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Rapid Bathymetry Detection With Sentinel Application Platform (Snap) Using Sentinel Imagery 2a

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Abstract

Indonesia is the largest archipelagic country where 77% of its territory encompasses coastlines, shallow waters to deep sea waters areas. One of the required important information for Indonesia particularly for protecting its rich marine habitat and supporting shalow-water navigation is bathymetry. Additionally, bathymetry information can be used to support several other purposes, such as shipping, determining the right area for ports, and determining coastal cultivation areas. Remote sensing technology has an important role to provide bathymetric information quickly and cover a wide area in an archipelagic country like Indonesia, mainly when field measurement is hindered by logistical issues due to the remoteness of target areas. This study attempts to contribute to the solution of the issue by performing bathymetry extraction using Sen2Coral algorithm available in Sentinel Application Platform (SNAP) image processing software. The specific purpose of this study is to rapidly derive bathymetry in shallow marine waters using Sentinel 2A data. The research location is in the islands of Putri, Melintang, Macan, Dolpin and located in Seribu Islands, Jakarta. The data used are Sentinel 2A imagery acquired on April 24, 2021, in situ batymetry and tidal data. The results showed that Sentinel 2A can produce a depth range of 0 – 30.64 meters. The accuracy of the calculated bathymetric using Sentinel 2A is 68%.

Keywords: Bathymetry, Sen2Coral, SNAP, Sentinel 2A

Introduction

Indonesia is an archipelagic country with 77% of the ocean area, which includes shallow sea waters to deep sea waters. The area of inland waters and archipelagic waters is 3,110,000 km2, coastline length is 108,000 km and the number of islands is +17,504 (Kemenkomarves, 2018). So far, making bathymetric information has been dominated by measuring depth using a multibeam or single beam echoso under. The use of these tools in shallow sea waters takes a long time, and is expensive, has operational limitations and is dangerous. (Kanno et al., 2011; Nuha et al., 2019).

Since 1970, satellite remote sensing technology has been used as an alternative to perform bathymetry mapping. There are several models of satellite image extraction methods to obtain bathymetric information, including empirical methods, analytical methods and semi-analytic models. Several empirical models that have been carried out include Setiawan et al., 2014, Manessa et al., 2016, Manessa et al., 2017, Hartuti et al., 2017, Setiawan et al., 2019, Setiawan et al., 2020. Bathymetry can support the mapping of coral reef habitats such as bottom substrate and seagrass (Siregar et al., 2010). Many aspects of the sea, both spatial planning, marine environment, aquaculture require bathymetric data (Hell et al., 2012), ship dock construction planning, shipping safety, maintenance of cables and pipelines under the sea, and realizing marine highways (Julzarika, 2017), as well as aquaculture activities (Setiawan et al., 2014) as well as determining the location of shipping ports, determining coastlines, determining cultivation areas, determining the location of shallow marine habitats and managing coastal areas (Nuha et al., 2019). Therefore, the availability of bathymetry information in Indonesia is a necessity.

Remote sensing technology is very effective and efficient to be used for compiling and revising natural resource information (Butler, 1988; Lilles and and Kiefer, 1987). This technology will record a surface area and the area around it (Danoedoro, 1996). The recorded information are stored within satellite images at each wavelength available from the satellite as reflectance. This wavelength reflectance value is used for deriving bathymetric information. The development of remote sensing technology has become a data source for producing Satellite-Derived Bathymetry (SDB) information. Research on SDB bathymetry algorithms and processing are constantly evolving. Developments and refinements are made in order to simplify the processing system.

This research was conducted by utilizing the Sen2coral algorithm on SNAP (Sentinel Application Platform). The SNAP application created by the ESA. This application is an open source application, a collection of several toolboxes commonly used to process Sentinel data. Some functions are available on this tool, e.g for product / data display, band exploration, masking, resampling, subsets, and many other functions, including several plugins developed by other developers. Therefore this algorithm can speed-up the derivation of bathymetery information from satellite images.. The Sen2coral algorithm on SNAP uses the ratio of blue and green channels. Sen2Coral is one of the SNAP plugins developed by Omar Barrirelo which also contains a collection of several other algorithms including the Deglint algorithm and Empirical Bathymetry (Step.ESA.Int, 2021).

The purpose of this study was to implement rapid and accurate bathymetry mapping in shallow marine waters using the medium resolution satellite imagery of Sentinel 2A in Seribu Islands, Jakarta.

Sentinel-2 consists of two constellation satellites, Sentinel-2A and Sentinel-2B, orbiting the poles in a sun-synchronous orbit at an altitude of 786 km. The two identical satellites are 180 degrees apart from each other.

The satellite is a medium resolution satellite with a temporal resolution of 10 days for one satellite or 5 days with two satellites. This satellite can be used for supporting operational observations such as land cover maps, land change detection maps and geophysical variables. Sentinel imagery used in this

Table 1. Specifications for the spatial and spectral resolution of Sentinel 2 . Image (Geoimage.com.au.)

Spatial Resolution	4 at 10m (blue, green, red, NIR) 6 at 20m (vegetation red edge, narrow NIR, 2 larger SWIR) 3 at 60m (aerosol, water vapour, SWIR cirrus)
Spectral Bands	Band 1-Coastal Aerosol: 442.7nm Band 2-Blue: 492.4nm Band 3-Green: 559.8nm Band 4-Red: 664.6nm

	Band 5-Vegetation red edge: 704.1nm
	Band 6-Vegetation red edge: 740.5nm
	Band 7-Vegetation red edge: 782.8nm
	Band 8-NIR: 832.8nm
	Band 8A-Narrow NIR: 864.7nm
	Band 9-Water vapour: 945.1nm
	Band 10-SWIR Cirrus: 1373.5nm
	Band 11-SWIR: 1613.7nm
	Band 12-SWIR: 2202.4nm

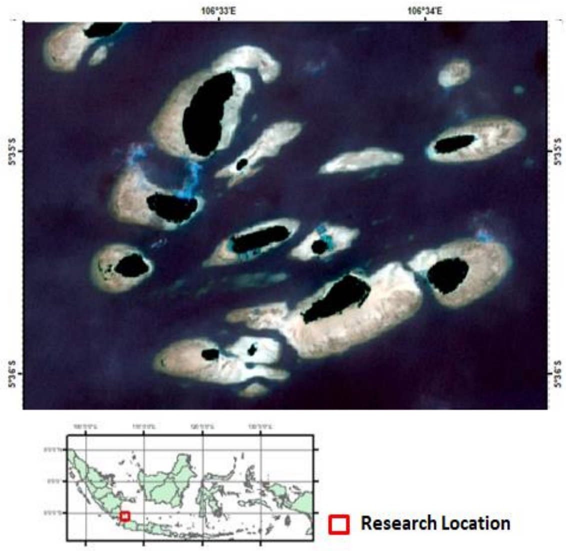
research is MSI2A (Multispectral Instrument 2A) product with 100x100 km^2 areal coverage per scene. This level 2 data are already atmospherically corrected, providing reflectance images for BOA (Bottom of Atmosphere) (Sentinels.Copernicus.eu., 2021). The specifications for the spatial and spectral resolution of Sentinel 2 images can be seen in Table 1.

Methodology

Data and Location

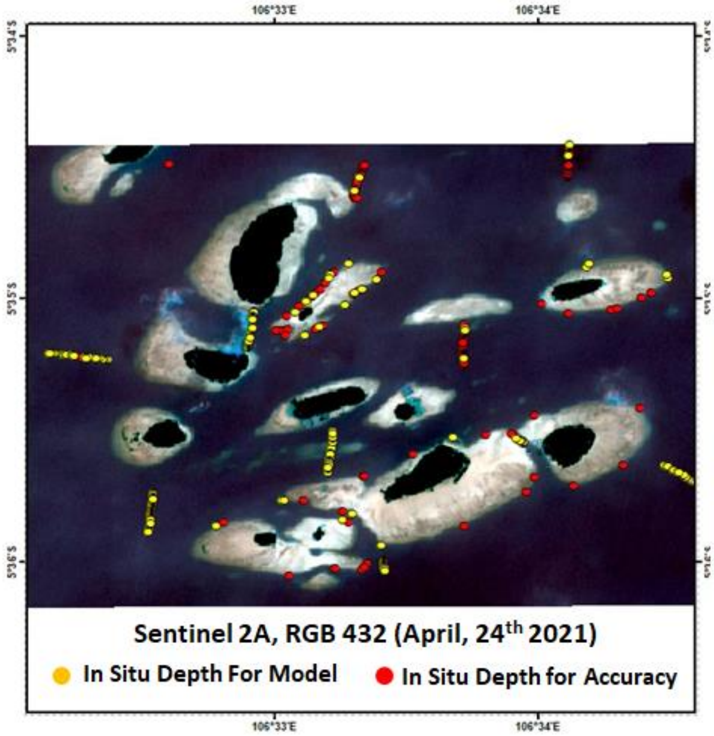
The research was conducted in the shallow waters of Putri Island, Melintang Island and Macan Island, Dolpin Island, Perak Island, Seribu Islands, Jakarta, located at coordinates of 5.570299 - 5.602705 South Latitude and 106.537843 - 106.576017 East Longitude (Figure 1). The shallow waters of the the Islands at this location have a typical clear case-1 water characteristics suitable for testing satellite derived bathymetry method using the sen2coral SNAP algorithm.

Figure1. Research Location



The data used in this study is Sentinel 2A image with the acquisition date April 24, 2021. In situ depth data were collected using single beam echouso under and tidal measurements were collected through in situ depth measurement activities in the field from 19 – 23 May 2021. Tidal data were used to correct in situ depth data measured in the field. In situ tidal corrected depth data are used to model the sen2coral SNAP algorithm and the accuracy testing process. The distribution of the in situ depth data and the Sentinel 2A image is shown in Figure 2.

Figure2. In Situ Depth and Sentinel 2A Image Data

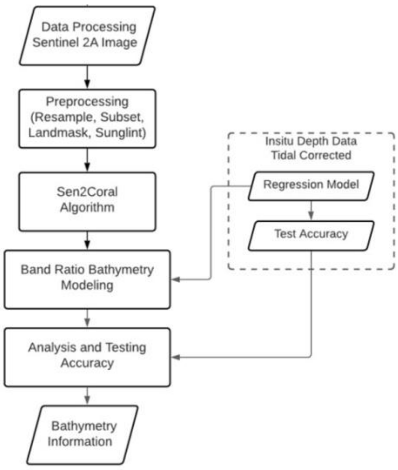


Data Processing

Data processing consists of pre-processing, bathymetry extraction and accuracy assessment. Pre-processing for image data in this study includes resample, subset, landmask and sunglint. Pre-processing for in situ data includes performing tidal correction for depth data from single beam echosounder. Atmospheric and radiometric corrections were not carried out because the data used were already in the form of atmospherically and radio meterically corrected. Resample and data subset is conducted by calling and cutting image data to match the required location. The sunglint correction is carried out to eliminate the effect of the sun's reflection on the surface of the waters which affects the spectral value of the satellite image. Tidal correction is carried out to correct the in situ depth information measured during the field survey. Tidal data is measured during 1 palm tidal period, which is 4 days.

Extraction of Sentinel 2A Satellite Imagery for bathymetry detection is applied by using the principle of wave propagation in water. The reflected wave value is represented by the spectral value of the image. Bathymetric detection modeling using the sen2coral algorithm in SNAP was performed by performing regression between in situ depth data and the value of the ratio of the blue band to the green band. The output of the sen2coral SNAP algorithm is bathymetric information in the unit of meters. The bathymetric detection value is determined from the regression equation generated from the data pair. The bathymetry value from the algorithm results was then compared with other tidal corrected insitu depth data for accuracy calculations. The flow of research activities can be seen in Figure 3.

Figure 3 Reasearch Flowchart



The estimated bathymetry value is determined from the processing of the three visible channels, namely the blue channel, the green channel and the red channel of the Sentinel 2A image. The resulted bathymetry values were then compared with each other to observe the differences that occur and then the accuracy of each bathymetric information extraction was calculated.

The depth accuracy of each model is calculated using equations 1 dan 2:

$$R^2=1-\sum_i (h_i-\hat{h}_i)^2 \Big/ \sum_i (h_i-\bar{h})^2 \quad (1)$$

$$RMSE=\left(\sum_{i=1}^{n} (h_i-\hat{h}_i)^2/n\right)^{0.5} \quad (2)$$

where h is the in situ depth measurement, $\hat{h}$ the estimated depth of each model, $\bar{h}$ is the mean in situ depth value, and n is the number of input data.

In addition to calculating the overall accuracy using the confusion matrix, this study also calculates the accuracy of the classification results using kappa analysis. Kappa analysis can be used to cover the lack of overall accuracy of the confusion matrix. The calculation of the kappa coefficient (K) is carried out with the following equation (Djamaluddin et al., 2019):

$$K = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+}x_{+i})}{N^2 - \sum_{i=1}^{k}(x_{i+}x_{+i})} \quad (3)$$

Where N is the total number of all pixels used for observations; k is the number of lines in confussion matrix (number of classes); x_{ii} is the diagonal value of the i-th row and i-th column confussion matrix; x_{+i} is the number of pixels in the i-th column; and x_{i+} is the number of pixels in the i-th row.

Results and Discussion

Pre-processing on the sen2coral algorithm on SNAP begins with the calling of the Senitinel 2A data. Next is the data resampling process followed by cropping procedure. Advanced pre-processing is landmasking and sunglint correction processes. Landsmasking and sunglint correction algorithms are available in the sen2coral tools of SNAP. The results of the sunglint correction processing shows sharper images in shallow waters compared to the uncorrected images.

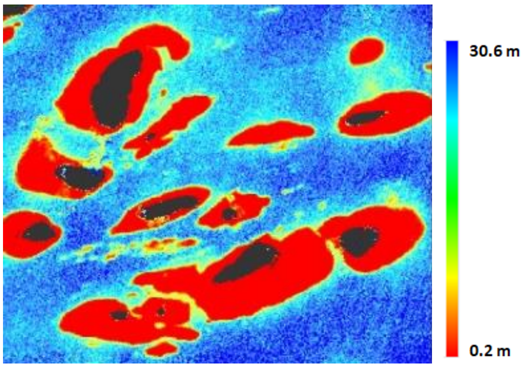
The preprocessing of the image data ends with the sunglint process in the hope that the reflectance data from the visible bands of the Sentinel image to are free from atmospheric influences and the reflected sunlight on the water surface, The sunglint correction process is to to ensure that the reflectance value of the visible band received by the sensor represents the reflection from the bottom of the water surface.

The sen2coral algorithm in SNAP is the band ratio formulation. It uses the ratio of the natural logarithm of the blue band and the green band developed by Stumph et al, 2003. Therefore, the spectral data of Sentinel 2A image used for bathymetry detection using this algorithm are blue and green bands. Simultanwith the preprocessing of the Sentinel 2A image data, the tide-corrected insitu depth data was also prepared. Insitu depth data are grouped into two parts. The first part is used for developing the bathymetric model and the second part is used for the validation process.

After pre-processing of the data, the next step is to process the bathymetry extraction. Bathymetry detection in the sen2coral SNAP algorithm uses empirical bathymetry processor tools. The input used are sunglint corrected image and in situ depth data. All input data are processed through tools available in SNAP. The sen2coral SNAP algorithm performs the processing of bathymetry detection by creating a regression model that is formed between the two pairs of data. The two pairs of data are data from the band ratio between the logarithm of the blue band and the green band with in-situ depth data. The result shows that bathymetery information derived from Sentinel 2A data using the sen2coral algorithm available in SNAP software applied to are capable of revealing depth information up to 30.6 m as shown in Figure 4.

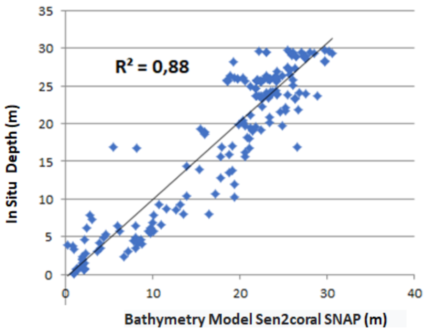
After the bathymetry detection process, the accuracy assessment was conducted by comparing between the results of the bathymetry values of Sentinel 2A images and insitu depth data is carried out. This process is then validated through several statistical parameters including the coefficient of determination, RMSE value, accuracy and Kappa values. Coefficient of determination (R^2) between the image-based bathymetry and the in situ depth data shows a value of 0.88. The results of the distribution of these data comparison can be seen in Figure 5.

Figure 4. Bathymetry Detection Results with the Sen2Coral SNAP Algorithm



The calculation of the RMSE, accuracy and Kappa values is made based on the confusion matrix in Table 1. The confusion matrix is made in 5 depth class intervals, namely depth class of 0 - 2 m, 2.01 – 5 m, 5.01 – 10 m, 10.01 – 20 m, and > 20 m, respectively. Creating class intervals was conducted to observe in more detail the accuracy and RMSE for each depth class. The results of the confusion matrix of the 5 depth classes are shown in Table 2.

Figure 5. Distribution of Bathymetric Sen2Coral SNAP Algorithm with In Situ Depth Data



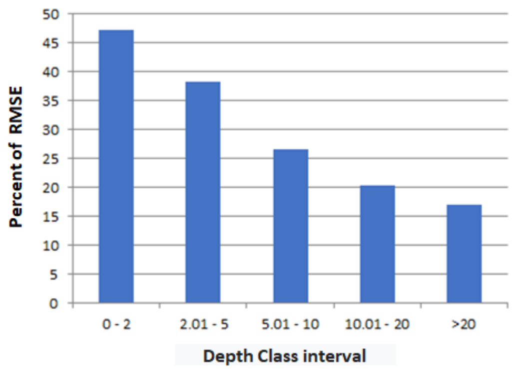
The validation of the satellite-based bathymetry model of the present study was conducted using 191 in-situ bathymetry data points collected during the field works. The accuracy of the model was assessed using several statistical indicators, including coefficient of determination (R^2), root mean square (RMSE) and Kappa coefficient.

Based on the results of the accuracy test, the overall accuracy value is 68% with a kappa coefficient value of 0.51. The results is still under the good category as the overall accuracy is still above 60% and the kappa coefficient value is still in the range of 0.4 - 0.8, which indicates it is in the medium category.

The RMSE calculated for each depth interval of 0 - 2 m, 2.01 – 5 m, 5.01 – 10 m, 10 – 20 m, >20 m are 0.94 m, 1.92 m, 2.66 m, 4.06 m and 5.08 m, respectively. The image-based bathymetry at a depth of more than 20 meters yielded a percentage of RMSE of 16.9%. The RMSE value for this class has the smallest error percentage compared to the other depth classes. The dynamic distribution of the RMSE percentage in the five depth classes from the sen2coral SNAP algorithm can be seen in Figure 6.

The simultaneous plotting of the image-based bathymetry and insitu depth data for accuracy assessment purpose is shown in Figure 7. From the figure, it can be seen that the sen2coral SNAP algorithm at depth classes of less than 5 meters have RMSE percentage of more than 30%.

Figure 6. Distribution of RMSE Percentage Result of Sentinel 2A Image Bathymetry Detection



The result of the present study is comparable to previous similar research. Setiawan et al. (2021) used SPOT 7 satellite imagery in Karimunjawa Island, Central Java by applying semi-analytical method. They were capable of producing bathymetric information to a depth of 11. 45 meters. Arya et al. (2016) were able to produce satellite-based bathymetry map from SPOT-7 to a depth value up to 21 meters in Mamuju Belang Belang Bay using a semi-parametric empirical method. Manesa et al. (2016) produced satellite-based bathymetry map Worldview-2 multispectral imagery to a depth up to 11 meters in Gili Matra Lombok with using random forest empirical method. Similarly, Siregar et al (2010), using Quick Bird imagery in Panggang Island, obtained a depth of up to 10 meters using Jupp's empirical model.

When compared to the marine map No. 78 produced by the Navy Center for Hydro-Oceanogrpahy (Pushidrosal), the resulted image-based bathymetery map of the present study has some similarities and differences (Figure 8). Figure 8 shows several similar points on the two dataset as shown in points with number 1, 2 and 3. The sen2coral algorithm is able to provide depth information for shallower areas which are not detected in the marine map of the Navy Center for Hydro-Oceanogrpahy (Pushidrosal), as shown in points number 4, 5 and 6. It is also a positive result that the method used in this study succeeded in detecting depth information deeper than 30,06 meters . The result of the satellite-based bathymetry is shown in Figure 9.

Table 2. Accuracy Test Results

Insitu (m) / Estimation (m)	0 – 2	2.01 – 5	5.01 – 10	10.01 – 20	> 20	Row Total	RMSE (m)
0 – 2	8	11	0	0	0	19	0.94 m
2.01 – 5	5	6	8	0	0	19	1.92 m
5.01 – 10	0	4	6	10	0	20	2.66 m
10.01 – 20	0	0	2	18	13	33	4.06 m
> 20	0	0	0	8	92	100	5.08 m
Column Total	13	21	16	36	105	191	
Accuracy	68%						
Kappa	0,51						

Figure 7. Bathymetric Distribution of Sen2coral SNAP Model with Insitu Depth

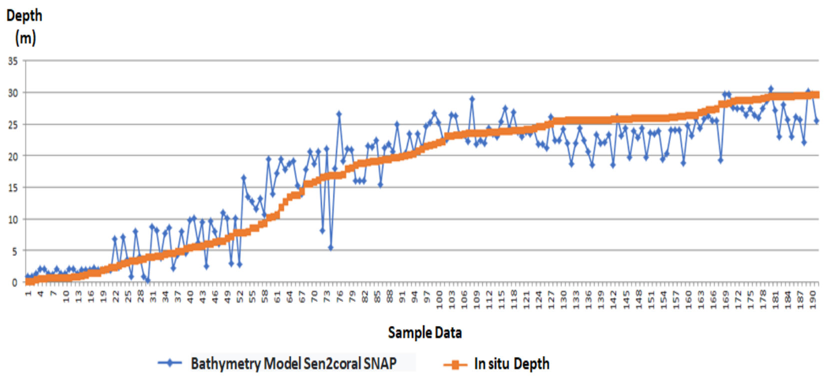


Figure 8. Results of Bathymetry Model Sen2coral SNAP (right) with Marine Map No. 78 (left)

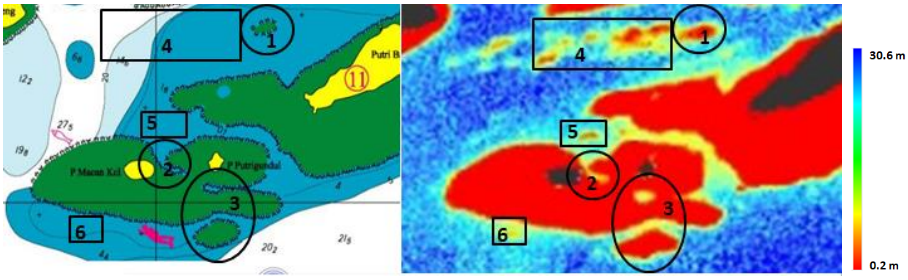
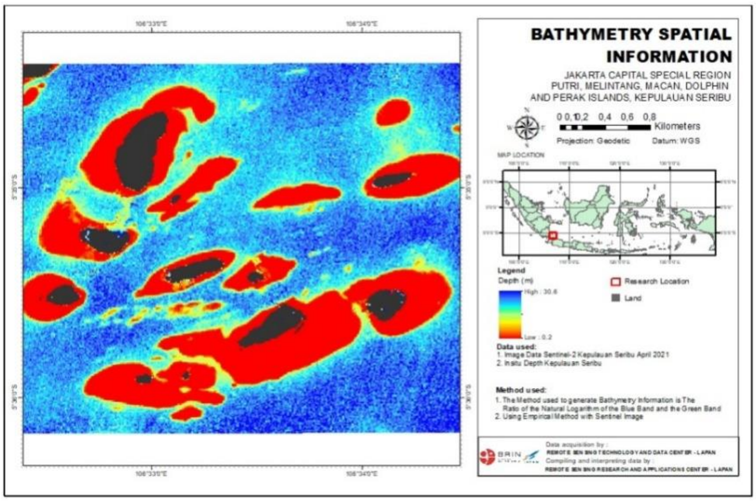


Figure 9. Seribu Islands Bathymetry Information Model Sen2coral SNAP



Conclusion

Bathymetry detection using the sen2coral SNAP algorithm applied on Sentinel 2A imagery covering some islands in Seribu Islands, Jakata can detect depth information up to 30.6 meters. The accuracy test shows that the algorithm produces coefficient of determination of 0.88, an accuracy of 68% and a Kappa coefficient of 0.51. When compared to the marine map No. 78 produced by the Navy Center for Hydro-Oceanogrpahy (Pushidrosal), the bathymetry information derived using the sen2coral SNAP algorithm, , has several similar patterns, although there are several points that have different results which will be addressed in the subsequent research.

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