BATHYMETRIC EXTRACTION USING PLANETSCOPE IMAGERY (Case Study: Kemujan Island, Central Java)

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Abstract. Bathymetry refers to the depth of the seabed relative to the lowest water level. Depth information is essential for various studies of marine resource activities, for managing port facilities and facilities, supporting dredging operations, and predicting the flow of sediment from rivers into the sea. Bathymetric mapping using remote sensing offers a more flexible, efficient, and cost-effective method and covers a large area. This study aims to determine the ability of PlanetScope imagery to estimate and map bathymetry and to ascertain its accuracy using the Stumpf algorithm on the in-situ depth data. PlanetScope level 3B satellite imagery and tide-corrected survey data are employed ; satellite images are useful in high-precision bathymetry extraction. The bathymetric extraction method used the Stumpf algorithm. The research location was Kemujan Island, Karimunjawa Islands, Central Java. The selection of this region was based on its water characteristics, which have a reasonably high variation in depth. Based on the results of the data processing, it was found that the PlanetScope image data were able to estimate depths of up to 20 m. In the bathymetric results, the R^2 accuracy value was 0.6952, the average RMSE value was 2.85 m, and the overall accuracy rate was 71.68%.

Keywords: *marine resources activity, Stumpf algorithm, Karimun Jawa Island, remote sensing, water characteristics*

1 INTRODUCTION

Nowadays, bathymetric technology development is becoming well known in mapping for scientific purposes, including fisheries management, tsunami propagation modeling, and in the oil-gas industries. Previously, bathymetric data were only used for navigation purposes because of the very high cost of the research equipment (such as multibeam and single-beam echosounders and side scan sonar), survey vessels and personal expertise as well as the length of time involved. However, some coastal areas cannot be accessed by the survey vessels because the water depth is shallow, making that type of measurement inefficient.

One of the technological developments in bathymetric measurement is that of remote sensing using a multispectral or hyperspectral sensor. This type of satellite imagery helps obtain information in areas that are difficult to access by survey vessels. The depth information obtained by analysing satellite imagery is known as Satellite-Derived Bathymetry (SDB). Using multispectral sensors, some studies have employed satellite imagery with a high spatial resolution of more than 30 m, such as that from Landsat, SPOT, IKONOS, and WorldView. Satellite images are useful in high-precision bathymetric extraction.

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This study uses PlanetScope satellite imagery with a 3 m spatial resolution to extract water depth. There are three levels of PlanetScope imagery: basic scene (Level 1B), ortho scene (Level 3B), and ortho tile (Level 3A) (Planet Lab Inc., 2020). An orthorectified scene is shown visually (RGB) and analytically as a digital number (DN), radiance, and surface reflectance (SR). Poursanidis, Traganos, Chrysoulakis, & Reinartz (2019) were the first to attempt to employ Planet data in SDB for fine and accurate bathymetric prediction. The basic concept of SDB is that light transmission depends on the exponential wavelength, penetration and attenuation in the water in relation to the depth. According to Pe'eri et al. (2014), 350 nm (ultra-violet) - 700 nm (red) is the range of the light wavelength that is less capable of being attenuated in seawater. However, wavelengths greater than 700 nm (near-infrared) are less sensitive in seawater and are suitable for reflecting land and water boundaries.

The novelty of this research is the use of PlanetSope imagery with the Stumpf algorithm for bathymetric extraction in the Karimunjawa islands. PlanetScope satellite imagery data is rarely used in Indonesia, two of the few previous examples being the studies of Gabr et al. (2020) and Waskito dan Wicaksono (2019). This study was conducted in Kemujan Island waters, Karimunjawa Islands, using the Stumpf algorithm method. Stumpf et al. (2003) developed a ratio model comparing two bands of water reflectance factors. They assumed that using a two band comparison would decrease the albedo effect of water, a problem found in bathymetric mapping. This study aims to determine the ability of PlanetScope multispectral satellite imagery in estimating and mapping bathymetry and to establish the accuracy of water bathymetry using the Stumpf algorithm and PlanetScope imagery on the in-situ depth data. The results of the research will be very useful for the management of coastal areas and small islands, especially the Karimunjawa Islands. Furthermore, bathymetric information can be used to assist in determining ideal zones for marine tourism, conservation zones and other zoning in an effort to improve the sustainability of coastal resources.

2 MATERIALS AND METHODOLOGY

2.1 Location and Data

The research area was Kemujan Island, located in the Karimunjawa Islands. Administratively, it is included in Jepara District, Central Java, Indonesia (Figure 2-1).

The data used was PlanetScope Level 3B imagery. This is an analytic ortho scene, on which orthorectification has been conducted and projected into the Universal Transverse Mercator (UTM). Level 3B was also conducted on surface reflectance (SR) so as not to need atmospheric correction. The imagery data were acquired on August 25, 2019, and the band information is presented in Table 2-1.

Figure 2-1: Study Site: Satellite image of Karimunjawa islands. The yellow dots show the depth measurement data.

Table 2-1: PlanetScope image band information. (Source: Planet Lab Inc., 2020)

Band Number	Description	Wavelength (μm)	Spatial Resolution
Band 1	*Blue*	0.455–0.515	3 m
Band 2	*Green*	0.500–0.590	
Band 3	*Red*	0.590–0.670	
Band 4	*Near-infrared*	0.780–0.860	

2.2 Data Standardisation

PlanetScope imagery that has been converted becomes SR, which is followed by a masking process. This process is conducted to cover the land area, and radiometric correction is performed to reduce the radiometric distortion in the image. Water masking is performed using band 2 (Green) and band 4 (NIR) to focus on the study and reduce the imagery process load. Both bands are also designed to maximise the reflectance of the water body in the green band and to minimise it in the NIR band (Sun et al., 2012).

2.3 Methods

2.3.1 Bathymetric Estimation

According to Muzirafuti et al. (2020), the ability of satellite sensors to collect water information in multispectral bands allows for research on bathymetry. A methodological bathymetric approach using two spectral bands (blue and green) in conjunction with in situ bathymetry, taking into account the quality of water and the propagation of light through the water column has been proposed by Stumpf et al (2003). Although most near infrared light is absorbed by clear water, it is still a useful parameter for the land/water boundary extraction process (Jensen, 2007). Green and blue light penetrate the water column and are exponentially attenuated as the water depth increases, leading to the principle of bathymetric extraction (Gao et al., 2007).

The method of water depth estimation through PlanetScope imagery uses an algorithm developed by Stumpf et al. (2003). This method applies the basic principle that each band has a different absorption rate in the water column. These different rates will generate ratios between the bands, which will consistently change simultaneously when the depth changes. Bands with a high absorption rate will continue to decrease as the depth increases. Equation (2-1) shows the Stumpf algorithm:

$$Z = m_1 \frac{ln(nR(\lambda_2))}{ln(nR(\lambda_1))} - m_0 \quad (2\text{-}1)$$

where Z = depth estimation; m_1, m_0 = the constant coefficients of the regression results; n = constant; R(λ1,2) = radiant for the λ_1 and λ_2 spectra.

Therefore, to obtain the estimated depth from the regression results of the reflectance value ratio in each band used, equation (2-1) can be re-written according to the linear regression equation to become:

$$Y = aX + b \quad (2\text{-}2)$$

Where a = coeffiicent m_1; b = coefficient m_0; and X = the ratio results of the band reflectance value.

Calculation of the Stumpf algorithm produces the bathymetry of Kemujan Island in a raster (2D). ArcScene is a tool from ArcGIS that specialises in 3D visualisation; using it, bathymetry in a 2D raster can be displayed in 3D.

2.3.2 Accuracy Test

Accuracy assessment is an essential step in the data processing of remote sensing, generating data informatively. An accuracy test of the depth estimation value is conducted by measuring the Root Mean Square Error (RMSE) and the Confusion Matrix.

RMSE is generated from the average root of the error square number between field value differences and imagery processing result values, and is expressed in meters (m). A lower RMSE value shows a better equation model of depth estimation (Nurkhayati, 2013). RMSE is defined as the error rate in the prediction results; as it becomes lower (close to 0), the prediction results will be more accurate (Suprayogi et al., 2013). RMSE can be calculated using equation (2-3):

$$RMSE\ (m) = \sqrt{\sum_{i=1}^{n} \frac{(\frac{100e}{Vti})}{n}} \qquad (2\text{-}3)$$

where e is the difference between the imagery depth value (Vti) and the field depth value (Vai), and n is the number of depth points used for the validation.

The confusion matrix puts the values from the in-situ data into columns and the estimation data into rows. The diagonal part of the matrix displays the correct classified pixel value. One of the bases for the accuracy test is overall accuracy (OA) by calculating the number of correct pixel divisions compared to the total number. Besides OA, individual class classification accuracy can be calculated by producer accuracy (PA) and user accuracy (UA). PA is obtained by dividing the number of correct pixels in a class by the number of pixels obtained from the in-situ data (column total). When the pixels in the estimation data are correct, a class is divided by the total number of estimation data pixels (row total), a calculation which is known as user accuracy (UA) (Banko, 1998).

3 RESULTS AND DISCUSSION

The combination of the Blue and Green bands in the PlanetScope imagery is used to calculate the depth estimation. The use of the Blue/Green band ratio is to normalise the primary reflection effect change due to the water column. In the PlanetScope imagery, the Blue/Green bands are on bands 1 and 2. Figure 3-1 shows the relative depth ratio generated from the imagery data processing, obtaining a ratio value of 14.38 to 67.13. In the colour distribution in the map, light blue is assumed to represent shallow water, and dark blue quite deep water. The low-value distribution is located near the land, which is then surrounded by the high-value distribution.

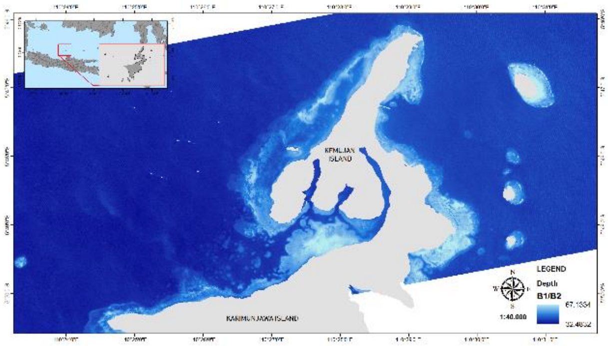

Figure 3-1: Relative depth results using b1/b2

The relative depth results were entered into the in-situ data, and then the regression calculation was made. The ratio of the regression value of both bands and the in-situ data form the regression graph in Figure 3-2.

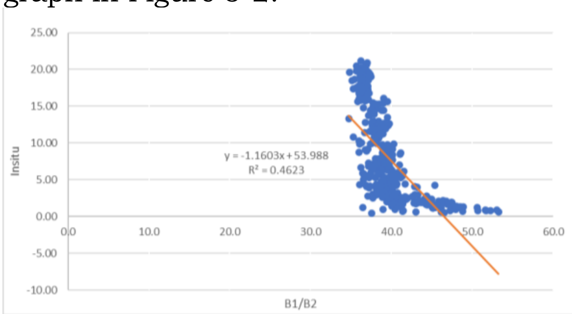

Figure 3-2: Regression model graph from the relative depth results

The function of the regression is used to determine the depth value using the regression equation:

$$Y = -1.1603x + 53.988 \qquad (3\text{-}1)$$

The equation results are then entered into the Stumpf algorithm to obtain absolute bathymetric values. Bathymetric data from the processing results in satellite imagery cannot be used directly because the data are lacking. The data regarding absolute depth were entered into the in-situ data. The corrected data were then compared with the in-situ measurement data to observe the accuracy value. The bathymetry estimation results generated negative values under 0, with a maximum value generated of 13.8 m. Therefore, depth values under 0 (zero) were eliminated from the bathymetry map because it is a depth value with a high error rate. This is confirmed by Nurkhayati (2013), who states that depth values under 0 should be eliminated because they are values with relatively high bias. The bathymetry map is shown in Figure 3-3.

The bathymetry map classification is oriented towards the results of absolute depth, resulting in four classes. The regression results (Figure 3-4) obtained a determination coefficient value (R^2) of 0.6952, showing that absolute depth could explain 69% of the in-situ depth values. R-Square (R^2) is between 0 and 1; a number closer to 1 is better.

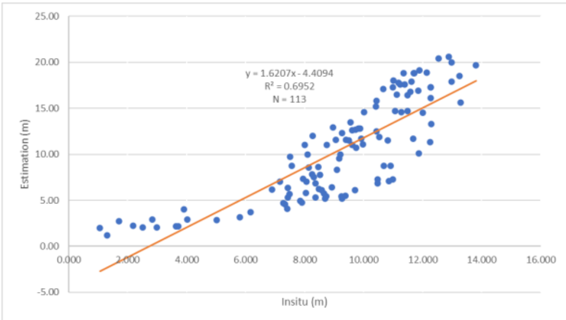

Figure 3-4: Regression model graph from the absolute depth results

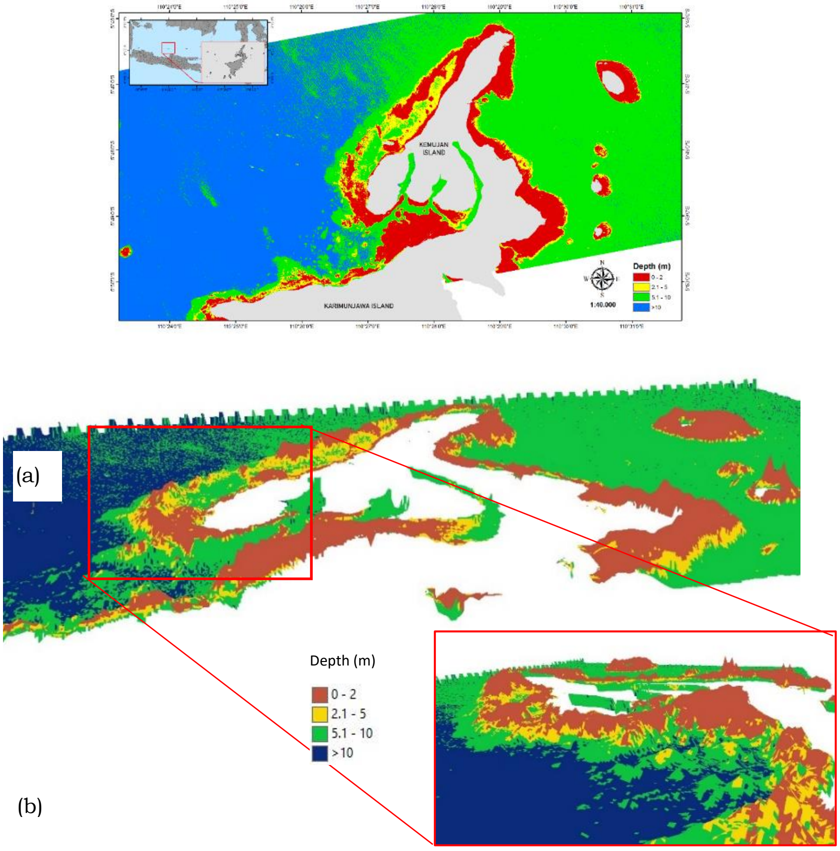

Figure 3-3: Absolute depth results using the Stumpf algorithm: (a) 2D and (b) 3D

Table 3-1. Accuracy test calculations using the confusion matrix

Insitu(m) / Extraction(m)	0 - 2	2.1 - 5	5.1 - 10	>10	Total	User Accuracy (%)
0 - 2	2	1			3	67
2.1 - 5		8			8	100
5.1 - 10		8	31	17	56	55
>10			6	40	46	87
Total	2	17	37	57	113	
Producer Accuracy (%)	100	47	84	70		71.68%

An accuracy test was conducted to establish the accuracy of the bathymetric data generated by the imagery processing. Such tests are generally performed to compare data generated from the analysis of remote sensing and from field surveys (Siregar et al., 2008).

Table 3.1 shows that the matrix of theoretical confusion (the error matrix) of the bathymetric estimation uses PlanetScope satellite imagery. Columns in the matrix show the pixel class and the actual value (in-situ), while rows represent the pixel class of the estimation results by image. The diagonal part of the table shows the correct pixel classification.

The highest accuracy based on the producer and user accuracy values was 100% at depths of 0 - 2 m and 2.1 - 5 m respectively. In contrast, the overall accuracy (OA) value reaches a good level of 71.68%. The OA value is obtained by dividing the number of correct pixels (on the diagonal) by the total number.

4 CONCLUSION

The study has illustrated the depth of Kemujan Island waters in 2D and 3D. The Stumpf algorithm in the PlanetScope image data processing can estimate depths of 0 to 20 m. In the accuracy test calculation, the R^2 value was 0.6952; if this figure approaches 1, the estimation results are better. Based on the results, PlanetScope imagery is suitable and recommended for use to extract bathymetric information. The accuracy test with the confusion matrix calculation was classified into four bathymetry classes, with an overall accuracy value of 71.68%.

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AUTHOR CONTRIBUTIONS

A.S.S conceived the research idea, proposed the methodology, conducted the analysis and prepared the manuscript. K.T.S coordinated the satellite imagery, participated in the methodology and analysis and contributed to the manuscript. J.A coordinated the in-situ data and contributed to the manuscript.

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