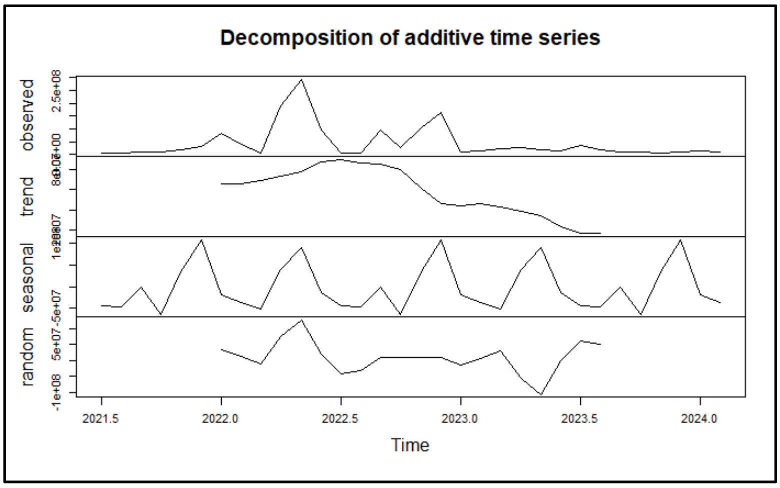

Figure 9. Time-series decomposition results of the detected debris area.

The time-series decomposition presented in figure 9 shows that the detected area of floating plastic debris in Jakarta Bay consists of three main components: trend, seasonality, and randomness. The trend component indicates an increase in debris-covered area from mid-2021 to mid-2022, followed by a decline toward the end of 2023. The seasonal component reveals a recurring annual pattern, which is likely influenced by wet and dry monsoon cycles. Meanwhile, the random component reflects unexpected fluctuations caused by external factors or data anomalies. Overall, this analysis suggests that the distribution of floating debris is influenced not only by long-term trends but also by seasonal variability and stochastic events.

3.3. Impact analysis of floating plastic debris distribution

The final stage of this study was to analyze the spatial impacts of floating plastic debris in Jakarta Bay. The objective was to identify the coastal areas most affected by debris accumulation. To achieve this, two spatial analysis methods were employed: the buffer method and Thiessen Polygon (Voronoi Polygons in QGIS). The analysis was conducted for July 2024, which represents the period following the implementation of the National Ocean Love Month (Gernas BCL) program initiated by the Ministry of Marine Affairs and Fisheries between May and June 2024 [22]. In the buffer analysis, a radius of 500 meters from the outermost detected debris extent was applied. This distance was determined based on the Minister of Public Works and Public Housing Regulation No. 19/PRT/M/2012, which specifies that the limited cultivation subzone, an area designated primarily for managed use of natural, human, and artificial resources under certain restrictions, should extend 500 meters from the outer boundary of the buffer zone [18]. The buffer zone serves to mitigate the environmental impacts of waste-related activities on surrounding areas. The results of the buffer analysis for July 2024 are presented in the figure below.

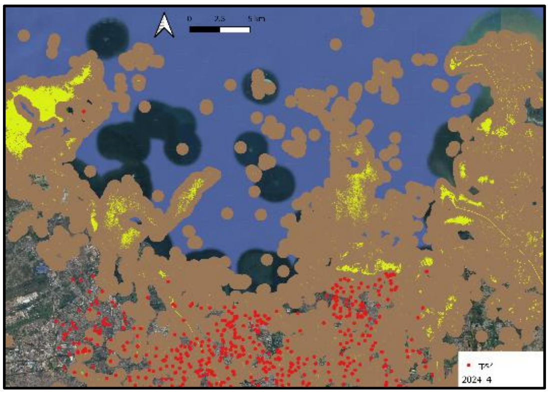

Figure 10. Buffer analysis results for April 2024 with a 500 m radius from the waste disposal sites (TPS).

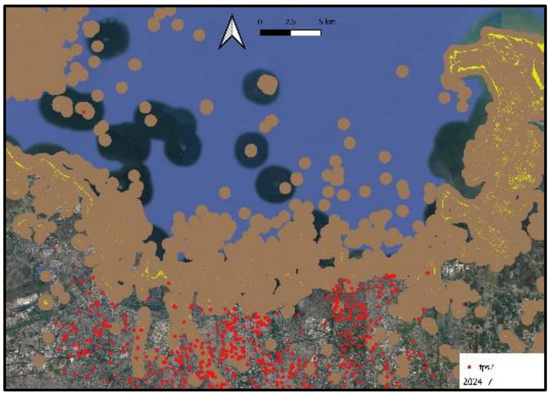

Figure 11. Buffer analysis results for July 2024 with a 500 m radius from the waste disposal sites (TPS).

Based on the 500-meter buffer visualization of floating plastic debris distribution in Jakarta Bay (figures 10 and 11), a significant difference can be observed between April 2024 and July 2024, both in terms of spatial coverage and the potential affected areas in coastal and terrestrial zones. Overall, the buffer analysis provides critical spatial insights for prioritizing intervention and mitigation measures. The 500-meter buffer zones around detected debris highlight vulnerable areas that may serve as a basis for policy actions, such as strengthening coastal waste management systems, installing debris interception nets at river mouths, or engaging local communities in shoreline monitoring.

Furthermore, the buffer results suggest that policymakers, particularly the local Environmental Agency and related institutions, should consider establishing additional waste disposal sites (TPS) in areas lacking such facilities but showing debris accumulation, such as in the eastern coastal area of

Muara Gembong. This finding indicates the importance of enhancing waste management infrastructure to address unserved regions. In addition, the presence of debris hotspots still located within a 500-meter radius of existing TPS suggests that community behavior remains a key challenge. This phenomenon can be explained through the Theory of Planned Behavior (TPB), which posits that individual actions are influenced by three main components: attitudes toward the behavior, subjective norms, and perceived behavioral control [24]. In this context, local communities may hold neutral or negative attitudes toward waste management, experience limited social pressure to dispose of waste properly, and perceive low control or accessibility to adequate waste facilities. These factors collectively contribute to weak intentions and actual practices in responsible waste disposal.

In addition to buffer analysis, this study also applied the Thiessen Polygon method to delineate Jakarta Bay into zones influenced by floating plastic debris detection points. This spatial analysis allows for the identification of areas with potentially higher contributions to plastic debris accumulation and provides a clearer understanding of the spatial distribution of marine debris.

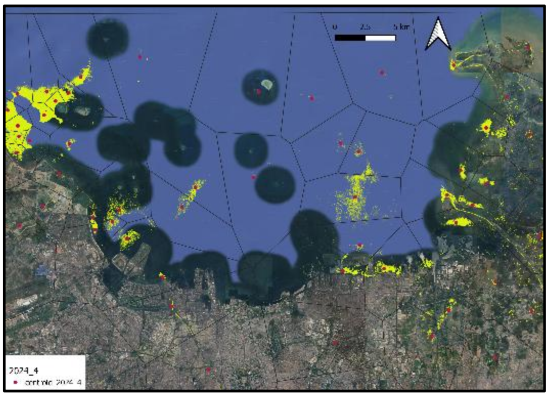

Figure 12. Thiessen Polygon results for April 2024.

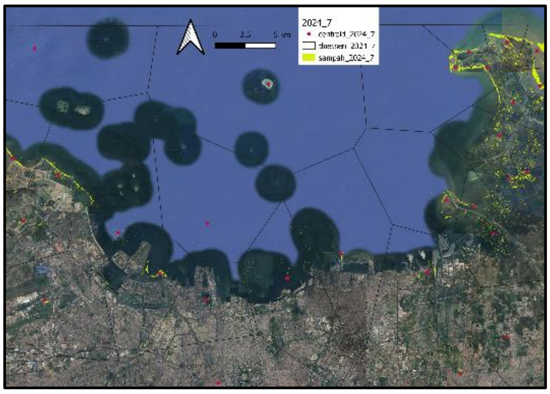

Figure 13. Thiessen Polygon results for July 2024.

The visualizations in figures 12 and 13 show a decline in the number of debris concentration centers in July 2024 compared to April 2024, as indicated by the reduced number of centroids and the larger size of each polygon. This suggests that debris concentrations were fewer and more spatially centralized, particularly along the northeastern coast and major river mouths. In contrast, the central and western waters of Jakarta Bay exhibited a significant reduction in both the number of polygons and centroids, indicating decreased accumulation of floating debris during that period. This pattern was likely influenced by changes in wind direction and ocean currents during the dry season in July, as well as lower waste inflows from land due to reduced rainfall.

Overall, the Thiessen Polygon results provide a more structured spatial representation of affected areas, highlighting the spatial proximity between land-based sources and debris accumulation sites. These patterns can be leveraged to design more effective marine debris management and prevention strategies, particularly by prioritizing coastal areas with higher detection densities of plastic debris. Moreover, this approach is relevant for supporting spatially informed decision-making, such as the placement of waste management facilities or the planning of localized mitigation campaigns.

The spatial distribution results reveal that plastic debris accumulation is concentrated near river mouths and densely populated coastal areas, emphasizing the strong land-based contribution to marine pollution. These findings suggest that policy interventions should prioritize integrated watershed and coastal waste management, particularly targeting river discharge control and solid waste collection within 500 meters of the coastline. The results can inform local authorities, including the DKI Jakarta Environmental Agency, to optimize waste transportation routes and strategic placement of temporary waste disposal sites (TPS). Additionally, periodic satellite-based monitoring could support evidence-based policy evaluation for initiatives such as the National Ocean Love Month (Gernas BCL).

4. Conclusion

Based on the combined Area Under the Curve (AUC) of ROC from NDVI and FDI, the Boolean logic classification achieved a balanced accuracy of 0.652, indicating that the detection performance was reasonably good. The classification results of floating plastic debris along the Jakarta Bay coastline in April 2024 revealed a higher accumulation area compared to July 2024, following the implementation of the National Ocean Love Month (Gernas BCL) program. The distribution of plastic debris was concentrated along Muara Gembong Beach, Marunda Beach, and Tanjung Pasir Beach.

The analysis of FDI and NDVI from July 2021 to November 2024 using median composites and time-series decomposition uncovered seasonal, trend, and random variations. FDI generally increased until 2023 before declining in 2024, while NDVI increased until early 2023 and subsequently decreased through 2024. The peak seasonal increase in plastic debris occurred each June, likely driven by environmental factors and human activities.

The 500-meter buffer zones around debris detection points along the coastline indicated that most floating plastic debris was located within 500 meters of existing waste disposal sites (TPS). However, certain locations, such as Muara Gembong Beach and Tanjung Pasir Beach, still lacked TPS facilities within this radius. The Thiessen Polygon analysis further revealed high-intensity zones along the western and eastern coasts, particularly near river mouths, ports, and settlements. In contrast, the central offshore areas exhibited low debris detection, suggesting that land-based activities are the dominant contributors to marine pollution in Jakarta Bay.

This study demonstrates the practical applicability of the Floating Debris Index (FDI) and Normalized Difference Vegetation Index (NDVI), when combined with spatio-temporal and spatial impact analyses, in detecting and assessing floating plastic debris in Jakarta Bay. Beyond its methodological contributions, this approach offers policy relevance by providing a replicable framework for monitoring and managing marine litter in other coastal regions. Future research should advance this framework toward near-real-time satellite-based monitoring and the integration of oceanographic parameters to support adaptive and sustainable marine pollution mitigation strategies.

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