Benthic Habitat Classification Using Sentinel-2a Image With and Without Water Column Correction in Pengudang Village, Bintan Regency

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Abstract
Research on the mapping of benthic habitats in the waters of Pengudang Village, Bintan Regency, uses Sentinel-2A imagery. This mapping process has the potential to display the results of classification of benthic habitats in shallow waters. The purpose of this study was to assess the Maximum Likelihood Classification (MLH) algorithm model for mapping benthic habitat cover through Sentinel-2A satellite imagery using the lyzenga water column correction and without water column correction and to calculate the accuracy of the MLH classification results for benthic habitats in waters Pengudang Village. This classification uses a pixel-based image classification which is grouped into a cover class for each pixel. This classification groups into 4 benthic habitat classes, namely dead coral sand (KMP), sea grass (LM), live coral sand (PKH) and sand (PS). The results showed that the application of the lyzenga correction using the MLH algorithm in mapping benthic habitats resulted in a significant accuracy rate (80,00%), while the application without lyzenga correction using the MLH algorithm resulted in an accuracy rate (76,00%). These findings support the use of the lyzenga correction method which can increase the level of accuracy by (4,00%) with the MLH algorithm as a guide in better mapping of benthic habitat cover in Pengudang Village.
Keywords: Lyzenga , Sentinel-2A imagery, MLH, Pengudang Village, Benthic Habitat, Mapping

INTRODUCTION

Indonesia is an archipelagic country consisting of large and small islands totaling approximately 17,504 islands (Arianto, 2020). One of the small islands in Indonesia is Bintan Island. Bintan Island is one of the largest islands in the Riau Archipelago (A. B. Irawan & Ade Yudono, 2014). Pengudang Village is located on Bintan Island, specifically including Telok Sebong District, in the Bintan Regency area, Riau Islands (Suhendra et al., 2022). Pengudang Village is one of the villages that stands out for its diverse ecosystem at the bottom of shallow waters. The components that make up the waters of Pengudang Village include various types of substrate such as sand, mud, coral, rocks and sea plants, as well as the existence of organisms and communities that live in these waters. From an ecological perspective, it is important to understand the diversity and characteristics of benthic environments, including ecosystems such as coral reefs, seagrasses, and algae, which form the bottom substrate of waters (Wang et al., 2022). The importance of data and information regarding benthic habitats is key in efforts to maintain and preserve aquatic ecosystems. Mapping using remote sensing is needed to understand and monitor the condition of the bottom of the waters (Siregar et al., 2020).

Benthic habitat mapping using remote sensing utilizes advanced technology that uses image data from satellites, aircraft or other remote sensors to accurately identify and map the benthic habitat environment at the bottom of the water. This benthic habitat mapping uses Sentinel-2A imagery with techniques utilizing image data taken by the Sentinel-2A satellite to recognize, understand and image benthic habitat at the bottom of the waters. Imagery from Sentinel-2A generally offers high spatial resolution and covers a wide range of spectral channels with the ability to detect objects in shallow water according to its spatial resolution. By combining data with image processing techniques and analysis models, benthic habitat mapping can be carried out with a high level of accuracy (Gascon et al., 2017).

The capabilities of the Sentinel-2A satellite imagery can identify benthic habitats that are greatly affected by interference present in the water column. Efforts to reduce this interference can be done by improving image quality through a water column correction process using the Lyzenga equation, as explained (Prayuda, 2014). This water column correction process apparently has a significant impact on the spectral characteristics of benthic habitats, as highlighted by research conducted (Hafizt & Danoedoro, 2015). A number of studies have been conducted to evaluate the effects of applying water column corrections in improving the accuracy of benthic habitat mapping. For this reason, this research was carried out by testing the level of accuracy of benthic habitat mapping using Sentinel-2A imagery, both by carrying out Lyzenga water column corrections and without water column corrections through a supervised classification approach using the MLH (Maximum Likelihood Classification) algorithm in the area. Pengudang Village.

RESEARCH METHODS

Time and Place

This study was conducted in Pengudang Village, Bintan Regency, Riau Islands, on 10 - 11 June 2023. This research involved several stages, starting from making observation maps before going to the field, followed by direct (in-situ) observations of benthic habitats and taking photos using an underwater camera. Each observation point is 15 meters from other data collection points with a total of 120 points. Next, data processing was carried out from the Sentinel-2A image. Data processing begins on June 14 – September 8 2023 which is carried out in the OCM (Oceanography, Computation, Modeling) Lab, Faculty of Marine and Fisheries Sciences, Raja Ali Haji Maritime University, Tanjung Pinang City.

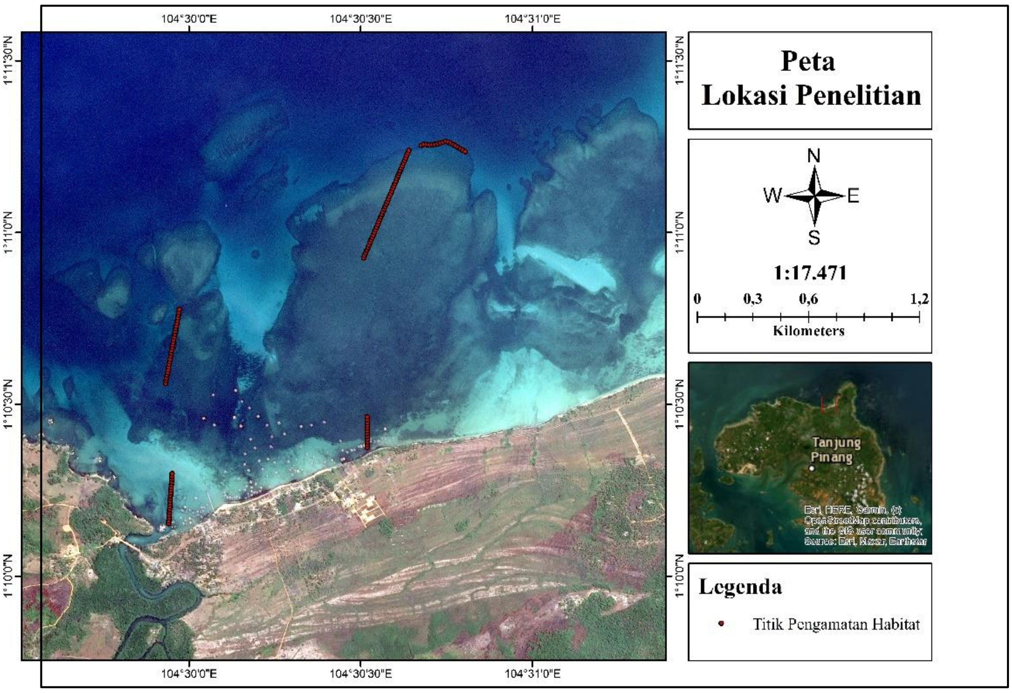

Figure 1. Map of Research Location

Tools and Materials

The equipment used in this study is a field survey device and software for data analysis. The following are some of the tools and materials and software used in this study presented in Table 1 and 2.

Table 1. Field Survey Equipment

No	Tools and Materials	Uses
1	GPS	Determine coordinate points
2	Underwater Camera	Habitat class photo capture
3	Diving equipment	Habitat class validation and photo capture
4	Transect squared 1 m x 1 m	Observation of benthic habitat
5	Laptop	Data processing and analysis hardware
6	Pencil and newtop paper	Underwater writing aids
7	Sentinel 2A imagery	Image data to be processed

Table 2. Software Type

No	Software	Role
1	Coral Point Count With Extensions (CPCe) 4.1	Analysis of benthic habitat cover
2	ArcGIS 10.8	Map layeout creation
3	Microsoft Excel 2013	Data tabulation, diagram presentation
4	XLSTAT	Statistical analysis
5	ENVI 5.3	Image preprocessing

Data Collection Techniques

Field data collection involves two main methods: direct observation (GTH) at the research location and taking photos with an underwater camera. Direct observations were carried out using a quadrat transect measuring 1 meter x 1 meter which was given a striking color so that it was easily visible in the water (English et al., 1997; Roelfsema & Phinn, 2008). The transect plot size of 1 meter x 1 meter was adjusted to the spatial resolution of the Sentinel-2A image used in this research. At each observation location point, photographs were taken 7-8 times using quadratic transects to represent the benthic habitat composition which is equivalent to one pixel of a Sentinel-2A image with a spatial resolution of 10 meters. Overall, there are 120 field observation points in the waters of Pengudang Village.

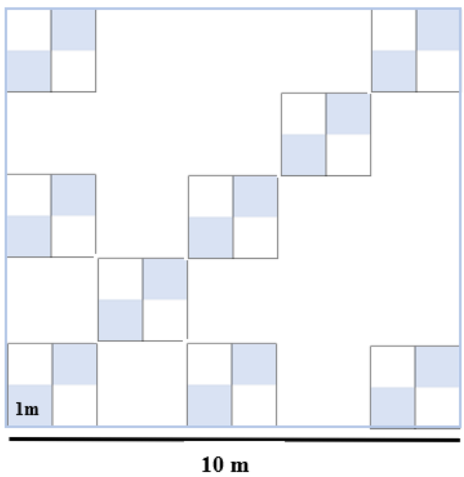

Figure 2. Sentinel-2A Image Data Capture Transect

Data collection regarding benthic habitat was carried out using a systematic random sampling method with a distance of approximately 15 meters between each point. Each photo of underwater cover was analyzed using Coral Point Count with Excel Extensions (CPCe) software developed by (Kohler & Gill, 2006). Next, the data was processed using the Agglomerative Hierarchical Clustering (AHC) method with XLSTAT software, applying the Bray-Curtis algorithm. The result is a dendrogram that depicts a benthic habitat classification scheme based on data from field surveys. After carrying out AHC analysis of data collected in the waters of Pengudang Village, four main classes were found, namely sand (PS), seagrass (LM), dead coral sand (KMP), and live coral sand (PKH).

Data Processing Techniques

The satellite image used in this research is the Sentinel-2A image, this image is processed using ENVI 5.3 software which begins with the layer stacking process, composite band, cropping, masking data and Lyzenga correction.

1. Layer Stacking and Composite Band. Stacking or layer stacking is the process of combining various bands into one single layer. The aim of using composite bands is to combine several image bands so that the objects visible in the image are more easily recognized and differentiated. This composite band provides an RGB (Red-Green-Blue) color display similar to photos taken from a color camera. In analyzing benthic habitat in shallow waters, we use the true color composite band, which consists of a combination of blue, red and green (Prayuda, 2014).
2. Cropping and Masking Data. Cropping is an image cutting process that is carried out to cut the study area that will be processed in the image which is carried out to limit the area that will be analyzed. Masking data is an analysis used to eliminate the effects of land areas, deep waters, and other objects that are not needed in the image data processing process.
3. Water Column Correction (Lyzenga). Water column correction is used to improve image quality by overcoming interference caused by changes in the water column which involves calculating band a and band b to create a new channel that will be used as one band in the final image. Which involves calculating the ratio of attenuation coefficients of two different visible bands in the image. The process of obtaining the attenuation coefficient value begins with selecting a training area at the research location. This involves one of the common techniques where the relationship between the variance and covariance attenuation values is used to carry out water column corrections, namely by applying an algorithm developed by Lyzenga (1978) known as the Depth Invariant Index (DII).

   $$\text{Depth Invariant Index} = \text{In}(B_2) - \left(\frac{Ki}{Kj}.\,\text{In}(B_3)\right)$$

   Information :
   Ki/Kj: Coefficient ratio with band pair i

Data Analysis

Benthic Habitat Cover Categories

Benthic habitat cover analysis on each image taken using a 1m x 1m quadrat transect was carried out using Coral Point Count with Excel extensions (CPCe) software to classify the cover category (Kohler & Gill, 2006). There are four random point calculation models that can be used in CPCe, namely simple random, stratified random, uniform grid, and equally spaced grid. In the CPCe analysis, benthic habitat cover is divided into six classes which include: live coral (KH) with codes Br (Branching), Mv (Massive), Pl (Plate), SC (Soft Coral), and Mx (Mixed); dead coral (KM) with codes DC (Dead Coral) and DCA (Dead Coral Algae); coral fracture (PK) with code Rb (Rubble); seagrass (LM) with code Ss (Seagrass); algae (AL) with the code Ma (Macro Algae); and sand (PS) with the code Sd (Sand). In this research, the type of stratified point specification used is a uniform grid consisting of 30 points placed regularly in each photo quadrant. (Fig. 3)

Figure 3. Percentage analysis of benthic habitat using CPCe

AHC (Agglomerative Hierarchical Clustering) Analysis

Data resulting from analysis using CPCe (Coral Point Count with Excel extensions) in Excel format were then analyzed using the AHC (Agglomerative Hierarchical Clustering) method using XLSTAT software. In this AHC analysis, the unweighted pair-group average algorithm with the Bray-Curtis dissimilarity metric is used. The results of this analysis produce a dendrogram and habitat classification scheme. The Bray-Curtis index is used to assess the level of similarity or difference between two communities, especially in terms of the number of individuals or organisms present in the community, which can be measured quantitatively. In this research, the author used a dissimilarity value of 0.4. According to (Corliss et al.,1974), clauster analysis can be calculated using the following formula:

$$\frac{1}{|A|.|B|}\sum_{X\in A}\sum_{y\in B} d(x,y)$$

Where:

A ,B : Set or clasuter
d : Average distance
x,y : Pair in clauster

Maximum Likelihood Classification (MLH)

The maximum likelihood classification method takes into account the maximum probability of a number of pixels in the input image to approach image classification. The aim of this method is to reduce overlap between classes, but it requires more time (Sangadji et al., 2018). The decision rule of the maximum likelihood method is based on the equation below:

$$P = In(Ac) - 0{,}5\left(|\sum c|\right) - 0{,}5[(X-\mu c)^{T}(Xc^{-1})(X-\mu c)]$$

Where:

P : Maximum likelihood distance weight
C : Class index
X : Pixel value of the class group
μc : Average of results for class c
Ac : A priori percentage to class c
|σc| : Determinant of the diversity matrix for class c
Σc -1 : Class c inverse matrix model
T : Matrix rotation

Accuracy Test

Remote sensing data that has been classified is validated using an error matrix (error matrix/confusion matrix). This stage involves a comparison between the classification results of the image with a class map that is appropriate to the field situation. The actual class is obtained from field observations, and accuracy testing follows the guidelines provided by (Congalton & Green, 2008). Overall accuracy between remote sensing classification data and reference data can be calculated in the following way:

$$\text{Overall Accuracy (OA)} = \frac{\sum_{i=1}^{n} X_{ii}}{N} \times 100\%$$

$$\text{User Accuracy (UA)} = \frac{X_{ii}}{X_{+I}} \times 100\%$$

$$\text{Producer Accuracy (PA)} = \frac{X_{ii}}{X_{i+}} \times 100\%$$

$$\text{Kappa accuracy} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=}^{r} x_i + x_i}{N^2 - \sum_{i=}^{r} x_i + x_i} \times 100\%$$

Where:

n : Number of rows in the User Accuracy (UA) matrix
K : Number of observations
Xii : The number of observations in the i-th column and i-th row
X+i : Number of observation in the i-th column
Xi+ : Number of i-row observation

RESEARCH RESULTS AND DISCUSSION

Classification Scheme

A cluster analysis-based classification scheme produces data in the form of a dendrogram and central object values are generated from field data. Based on field data that has been collected. After analysis using the AHC method, 6 classifications can be obtained, namely live coral, dead coral, coral fragments (rubble), seagrass, algae and sand. The application of the AHC (agglomerative hierarchical clustering) method for the classification of benthic habitats obtained 4 types of habitat from the simplification results by considering the most dominant class based on the average distance in the benthic habitat cluster, namely sand (PS), seagrass (LM), dead coral sand (KMP).) and live coral sand (PKH). (Fig. 4)

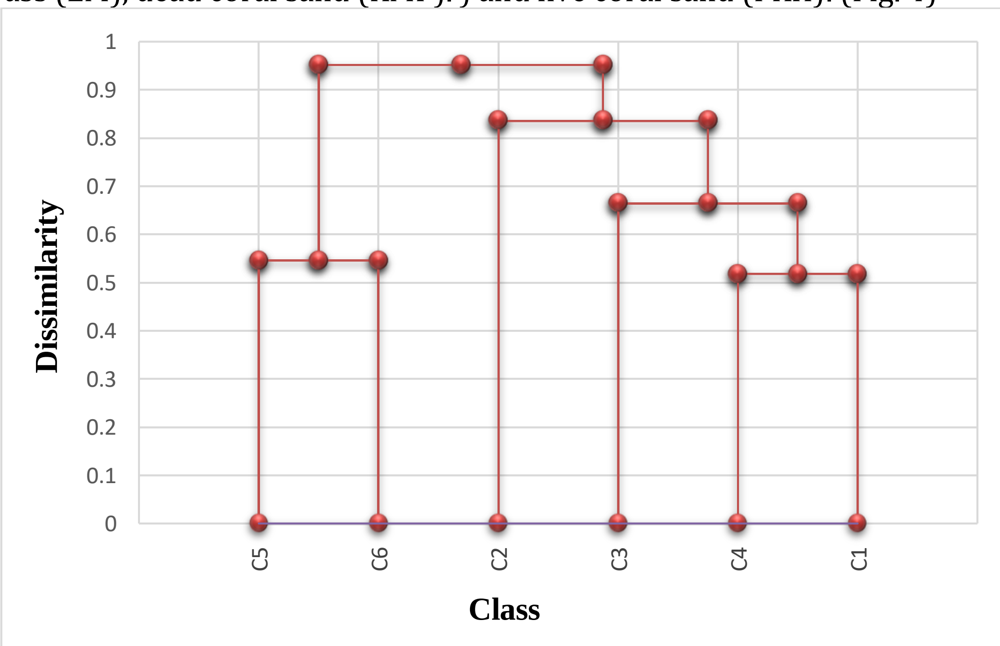

Figure 4. Dendogram Of Bray-Curtis Clauster Analysis Results

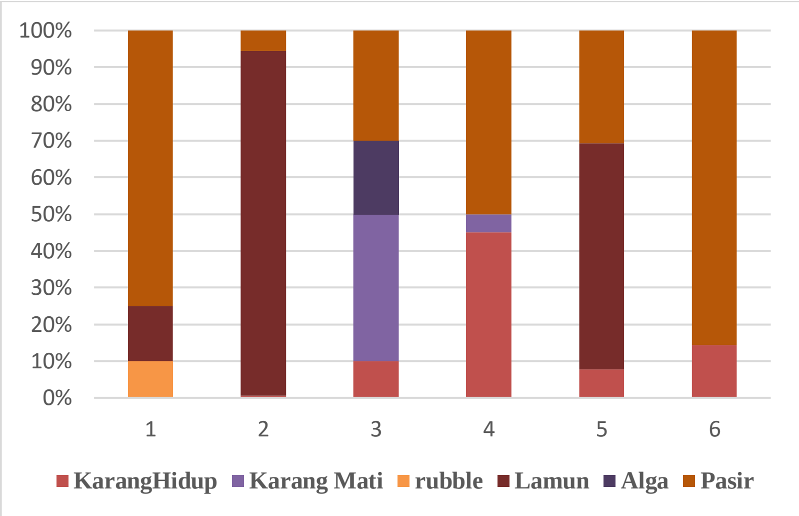

Figure 5. Percentage Classification Scheme Analysis Bray-Curtis

Water Column Correction (Lyzenga)

a. Calculation of Variance and Covariance Values. The calculation of variance and covariance values is carried out using the variance and covariance formula equations in the data analysis. The results of the calculations can be seen in (Table 3) below:

Table 3. Results of calculating variance and covariance values

Value Variance And Covariance	Result
Variance 2	39930,63
Variance 3	32890,86
Variance 4	5707,55
Covariance 2 and 3	3438,26
Covariance 2 and 4	13842,84
Covariance 3 and 4	1199,31

b. Implementation of the lyzenga algorithm. According to (Arief, 2013) the Ki/Kj value shows homogeneity, with values ranging from one to zero. It is important to note that depth greatly influences underwater image recording.

Table 4. Lyzenga Algorithm Calculations For Each Band

Algorithm Lyzenga	
Band 2 and 3 (Xij23)	(alog(B2))-(0,407359*(alog(B3)))
Band 2 and 4 (Xij24)	(alog(B2))-(0,826103*(alog(B4)))
Band 3 and 4 (Xij34)	(alog(B3))-(0,044034*(alog(B4)))

Benthic Habitat Classification

Classification of benthic habitat in the waters Pengudang Village, Bintan Regency using Sentinel-2A with pixel-based image classification Maximum Likelihood (MLH) with two algorithms with using water column correction and without water column correction. The number of points used for classification is 70 points representing each class of benthic habitat cover. The following are the classification results using water column correction algorithm model and without water column correction. (Fig. 6 and Fig. 7)

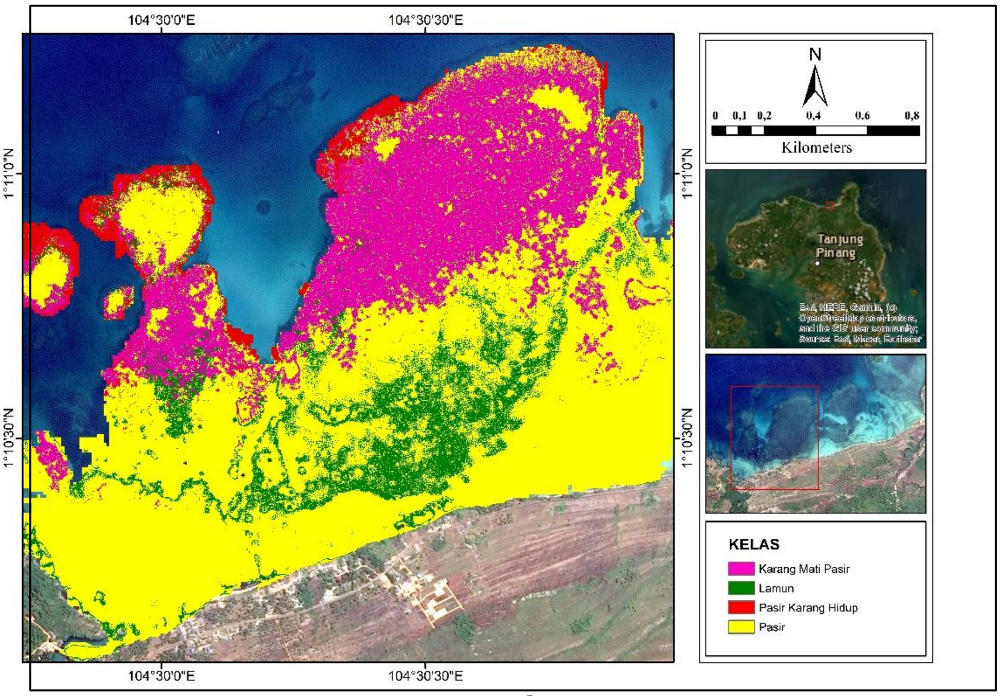

Figure 6. Using Water Column Correction

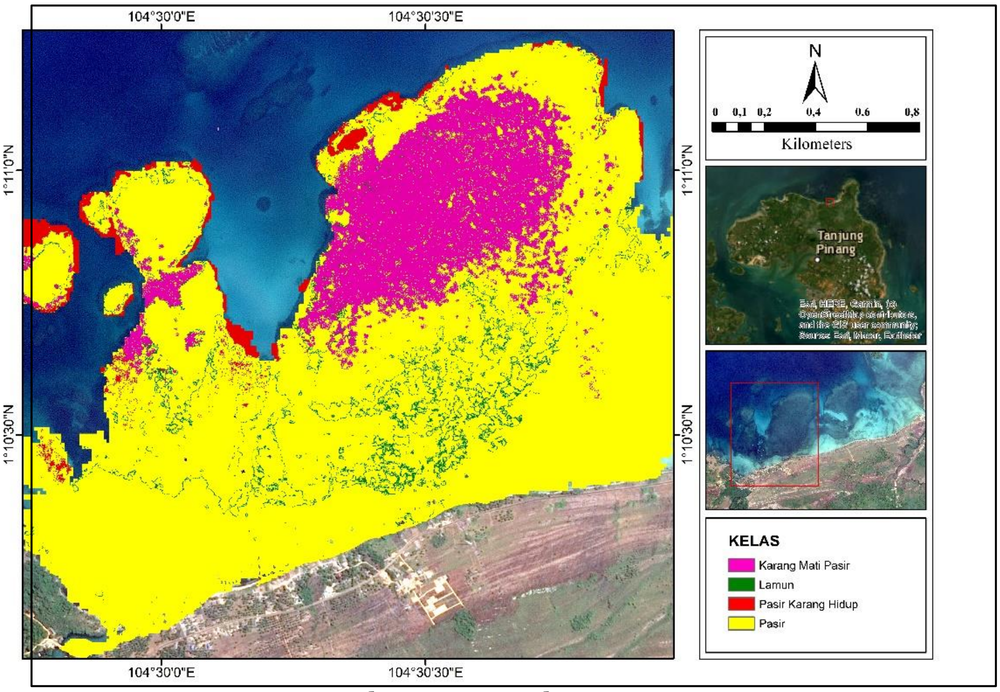

Figure 7. Without Water Column Correction

Accuracy Test

In this study, accuracy was tested using the confusion matrix method which compares the image classification results with the number of survey points used as the actual class reference. Accuracy test results with and without using water column correction will show different results. Using satellite data to improve water column depth measurements in benthic habitat mapping can increase the level of accuracy of the information produced. The following are the accuracy test results in (Table 5) and (Table 6) from classification using and without using water column correction with the MLH (Maximum Likelihoos Classification) algorithm.

Table 5. Accuracy Test Using Water Column Correction

	Field					
Habitat Class	KMP	LM	PKH	PS	**TOTAL**	UA
KMP	12	1	0	5	18	66,67
LM	0	2	0	0	2	100,00
PKH	0	0	9	1	10	90,00
PS	1	2	0	17	20	85,00
TOTAL	13	5	9	23	50	
PA	92,31	40,00	100,00	73,91	OA=	80,00

Table 6. Accuracy Test Without Using Water Column Correction

	Field					
Habitat Class	KMP	LM	PKH	PS	**TOTAL**	UA
KMP	12	1	0	7	20	60,00
LM	0	2	0	0	2	100,00
PKH	0	0	9	1	10	90,00
PS	1	2	0	15	18	83,33
TOTAL	13	5	9	23	50	
PA	92,31	40,00	100,00	65,22	OA=	76,00

Discussion

Classification Scheme

The dendogram results (Figure 4) of cluster analysis show that in the waters of Pengudang Village there are four dominant benthic habitat classes, namely class 1 sand (75%), class 2 seagrass (93.81%), class 3 dead coral (40%) with a mixture of sand (30%), and class 4 sand (50%) with a mixture of live coral (45%). four dominant benthic habitat classes were found based on the central object value (Figure 5). The classification scheme, which is based on field observations and analyzed using the Bray-Curtis method, produces six classes: class 1 (75% sand, 15% seagrass mixture, and 15% rubble), class 2 (93.81% seagrass, 6% sand mixture, 19%), class 3 (40% dead coral, a mixture of 30% sand, 20% algae, and 10% live coral), class 4 (50% sand, a mixture of 45% live coral, and 5% dead coral), class 5 (60% seagrass, 30% sand mixture, and 10% live coral), and class 6 (90% sand, 10% live coral mixture). Furthermore, simplification was carried out by combining the dominant classes from the six classes into four classification classes, namely class 1 (75% sand), class 2 (seagrass 93.81%), class 3 (dead coral 40% mixed with 30% sand). , and class 4 (50% sand mixed with 45% live coral).

Water Column Correction (Lyzenga)

From the calculation results, the variance and covariance values for bands 2,3 and 4 were obtained. The Lyzenga formula was used to calculate the Ki/Kj values, which can be found in (Table 4). When two bands, namely bands 2 and 3, are combined they produce a new band called Xij23 with a Ki/Kj value of 0.407359. Merging bands 2 and 4 produces Xij24 with a value of around 0.826103. Meanwhile, merging bands 3 and 4 produces a new band called Xij34 with a value of around 0.044034. The results of the Lyzenga correction will affect the accuracy value of the classification. Where the accuracy value using water column correction will be higher.

Benthic Habitat Classification

Benthic habitat classification in this study uses pixel-based image classification with the application of algorithms Maximum Likelihood Classification (MLH) with using water column correction lyzenga and without using water column lyzenga , which include supervised classification. In this study, 4 classes of benthic habitat were produced, namely sand (PS), seagrass (LM), dead coral mixed with sand (KMP), and sand mixed with live coral (PKH) each of which has a different color. (Figure 6 and Figure 7). It can be seen from the color of each class that the results of not using water column correction make the sand class (PS) classification more widespread in shallow water areas and waters around the rim, the seagrass class (LM) is less spread out compared to using lyzenga correction in the water area. shallow, the dead coral sand (KMP) class displays fewer results than using the lyzenga correction, the results for the live coral sand (PKH) class display the smallest distribution area and are not much different from using the water column correction.

Accuracy Test

The classification accuracy estimate was calculated using an error matrix (confusion matrix) where the overall accuracy (OA) of the classification results using water column correction was 80.00% (Table 5) and 76.00% (Table 7). The accuracy of the benthic habitat map produced with lyzenga water column correction using the MLH algorithm is higher than without using lyzenga water column correction with a difference in accuracy value of 4.00%. The accuracy (PA) procedure with water column correction for the dead coral sand class (KMP) has a value of 92.31%, the seagrass class (LM) has a value of 40%, the sand class mixed with live coral (PKH) has a value of 100% and the sand class (PS) has a PA value of 73.91%. The user accuracy (UA) using water column correction for the dead coral sand class (KMP) has a value of 66.77%, the seagrass class (LM) has a value of 100%, the live coral sand class (PKH) has a value of 90% and sand class (PS) has a UA value of 85%.

Meanwhile, the accuracy (PA) procedure without using water column correction using the MLH algorithm obtained each class value, namely dead coral sand (KMP) had a PA value of 92.31%, seagrass class (LM) had a value of 40%, sand class live coral (PKH) has a value of 100% and sand class (PS) has a PA value of 65.22%. As for user accuracy (UA) without using water column correction, it can be seen that the dead coral mixed with sand (KMP) class has a value of 60%, the seagrass class (LM) has a value of 100%, the live coral sand (PKH) class has a value of 90 % and sand class (PS) has a UA value of 83.33%. From the accuracy test results, it can be seen that the results of the PA and UA values between classifications with the application of water column correction and without water column correction produce results that are not much different. However, overall what differentiates the level of accuracy test is the overall accuracy value shows that the water column correction calculation has a higher level of accuracy. The research results show that using water column correction will display better and more detailed maps.

CONCLUSION

Based on the results of benthic habitat mapping research in the waters of Pengudang Village using Sentinel-2A imagery, it can be concluded that benthic habitat mapping includes four classes of benthic habitat, namely seagrass (LM), sand (PS), dead coral mixed with sand (KMP), and sand mixed with live coral (PKH). The classification results involving the use of water column correction with the Maximum Likelihood Classification (MLH) algorithm found that there were differences in the level of accuracy. When applying water column correction with the MLH algorithm, the results show an overlay accuracy rate of 80.00%, while without water column correction using the same MLH algorithm it only reaches 76.00%. The results of this research provide an indication that the Maximum Likelihood Classification (MLH) algorithm is effective in producing accurate mapping on Sentinel 2A imagery.

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