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Bathymetry mapping with empirical bathymetry method based on sentinel application platform case study: Bawean Island, Central Java

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Abstract. Bathymetry information is an important requirement for the marine and fisheries sector in Indonesia. However, the acquisition of information is done in the traditional way, namely surveys using single/multibeam echosounder devices carried by ships. This method was inefficient, especially to cover a wider area. The development of remote sensing technology can be a solution and has become a source of data for satellite-derived bathymetry (SDB). One of the areas of concern in this research is the eastern waters of Bawean Island located in the Java Sea. This research uses the SNAP method to determine the results and accuracy of bathymetry mapping in shallow sea waters east of Bawean Island. This method is generated from regression modeling between spectral values of satellite image data and in-situ depth data. The satellite data used is the Sentinel-2A image recorded on December 9, 2022. The results showed that the Sentinel-2A satellite can produce depth information up to 27.9 meters. The coefficient of determination, R^2, is 86%, and the confusion matrix accuracy value is 75.21%.

1 Introduction

Bathymetric information was obtained from surveys using single/multibeam echosounder devices carried by ships. This method can provide bathymetric information for all the marine waters in Indonesia. However, this method has limitations because it is expensive and has difficulties in shallow seawater. This limitation is an important problem, especially for

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countries that have large areas of shallow seawater with many small islands, such as Indonesia [1].

Remote sensing technology is an alternative method for optically detecting bathymetry, especially in clear, shallow seawater that is free from sedimentation and waves. The high concentration of sedimentation in shallow seawater affects the accuracy of Satellite-Derived Bathymetry (SDB) results [1]. The information recorded by satellite imagery at each wavelength was the reflectance value from the bottom of the sea surface. The reflectance value was used to obtain bathymetric information. Therefore, the Satellite-Derived Bathymetry (SDB) method is an alternative method for obtaining bathymetry data [2].

Up-to-date and accurate water environment information, such as bathymetry, is needed to support effective coastal policies and resource management and ensure human safety and well-being. Bathymetric information is important in maritime spatial planning, such as determining the construction of new piers on small islands, supporting shipping safety during military exercises for amphibious landings, and realizing sea highways [3]. Bathymetry information is also used to determine coastlines, aquaculture areas, shallow marine habitat life (coral reefs, etc.), and coastal management (habitat mapping) [4][5]. Bathymetry information in the field of fisheries can be used by fishermen as a reference for fishing areas and the use of fishing gear. Using bathymetry information, fishermen can determine the distribution pattern of fish species in water based on the depth of their habitat [6]. Therefore, the availability information of bathymetry is an important requirement for the marine and fishery sectors in Indonesia.

Bathymetry information derived from satellites is a cost-effective alternative that can quickly and efficiently provide high-resolution mapping of large areas. Satellite image extraction methods for obtaining bathymetry information include empirical methods, analytical methods, and semi-analytical models. In its application, the empirical method results from regression modeling between the spectral value of the image used and in-situ depth data. The empirical method is easier and more practical to use because it does not consider the process of electromagnetic wave propagation in a water column [7].

The research location was determined on Bawean Island (see **Fig. 1**) because Bawean Island is one of the islands in the Java Sea, has a strategic geographic location, is a conservation area, and has high potential for natural resources and environmental services [8]. The waters around Bawean Island have a depth of less than 100 meters, so it is called shallow water. Bawean Island has priority area status for marine tourism based on the zoning plan for coastal areas and small islands in East Java Province. Bawean Island acts as a shipping center and stopover for ships sailing from or to the islands of Kalimantan and Sulawesi, with quite complex sea dynamics [9]. Interactions between the ocean, atmosphere, tides, and human activities can cause variations in the water depth. Therefore, updating bathymetric information, especially for shallow waters on Bawean Island, is necessary to support the safety of shipping activities. Therefore, remote sensing technology is utilized as an alternative for bathymetry mapping. This research uses the SNAP method to determine the results and accuracy of bathymetric mapping in shallow seawater in the eastern part of Bawean Island.

2 Materials and methodology

This study used Sentinel-2A satellite data and in-situ depth data. The Sentinel-2A data was obtained from the Copernicus website (https://scihub.copernicus.eu/). The satellite image data used were data with a recording period of December 9, 2022. The in-situ depth data used in this research were obtained from coastal environmental maps obtained from the Geospatial Information Agency (BIG).

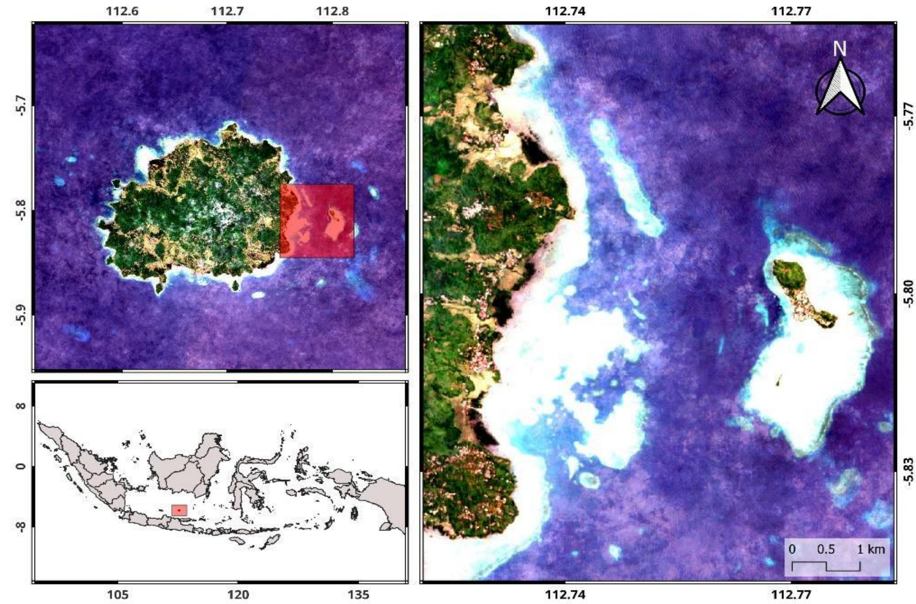

Fig. 1. Location of the research area.

The bathymetry information in this study was developed by processing Sentinel-2 satellite image data using the SNAP software with empirical bathymetry tools. Setiawan [10] stated in their research that the Sen2Coral plugin on the SNAP. Atmospheric correction with Sen2Coral produces a Bottom of Atmosphere (BoA) image, which is the reflectance of an image that has been freed from atmospheric effects and corrected for surface and cloud cover [11]. Simultaneously, tide-corrected in-situ depth data were collected. The in-situ depth data were then grouped into two parts. This tool is a commonly used shallow water mapping technique to estimate bathymetry using the empirical regression method with the Sen2Coral plugin [12]. The Sen2Coral plugin on SNAP can be implemented by following the stumpf algorithm [13]. The bathymetric equation of Stumpf [13] is stated by the following formula:

$$Z = m_1 \frac{ln(nR(\lambda_2))}{ln(nR(\lambda_1))} - m_0 \quad (1)$$

where Z is absolute depth, m1 and m0 is the constant coefficient of modeling results, n is constant, $R(\lambda_1)$ is radiance for spectrum 1 (blue), and $R(\lambda_2)$ is radiance for spectrum 2 (green).

The accuracy values calculated were the coefficient of determination R^2, Root mean square error (RMSE), and confusion matrix. This matrix is made in 5 depth class intervals: depth classes 0-2 m, 2.01-5 m, 5.01-10 m, 10.01-20 m, and >20 m. Making class intervals is done to see in more detail the accuracy and RMSE in each depth class. The more class intervals that are made, the more accurate the results obtained.

The research flowchart begins by selecting Sentinel-2A satellite image data and collecting in-situ depth data. Next, pre-processing and sunglint correction were carried out on the Sentinel-2A satellite image data. Simultaneously with the image data correction process, in-situ depth data, which had been corrected for tides, were also grouped into two parts. The first part consists of 60% of the total in-situ depth data used to perform the empirical modeling. The second part, namely the remaining 40%, was used for accuracy calculations. Subsequently, the empirical bathymetry process of the stumph algorithm was carried out by regressing the first part of the in-situ depth data. This empirical process produces the absolute depth, which is the result of the bathymetry of the SNAP method. Next is the process of extracting bathymetric pixel values in the second part of the 40% depth dataset. This stage was performed to obtain pairs of absolute and in-situ depth data. From this pair of depth data, an accuracy testing process was carried out, including determining the coefficient of determination R^2, calculating the root mean square error (RMSE), and creating a confusion matrix. The research concludes with the results of bathymetric information. The processing process for this research is summarized in the flowchart in **Fig. 2**.

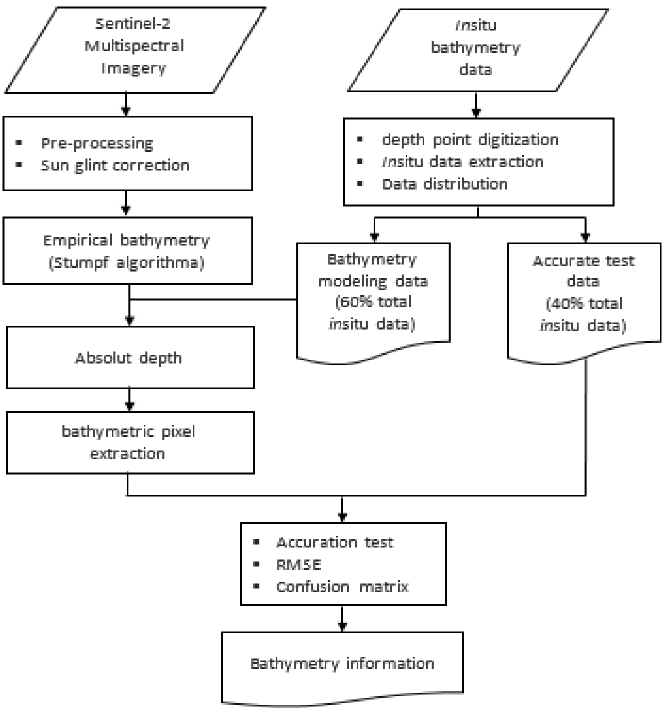

Fig. 2. The research flowchart.

3 Results and discussion

Pre-processing of data and sunglint correction were performed to prepare image data for further processing. This process was performed to eliminate errors in the bathymetric detection results caused by the image data used. All correction processes were performed using the sen2coral tools of the SNAP algorithm. Bathymetric detection is a continuation of Sentinel 2A imagery, which has undergone atmospheric, radiometric, and sunglint correction stages. Bathymetry is determined using the sen2coral algorithm which applies the ratio band formulation between the natural logarithm of the blue band and the green band. The sen2coral algorithm obtains bathymetry detection results through a regression model between ratio data from images and in-situ depth data. Sentinel 2A data bathymetric information using the sen2coral algorithm can produce depths of up to 27.9 m as shown in **Fig. 3**. According to **Fig. 3**, it can be seen that the variation in water depth between Bawean Island and Gili Island ranges from 0 to more than 20 meters. Depths of 0-5 meters are located around the island, whereas depths of more than 20 m are located in the western and southwestern parts of Gili Island.

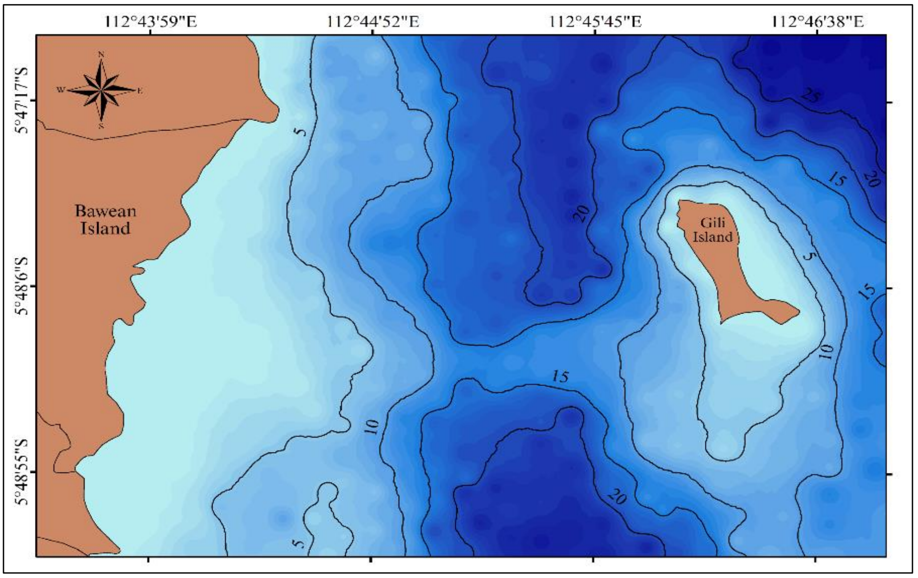

Fig. 3. Bathymetry information map of the East waters of Bawean Island.

The accuracy test results between Sentinel-2 satellite imagery data and in-situ depth data are presented in a confusion matrix table (**Table 1**) and a regression model graph (**Fig. 4**). The confusion matrix in this study was made in 5 depth class intervals. Rows in the confusion matrix Table 1 show the pixel class of in-situ values, and the column section shows the results of the Sentinel-2 satellite image pixel class estimation. The diagonal part of the matrix provides accurate classification of pixels [14].

Table 1. Confusion matrix absolute depth accuracy test results.

In-situ Depth (m)	SNAP Depth Estimate (meters)					
	0-2	2.01 - 5	5.01 - 10	10.01 - 20	> 20	Total
0-2	8	2	0	0	0	10
2.01 - 5	7	8	2	0	0	17
5.01 – 10	1	0	20	6	0	27
10.01 – 20	0	0	7	40	5	52
> 20	0	0	0	0	15	15
Total	16	10	29	46	20	121
RMSE	1.4	1.68	3.19	2.94	3.33	
Accurate						**75.21**

The spatial accuracy obtained was 75.21%, which can be said to be in a good category because the overall accuracy was still above 60% [10]. While the RMSE values calculated for each depth interval 0-2 m, 2.01-5 m, 5.01-10 m, 10-20 m, >20 m respectively are 1.4 m, 1.68 m, 3.19 m, 2.94 m, and 3.33 m. From the RMSE calculation results, it can be said that the bathymetric estimation error value generated by the SNAP software is quite small, so the bathymetric estimation data is quite accurate. In theory, the smaller the resulting RMSE value, the more accurate the bathymetric value estimated from the SNAP processing results [15].

Next, the coefficient of determination R^2 was used to determine the relationship between the bathymetric detection results from Sentinel-2A images and the in-situ measurement depth values. The coefficient of determination, R^2 produced in this study was 0.86. The R^2 value is close to 1, indicating that the bathymetry detection results from the Sentinel 2A image have a strong relationship with the in-situ depth measurement results [1, 10, 16]. The results of the comparison of the distribution of the data are shown in **Fig. 4**.

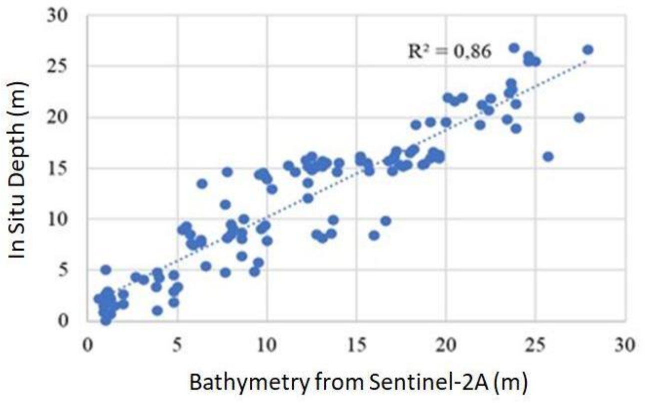

Fig. 4. Graph of absolute depth regression model results.

Because the depth of the waters of the eastern part of Bawean Island is relatively small, with the deepest depth being 27.9 meters, these waters are suitable for aquaculture using floating net cages (KJA) [17]. This area can also be used as a fishing ground for pelagic fish, such as flying fish (Decapterus) and tuna (*Euthynnus affinis*) [18]. In addition, this water area can be a location for underwater tourism, such as snorkeling and diving [8].

4 Conclusion

Bathymetric detection using SNAP applied to Sentinel 2A imagery recorded on December 9, 2022, in the shallow waters of the eastern waters of Bawean Island, East Java Province, produces depth information of up to 27.9 meters. Accuracy tests show that this method produces a coefficient of determination of 0.86, an accuracy of 75.21% and RMSE values for each depth interval 0-2 m, 2.01-5 m, 5.01-10 m, 10.01-20 m, and >20 m are 1.4 m, 1.68 m, 3.19 m, 2.94 m and 3.33 m.

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