

MAPPING OF CORAL REEF DISTRIBUTION USING THE LYZENGA ALGORITHM METHOD WITH SENTINEL-2 IMAGERY IN PASUMPAHAN ISLAND

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ABSTRACT

The coral reef ecosystem on Pasumpahan Island holds significant ecological and economic value but is vulnerable to environmental pressures. This study aims to map shallow-water benthic habitats and to assess the accuracy of Sentinel-2 satellite image classification using the Lyzenga water-column correction method. The research involved radiometric correction, application of the water-column correction algorithm, and supervised classification using the Maximum Likelihood algorithm. Field validation was conducted using 30 ground-check points to assess accuracy using a confusion matrix. The analysis results indicate that the shallow waters of Pasumpahan Island are dominated by the substrate class, covering 15.75 Ha, while the coral reef class covers 7.78 Ha. The accuracy assessment yielded an Overall Accuracy of 83.3% and a Kappa Coefficient of 0.67, indicating substantial agreement and confirming the method's validity for spatial mapping. This study concludes that the Lyzenga method is effective in mapping benthic habitats with adequate accuracy, and the resulting map can serve as baseline data for area managers for conservation zoning.

Keywords: Pasumpahan Island, CL Lyzenga transformation

1. INTRODUCTION

Coral reefs are among the most biologically diverse marine ecosystems, providing habitat for numerous marine organisms, protecting coastlines from erosion and wave action, and supporting fisheries and marine tourism. Despite their ecological and economic importance, coral reef ecosystems continue to degrade due to increasing anthropogenic activities and environmental changes, underscoring the need for effective, sustainable monitoring methods¹.

Pasumpahan Island, located in the coastal waters of West Sumatra, possesses considerable coral reef resources and has become an increasingly popular marine tourism destination. However, the expansion of tourism activities and environmental pressures may affect the condition of coral reef ecosystems. Therefore, accurate spatial

information on coral reef distribution is essential to support sustainable coastal management and conservation.

Remote sensing has become an effective approach for mapping shallow-water benthic habitats because it enables rapid and cost-efficient observation over extensive coastal areas. The integration of satellite remote sensing and field observations has also been recognized as an effective approach for improving the consistency and reliability of benthic habitat assessments across broader spatial scales. Recent studies have demonstrated that Sentinel-2 imagery provides reliable spatial and spectral information for coral reef mapping, particularly in shallow-water environments². Sentinel-2 also provides freely accessible imagery with high spatial resolution and revisit frequency, making it

suitable for long-term coastal ecosystem monitoring³.

One of the most widely used approaches for shallow-water habitat mapping is the Lyzenga water-column correction algorithm, which minimizes the influence of water depth on bottom reflectance and improves discrimination of benthic habitats. Previous studies have shown that the application of the Lyzenga transformation enhances the visualization and classification of coral reefs and other benthic substrates in multispectral satellite imagery^{4,5}.

Although satellite imagery provides an efficient means of mapping coral reefs, image quality may still be affected by sun glint, water-column effects, and spectral similarity among benthic habitats. Consequently, image pre-processing, water column correction, and classification accuracy assessment are essential to ensure reliable mapping results. In addition, water quality parameters such as temperature, salinity, water transparency, current velocity, and pH influence underwater light penetration and may affect the spectral response of benthic habitats, making them important supporting information for image interpretation.

Recent advances in medium-resolution satellite imagery have further demonstrated the capability of Sentinel-2 data to provide efficient and reliable information for shallow-water benthic habitat mapping when combined with appropriate image processing techniques⁶.

Therefore, this study aims to map the spatial distribution of shallow-water benthic habitats, particularly coral reefs and bottom substrate, around Pasumpahan Island using Sentinel-2 imagery and the Lyzenga transformation algorithm. Furthermore, the classification accuracy was evaluated using a confusion matrix, while water quality measurements were analyzed to support the interpretation of the mapping results.

2. RESEARCH METHOD

Time and Place

This research was conducted in January 2026 at Pasumpahan Island, West Sumatra Province. Data analysis was performed at the Physical Oceanography Laboratory, Faculty of Fisheries and Marine, Universitas Riau.

Method

This study utilized a survey method involving direct field data collection through direct observation, water condition assessment, and documentation at the research site. The primary data were collected through direct field surveys. Ground check points were determined using Purposive Sampling, a sampling technique based on specific considerations and characteristics considered most representative. A total of 30 Ground Check Points were collected, deemed sufficient for spatial representation given the relatively small study area and the specific habitat classes.

Procedures

The research procedure began with the acquisition of Sentinel-2 Level-2A satellite imagery from the Copernicus Data Space Ecosystem and field survey data. Image pre-processing consisted of band compositing, image cropping, land masking, and sun glint correction to reduce the effects of surface reflection using the method developed⁷. The corrected imagery was subsequently processed using the Lyzenga transformation to minimize the influence of the water column and enhance the visibility of shallow-water benthic habitats. The Lyzenga transformation was performed using the Depth Invariant Index (DII) proposed by Lyzenga, expressed as:

$$(DII_{ij}) = \ln(L_i) - [(K_i/K_j) \cdot \ln(L_j)]$$

Where DII_{ij} is the depth invariant index between spectral bands i and j , L_i and L_j are the reflectance values of bands i and j , respectively, and K_i/K_j is the ratio of the attenuation coefficients between the two bands. The transformation was applied to

three band combinations, namely Blue–Green (Band 2–Band 3), Blue–Red (Band 2–Band 4), and Green–Red (Band 3–Band 4), to generate depth-invariant images for benthic habitat classification.

Following the Lyzenga transformation, image classification was performed using the Maximum Likelihood Classification (MLC) algorithm in ArcGIS 10.8. The MLC algorithm assumes that spectral data are normally distributed and assigns each pixel to the class with the highest probability based on the statistical characteristics of the training samples, allowing pixels to be classified according to their probability of belonging to a particular habitat class⁸.

Training samples were established based on field observations to represent the two benthic habitat classes identified in this study, namely coral reefs and bottom substrate. Coral reef areas included both live coral colonies and dead coral maintaining their physical reef structure, whereas the bottom substrate class consisted of sand, coral rubble, and other unvegetated seabed materials.

Field validation was subsequently conducted using ground truth observations to verify the classified habitat classes. During the field survey, water quality parameters, including water temperature, salinity, pH, current velocity, and water transparency, were measured to characterize

the environmental conditions of the study area.

The classification accuracy was assessed using a confusion matrix following the method proposed by Congalton⁹. Overall Accuracy (OA) and the Kappa Coefficient were calculated using the following equations:

$$OA = \frac{\sum_{i=1}^k X_{ii}}{N} \times 100\%$$

Where X_{ii} is the number of correctly classified samples, and N is the total number of validation samples.

The Kappa Coefficient was calculated using the following equation:

$$K = \frac{N \sum_{i=1}^k X_{ii} - \sum_{i=1}^k (X_{i+} \cdot X_{+i})}{N^2 - \sum_{i=1}^k (X_{i+} \cdot X_{+i})}$$

where K is the Kappa Coefficient, N is the total number of samples, X_{ii} is the diagonal element of the confusion matrix, and X_{i+} and X_{+i} represent the row and column totals, respectively

3. RESULT AND DISCUSSION

Water Quality Parameters

Water quality measurements were conducted at three observation stations in the waters of Pasumpahan Island to characterize the environmental conditions of the study area. The measured parameters included water temperature, salinity, water transparency, current velocity, and pH. The results are presented in Table 1.

Table 1. Water quality parameters measured

Station	Coordinate	Temp (°C)	Salinity (ppt)	Transparency (m)	Current (m.s ⁻¹)	pH
S1	-1.120442, 100.369737	29,1	30,0	2,5	0,12	8,0
S2	-1.118736, 100.366851	29,4	30,2	2,0	0,15	8,0
S3	-1.117048, 100.370542	28,9	29,8	3,0	0,08	8,0
Mean	-	29,13	30,00	2,50	0,117	8,00

Based on field measurements, water temperature ranged from 28.9 to 29.4°C, with an average of 29.13°C. Salinity ranged from 29.8 to 30.2 ppt, averaging 30.00 ppt. Water transparency ranged from 2.0 to 3.0 m, with a mean of 2.50 m. Surface current velocity ranged from 0.08 to 0.15 m.s⁻¹, with an average of 0.117 m.s⁻¹, while the pH

remained constant at 8.0 across all observation stations.

The measured water quality indicates that the physical characteristics of the waters around Pasumpahan Island are generally favorable for coral reef growth. The average temperature of 29.13°C, salinity of 30.00 ppt, water transparency of 2.50 m, current

velocity of 0.117 m.s^{-1} , and pH of 8.0 were within the marine water quality standards for coral reef ecosystems established in Appendix VI of Government Regulation of the Republic of Indonesia No. 22 of 2021. These environmental conditions also support the acquisition and interpretation of Sentinel-2 imagery, as water transparency and light penetration are important for detecting shallow-water benthic habitats.

Furthermore, water depth and light penetration were important factors influencing the mapping results. In this study, the effect of water depth was minimized using the Lyzenga transformation, and the measured water transparency indicated sufficient light penetration to distinguish coral reefs from benthic substrates. These conditions are consistent with the successful classification accuracy obtained in this study, suggesting that the environmental characteristics of the study area supported reliable shallow-water benthic habitat mapping.

Sun Glint Correction and Lyzenga Transformation

The sun glint correction was applied to minimize the influence of specular reflection from the water surface on the Sentinel-2 imagery. The correction was performed using a linear regression model between the Near-Infrared (Band 8) and the visible bands (Bands 2, 3, and 4) based on deep-water samples. The regression analysis produced high coefficients of determination (R^2), reaching 0.9619 for Band 2, 0.9551 for Band 3, and 0.9708 for Band 4, indicating a strong linear relationship between the NIR and visible bands. The resulting regression equations were subsequently applied to correct the visible bands, effectively reducing the influence of surface reflection and improving the visual quality of the shallow-water imagery. The visual comparison before and after the sun glint correction is presented in Figure 1.

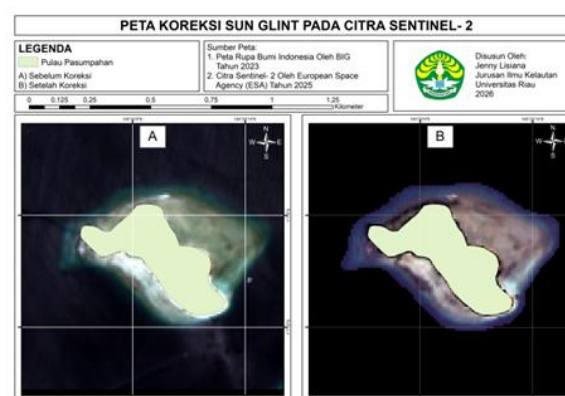


Figure 1. Sentinel-2 imagery before (A) sun glint correction and (B) after sun glint correction

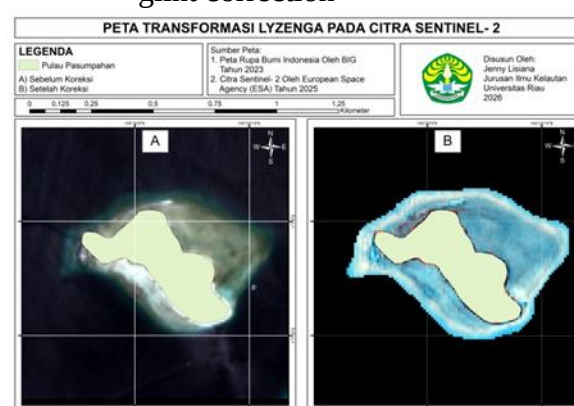


Figure 2. Sentinel-2 imagery before (A) Lyzenga transformation and (B) after Lyzenga transformation

Following the sun glint correction, the Lyzenga transformation was applied to reduce the water-column effect on the spectral response of benthic habitats. The transformation was based on a linear regression analysis of the logarithms of visible band pairs to derive attenuation coefficient ratios. The regression analysis showed high coefficients of determination: $R^2 = 0.9835$ for the Blue–Green pair, 0.9481 for the Blue–Red pair, and 0.9564 for the Green–Red pair, indicating that the transformation effectively captured light attenuation in the waters surrounding Pasumpahan Island (Figure 2).

As shown in Figure 2, the transformed imagery provided a clearer distinction between coral reefs and other benthic substrates than the original imagery. The application of the Depth Invariant Index (DII) reduced the influence of water depth

on spectral reflectance, enabling the Sentinel-2 sensor to detect bottom features more clearly. These results demonstrate that the Lyzenga transformation effectively improved the spectral information of shallow-water habitats and supported subsequent habitat classification in the study area.

Shallow-Water Benthic Habitat Classification

Shallow-water benthic habitat classification was performed using the Maximum Likelihood Classification (MLC) algorithm on the Sentinel-2 imagery after the application of the Lyzenga transformation. The classification results identified two benthic habitat classes, namely coral reefs and bottom substrate, representing the dominant habitats in the coastal waters of Pasumpahan Island. The spatial distribution of the classified habitats is presented in Figure 3.

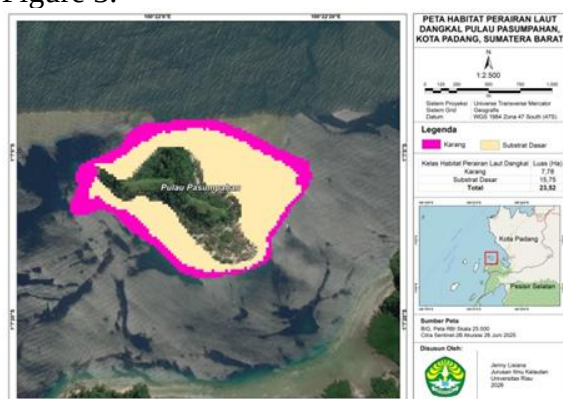


Figure 3. Shallow-water benthic habitat distribution map of Pasumpahan Island.

The classification results showed that the bottom substrate was the dominant habitat class, covering 15.75 ha, while coral reefs occupied 7.78 ha. Coral reefs were primarily distributed in shallow-water areas with relatively clear water conditions, whereas bottom substrate was more widely distributed throughout the study area. These findings indicate that the benthic habitats of Pasumpahan Island are dominated by bottom substrate, with coral reefs occurring in suitable shallow-water environments.

The predominance of bottom substrate over coral reefs indicates that sandy and coral rubble substrates largely characterize the shallow coastal waters around Pasumpahan Island. Coral reefs were mainly distributed in relatively shallow areas where environmental conditions were favorable for coral growth, as reflected by the measured water quality parameters. This distribution pattern suggests that the combination of suitable environmental conditions and image enhancement techniques, including sun glint correction and the Lyzenga transformation, enabled the Sentinel-2 imagery to effectively distinguish coral reefs from surrounding bottom substrates.

The spatial distribution pattern obtained from Sentinel-2 imagery demonstrates that the combination of sun glint correction, the Lyzenga transformation, and Maximum Likelihood Classification successfully distinguished coral reefs from the bottom substrate. The resulting habitat map provides valuable spatial information to support future coastal management and coral reef conservation efforts in the waters around Pasumpahan Island.

Accuracy Assessment

The accuracy of the shallow-water benthic habitat classification was evaluated using a confusion matrix based on field validation data⁹. The assessment produced an Overall Accuracy (OA) of 83.3% and a Kappa coefficient of 0.67, indicating substantial agreement between the classified image and the field observations¹⁰. The obtained Overall Accuracy exceeded the minimum acceptable threshold of 80% for thematic habitat mapping, indicating that the classification results were sufficiently reliable¹¹. The confusion matrix used for the accuracy assessment is presented in Table 2.

The obtained accuracy demonstrates that the combination of Sentinel-2 imagery, sun glint correction, Lyzenga transformation, and Maximum Likelihood Classification effectively distinguished coral reefs from bottom substrate in the study area. Although several misclassifications were

observed, they were mainly due to the similarity in spectral characteristics between benthic substrates and coral reefs in shallow

waters. Such spectral overlap is a common challenge in satellite-based mapping of shallow-water habitats.

Table 2. Confusion matrix of shallow-water benthic habitat classification

Classification Results	Coral Reefs	Substrat	Quantity	%
Coral Reefs	13	2	15	86,7
Substrat	3	12	15	80
Quantity	16	14	30	
Producer (%)	81,25	85,7		
Overall Accuracy (%)	83,3			
Kappa Coefficient	0,67			

Overall, the classification accuracy achieved in this study indicates that the applied methodology is reliable for mapping shallow-water benthic habitats in the waters of Pasumpahan Island. The resulting habitat distribution map can therefore serve as a useful source of spatial information to support coral reef monitoring and coastal resource management.

4. CONCLUSION

This study demonstrated that integrating Sentinel-2 Level-2A imagery, sun glint correction, the Lyzenga transformation, and the Maximum Likelihood Classification (MLC) algorithm was effective for mapping shallow-water benthic habitats in the waters around

Pasumpahan Island. The classification identified two dominant habitat classes, namely coral reefs covering 7.78 ha and bottom substrate covering 15.75 ha, with bottom substrate representing the predominant habitat type. The classification achieved an Overall Accuracy of 83.3% and a Kappa coefficient of 0.67, indicating that the applied methodology provided reliable results for shallow-water benthic habitat mapping. These findings demonstrate that Sentinel-2 imagery, combined with water-column correction techniques, can provide useful spatial information to support coral reef monitoring, coastal resource management, and future conservation planning in the waters around Pasumpahan Island.

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