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The Effect of Sunglint Correction for Water Depth Estimation Using Rationing, Thresholding and Mean Value Algorithms

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ABSTRACT

Satellite-Derived Bathymetry (SDB) is an alternative for obtaining shallow water depth data. The existence of images with various resolutions, the availability of a complete image band can develop the extraction results. This method is based on the principle of the satellite's visible band to estimate water depth. The mapping of shallow water depth is dependent on water conditions, both its brightness and surface. When the sensor senses a water object, the reflected reflection comes from the surface, and some sensors cannot penetrate the water object. The sun's position and the sensor's point of view when sensing it results in interference from the water surface (Sunglint). The sunglint effect on the image can be reduced by performing RGB band correction with NIR Infrared. This study aims to demonstrate the effect of Sunglint's correction on three SDB approaches, namely Thresholding, Rationing, and Mean Value on Worldview 3 imagery in Karimunjawa Islands, Central Java. This study's results indicate that the Sunglint correction on Worldview 3 imagery affects the depth extraction results. The best results are shown by Sunglint's correction using the Thresholding approach (B2-B7), which produces the best correlation with R2 of 0.7364 and (B7-B2) with R2 = 0.7351. Contrastingly, the lowest correlation was generated using the Mean Value ((B2 + B7) / 2) approach without Sunglint's correction with R2 = 0.4015. So this research proves that the Worldview 3 image with Sunglint correction can provide bathymetry data, especially in shallow waters.

***Keywords**: bathymetry mapping, sunglint correction, band ratio, Worldview 3, Karimunjawa*

INTRODUCTION

The coastal environment has various natural resources, including coral reefs, mangroves, and estuaries. This environment has a dynamic condition and high sensitivity to changes in the sea and land ecosystem. Management of the coastal environment will support maintain the sustainability process (Rudyanto, 2004). One of the activities in coastal environmental management is a mapping survey. Technological developments are supporting the survey because of the modern instruments and the number of image resolutions. A popular technology in mapping is a remote sensing technique. Remote sensing is the science or art of object acquisition without direct contact (Lillesand, T.M *et al.,* 2008). Currently, coastal and marine studies are becoming popular because of the large number of natural resources and large areas that have not been observed (Ariana *et al.,* 2017).

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Study of the water depth using satellite imagery is still a challenge, primarily to obtain high accuracy. Technological advances are in line with advances in sensing, including the Satellite-Derived Bathymetry (SDB) technique. Satellite-Derived Bathymetry (SDB) extracts water depth values from optical satellite images (Nuha et al. 2019). The existence of images with various resolutions and a complete number of bands is an alternative in improving the SDB technique's accuracy. This method is based on the satellite's visible band's principle to estimate the depth of the water (Green *et al.,* 2000). The accuracy obtained with the SDB method ranges from 2-30 meters due to spatial resolution (Jégat *et al.*, 2016). One of the methods commonly used in SDB research is the Empirical method. This method relates the spectral value in the image to the measured depth (Nuha *et al.*, 2019).

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The mapping of shallow water is dependent on both the water conditions and the surface (Gao, 2009). When the sensor senses a water object, the reflected reflection comes from the surface, and some sensors cannot penetrate the water object (Khorram *et al.,* 2016). When the waters are turbulent, satellite sensors will record specular reflections on the surface instead of the primary habitat. Specular reflection of solar radiation on the rough sea water surface is a disturbance factor in remote sensing shallow water environments. Where is the orientation of the water surface so that sunlight is directly reflected on the sensor, which is also influenced by the sun's position and the angle of view of the sensor. This effect is also called sunglint on image data (Hochberg *et al.*, 2003; Hedley *et al.,* 2005).

Sunglint is a phenomenon that occurs when sunlight is reflected by surface water with an angle of incidence equal to the angle of reflection (Hochberg *et al.,* 2003). When viewed from the height, the water will look bright shiny in that area, different from the adjacent area. Sunglint on Earth can only occur on the surface of the water. The reason is that the water surface is relatively smooth like a mirror, and tends to reflect light at the same angle. The effect of Sunglint on satellite images can be reduced by making corrections. Sunglint correction aims to eliminate the effect of sunshine due to the angle of the rays' angle, which is the same as its reflection, causing white spots on the water object in the image (Syaiful *et al.*, 2019). Hochberg *et al.*, (2003); Hedley *et al.,* (2005) stated that the purpose of this correction is to eliminate the effects of water waves. In their research, Hochberg *et al.*, (2003) stated that the Sunglint effect could cause information loss on the object to be extracted on the IKONOS imagery. *Goodman et al.*, (2008) explained that there would be a loss of 30% of the information for ocean depth extraction without Sunglint's correction.

Eugenio *et al.*, (2015) describes a physical combination of images applied for atmospheric correction to multispectral imagery to optimize sunglint removal. Meanwhile, Garaba *et al.,* (2012) stated that the RRS (700–950 nm) <0.010 Sr-1 spectral conditions covered most of the measurements influenced by sunglint, which provided efficient empirical markers. Harmel *et al.,* (2018) that the sunglint signal's spectral variation is in the range of 350 to 2500 nm. SDB research using sunglint correction was conducted by Traganos et al. (2018) using Sentinel 2A imagery on the Google Earth Engine (GEE) platform. The research resulted in the best accuracy R2 = 0.79, RMSE = 1.39 m, and R2 = 0.9, RMSE = 1.67 m. Like Traganos *et al.,* (2018) research, Caballero *et al.*, (2020) conducted an SDB study using Sentinel 2A/ B imagery with a spatial resolution of 10 m. This research shows that atmospheric correction, including removing the Sunglint effect on the image, affects the depth estimation results. The image preprocessing stage determines the results of the analysis. If the data used contain small errors, it can be ascertained that the analysis results will be better. This statement is supported by Ilori et al. (2020) in his research using Landsat 8 imagery. Ilori *et al.*, (2020) states that atmospheric correction in SDB analysis can improve depth accuracy results. Rahman *et al.*, (2019) stated that further analysis was carried out regarding atmospheric correction to map the essential shallow water habitat. Each class's effect can be done by comparing the pixel values in each shallow water class, namely the image before correction and after the sunglint correction. Hochberg *et al.*, (2011) stated that when the correction process has been applied, the image's appearance will be smoother, and the uneven water surface's influence can be eliminated. The application of sunglint correction results in differences in image appearance that can be seen from its texture, contrast, and color (Hochberg *et al.*, 2011).

Sunglint correction analysis on high-resolution imagery such as Worldview 3 needs to be done to determine how much influence the correction has on the depth extraction results. Consequently, the purpose of this study is to determine the effect of Sunglint's correction with three approaches, namely Thresholding, Rationing, and Mean Value of Worldview 3 imagery for estimating shallow water depth. The location of the research was carried out around the harbor of Karimunjawa Islands, Central Java. This location was determined due to the availability of measured depth data. Karimunjawa waters, especially around the harbor, have shallow and clear waters to be optimal in SDB analysis and consider satellite sensors' limitations in penetrating water objects.

METHOD

Materials and Data Processing Software

In-situ water depth measurements were conducted using the Bathy-2010 SyQwest Single Beam Echosounder (SBES), and the Geodetic Global

Positioning System (GPS) positioned on the survey ship to obtain real-time position information. Meanwhile, a tide master is used to obtain tide data. Data collection was carried out on March 20, 2019, - March 23, 2019. The image used is high-resolution imagery (Worldview 3) recorded on February 21, 2018, with radiometric correction. The Digital Globe carried out this correction with the DigitalGlobe's Atmospheric Compensation (ACOMP) algorithm (Digital Globe, 2016). The spatial resolution of Worldview 3 imagery is 31 cm (panchromatic) and 1.24 m (multispectral). Some software is used to analyze data, including ArcGIS for creating Region of Interest (ROIs) and ENVI for image processing. The following table explain Worldview 3 image specifications used in this study:

Table 1. Specification of Worldview 3 Imagery

Bands	Wavelength (nm)
Panchromatic	450 - 800
8 Multispectral (Red, red edge, coastal, blue, green, yellow, near-IR1 and near-IR2)	400 - 1040
8 SWIR	1195 - 2365
12 CAVIS Bands (Desert clouds, aerosol-1, aerosol-2, aerosol-3, green, water-1, water- 2, water-3, NDVI-SWIR, cirrus, snow)	405 - 2245

Research Location

This research was conducted in Karimunjawa Islands, Central Java, in March 2019. The location selection was based on the consideration of shallow and clear water conditions, due to the limitations of satellite image sensors in penetrating water objects. The following is a map of the research location sourced from ESRI World Imagery around the Karimunjawa Harbor:

Figure 1. Research locations around Karimunjawa Harbor.

Sunglint Correction

This correction aims to eliminate the effect of sunshine due to the angle of the rays' angle, which is the same as its reflection, causing white spots on the water object in the image. Syaiful *et al.,* (2019) stated that this correction aims to eliminate water waves' effects. Hochberg *et al.*, (2003); Hedley *et al.*, (2005) have refined the Sunglint correction algorithm as follows:

$$R'i = Ri - bi\ (RNIR - Min\ NIR) \quad \ldots\ldots\ldots \quad (1)$$

Where R'i is band i value after being reduced, Ri is the value of band i, bi is regression slope, RNIR is value NIR band, and Min NIR is the minimum value of NIR band.

Tide Correction

Tide corrections are carried out to produce depth values that are free from tidal influences. The algorithm used for this correction is as follows (Setyawan et al. 2014):

$$D = dT - rt \quad \ldots\ldots\ldots\ldots\ldots\ldots. \quad (2)$$

Where D is the measured depth, dT is the transducer corrected depth, and rt is the reduction of the tides.

Satellite-Derived Bathymetry Algorithms

Sartika *et al.,* (2018) said that the SDB algorithm uses the digital number and band ratio values by connecting the blue band with other bands. The use of the log-ratio in the SDB analysis provides the advantage of obtaining a ratio of 0.1 compared to the ratio ln. This study uses three approaches, specifically, Rationing, Thresholding, and Mean Value. Hartoko (2010); Sartika *et al.*, (2018) said that Thresholding determines the value limit for each band; rationing is a process to see the comparison value of each band and Mean Value, which is the process of determining the average of each band used in the analysis. Based on Hartoko (2010); Sartika *et al.*, (2018) said that the wavelengths of 450-510 nm in the blue band and 850-880 nm in the NIR Infrared band are suitable for coastal waters which are influential in determining the Value of water depth without being affected by land values. The following equations are used in this study Hartoko (2010); Sartika *et al.*, (2018):

1. Rationing Algorithm

$$Satellite\ Derived\ Bathymetry = \frac{Log\ Blue}{Log\ NIR\ Infrared} \ldots. (3)$$

or,

$$Satellite\ Derived\ Bathymetry = \frac{Log\ NIR\ Infrared}{Log\ Blue} \ldots. (4)$$

2. Thresholding Algorithm

$$\mathit{Satellite\ Derived\ Bathymety} = \mathit{Log\ Blue} - \mathit{Log\ NIR\ Infrared} \ldots (5)$$

or,

$$\mathit{Satellite\ Derived\ Bathymetry} = \mathit{Log\ NIR\ Infrared} - \mathit{Log\ Blue} \ldots. (6)$$

3. Mean Value Algorithm

$$\mathit{Satellite\ Derived\ Bathymetry} = \frac{(\mathit{Log\ Blue} + \mathit{Log\ NIR\ Infrared})}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where:

Log Blue : The second band on Worldview 3 imagery

Log NIR Infrared : The seventh band on Worldview 3 imagery.

Regression Analysis

The SDB technique uses the Empirical method to connect the image's spectral value with the measured depth (Syaiful *et al.*, 2019). It aims to see the level of correlation between the spectral values and the measurement depths. The following is the Simple Linear Regression Equation (8):

$$Y = aX + b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where a is the slope value, b is the intercept value, and X is the reflectance band ratio (Syaiful et al. 2019). According to Sartika et al. (2018), polynomial regression is a form of regression with the principle of adding up each explanatory power's effect up to the -m order in a curve that connects each variable (predictor and response). The following is the equation of the Polynomial regression (9):

$$y = a + bx + cx^2 + dx^3 + \cdots \ldots\ldots (9)$$

where:

y = the value of the depth of the SBES measurement

(a = m1, b = m2, c = m3)

x = SDB value up to the next-order point.

RESULTS AND DISCUSSION

Depth Data

The bathymetry data collection was carried out from March 20, 2019, to March 23, 2019. The use of GNSS during data acquisition was intended so that when recording could get a real-time position. The acquisition area around the Karimunjawa Harbor extends to the south and north. The following is the track display during depth data acquisition using SBES (Figure 2). This study uses depth data from 0 to 20 meters. The depth is grouped into four groups with ranges of 0-5 meters, 5-10 meters, 10-15 meters, and 15-20 meters. The number of each sample depth at the research location is presented in the following (Table 2):

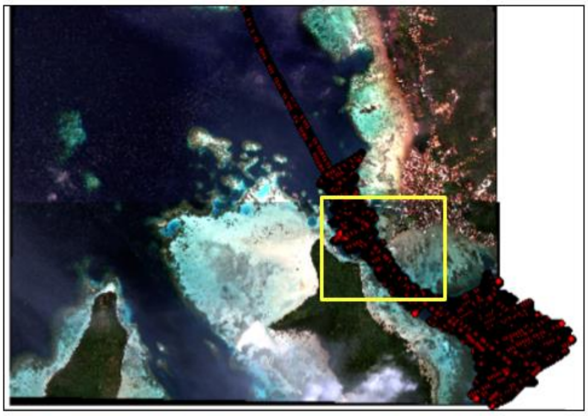


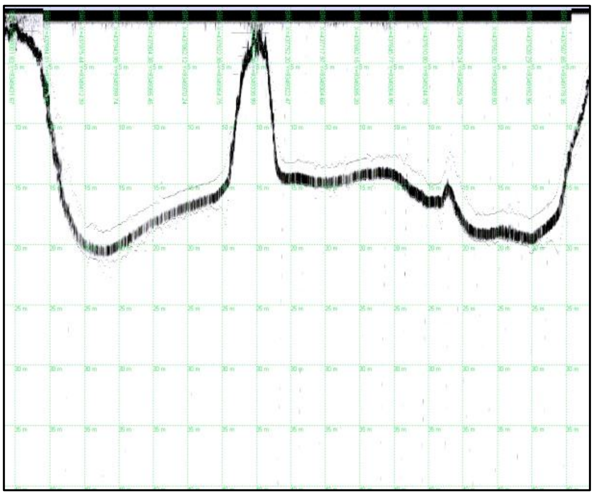
Figure 2. Ship Trajectory For Data Acquisition Using Single Beam Echosounder (SBES)

Table 2. Number of Depth Samples

Depth (m)	Number of Samples	Mininum Value (m)	Maximum Value (m)	Average (m)	Standard Deviation
0 – 5	20	1,32	4,95	2,34	0,98
5 – 10	20	7,27	9,83	8,69	0,68
10 – 15	20	10,14	13,56	12,08	1,05
15 – 20	20	15,44	19,84	17,38	1,17

Tide Correction

The acquisition of field tide data in the Karimunjawa Harbor area uses the Tide Master tool installed at the Harbor. Tide measurements were carried out for 2 x 24 hours. This tool's principle is to automatically measure sea-level changes with sensors connected to a computer device. The tide data is used to correct the SBES depth value from the results to produce a depth value free from the influence of tides. The average depth around Karimunjawa Harbor ranges from 0-25 meters, which is included in shallow seas. The following is a graph of the depth profile in the Karimunjawa Islands:



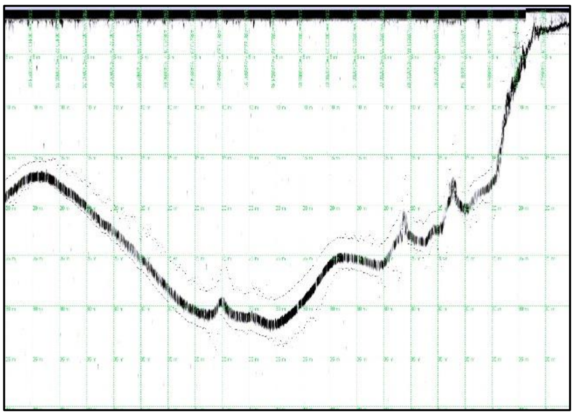
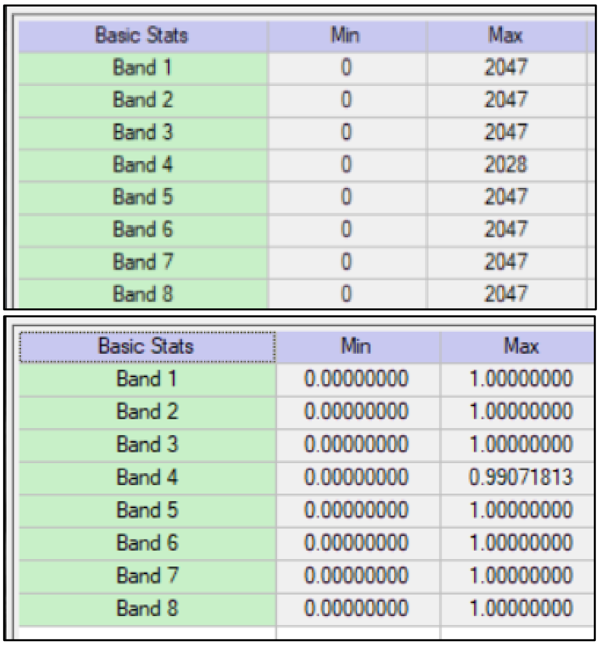


Figure 3. Depth Profile of Karimunjawa Islands

Band Scaling

Band Scaling aims to change the pixel value to have a value range of 0 to 1 (Nuha et al. 2019). The ORStandart2A level in the Worldview 3 imagery before scaling has a value range of 0 to 2047. The principle of this correction is to divide each image band by the maximum value of that Band. If a negative value is found in image processing, the data is automatically not accepted (error) and is not used in processing (Doelling *et al.,* 2018). The following is an image of the Digital Number (DN) value of the Worldview 3 image corrected by ACOMP:



Basic Stats	Min	Max
Band 1	0	2047
Band 2	0	2047
Band 3	0	2047
Band 4	0	2028
Band 5	0	2047
Band 6	0	2047
Band 7	0	2047
Band 8	0	2047

Basic Stats	Min	Max
Band 1	0.00000000	1.00000000
Band 2	0.00000000	1.00000000
Band 3	0.00000000	1.00000000
Band 4	0.00000000	0.99071813
Band 5	0.00000000	1.00000000
Band 6	0.00000000	1.00000000
Band 7	0.00000000	1.00000000
Band 8	0.00000000	1.00000000

Figure 4. Digital number value on Worldview 3 Imagery (ACOMP Correction & After Band Scaling)

Sunglint Correction

This correction is carried out on Worldview 3 imagery to minimize the effect of Sunglint in the water. This correction begins with the creation of ROIs in the area affected by the Sunglint effect. The following is an area Sunglint in Karimunjawa Islands:

Figure 5. Sunglint Effect on Worldview 3 Imagery

This study uses six regional locations that occur in Sunglint. The entire location takes area around Karimunjawa Harbor with different areas. The following is a table of the area that occurs in Sunglint around Karimunjawa Harbor (Table 3):

Table 3. Sunglint Area Around Karimunjawa harbor

Location	Area (m^2)
1	1.17
2	2.69
3	3.11
4	0.85
5	1.18
6	3.97

Sunglint correction uses Red, Green, Blue (RGB) ratio bands with NIR Infrared bands. The RGB band's use aims to display the image in a natural appearance to identify the Sunglint. From this correction, it is found that the three bands have a high correlation. The best correlation is obtained by connecting the red band with the NIR Infrared band with an R2 value of 0.9947. At the same time, the lowest correlation of the three bands is the Blue band with NIR Infrared of 0.981. The following is a Sunglint correction graph:

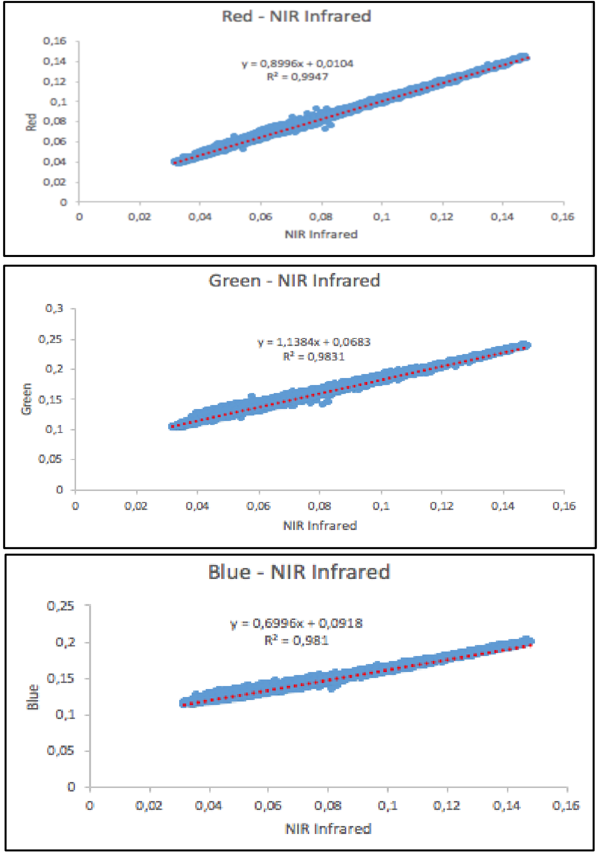


Figure 6. Sunglint Correction Graphs (Red, Green, Blue)

SDB Algorithm

In this study, the first point in the extraction of depth values is to make depth sampling in various groups. Secondly, the depth sampling results were inputted in the ENVI software as vectors to be converted as ROIs. Then the ROIs formed are converted into ASCII format. The results are carried out by polynomial regression analysis to see the relationship between the extracted depth and the measured depth. Statistical analysis uses three approaches: Thresholding, Rationing, and Mean Value, at a depth of 0-20 meters.

SDB Without Sunglint Correction

The first approach is bathymetry extraction using Worldview 3 imagery without Sunglint correction. This trial concludes that the Thresholding approach (B2-B7) produces R2 of 0.6466 with an upward curved regression line. This line shows that the increasing the depth value, the greater the value from the SDB extraction. The same thing also happened to Thresholding (B7-B2), where the resulting R2 value was 0.6597 with the same form of the regression line. Besides, the Rationing approach uses two types of ratios, namely (B2 / B7) and (B7 / B2). At Rationing (B2 / B7), the R2 value is 0.5034, with a downward curved regression line. This curve shows that increasing depth results in smaller SDB estimation values.

Furthermore, Rationing (B7 / B2) produces an R2 of 0.506 with an upward curved regression line. The graph shows that as the depth value increases, the depth estimation results using SDB also become more significant. Later, the last approach, namely using the Mean Value ((B2 + B7) / 2)) produces R2 of 0.4015 with a downward curved regression line. This curve shows that as the depth value increases, the estimated value results are getting smaller. So this approach produces a low correlation. The three approaches that have been done, the Thresholding approach produces the best correlation. On the other hand, the lowest correlation is the Mean Value approach, resulting in a downward curved polynomial line. The following is a graph of the three approaches that are carried out without Sunglint's correction:

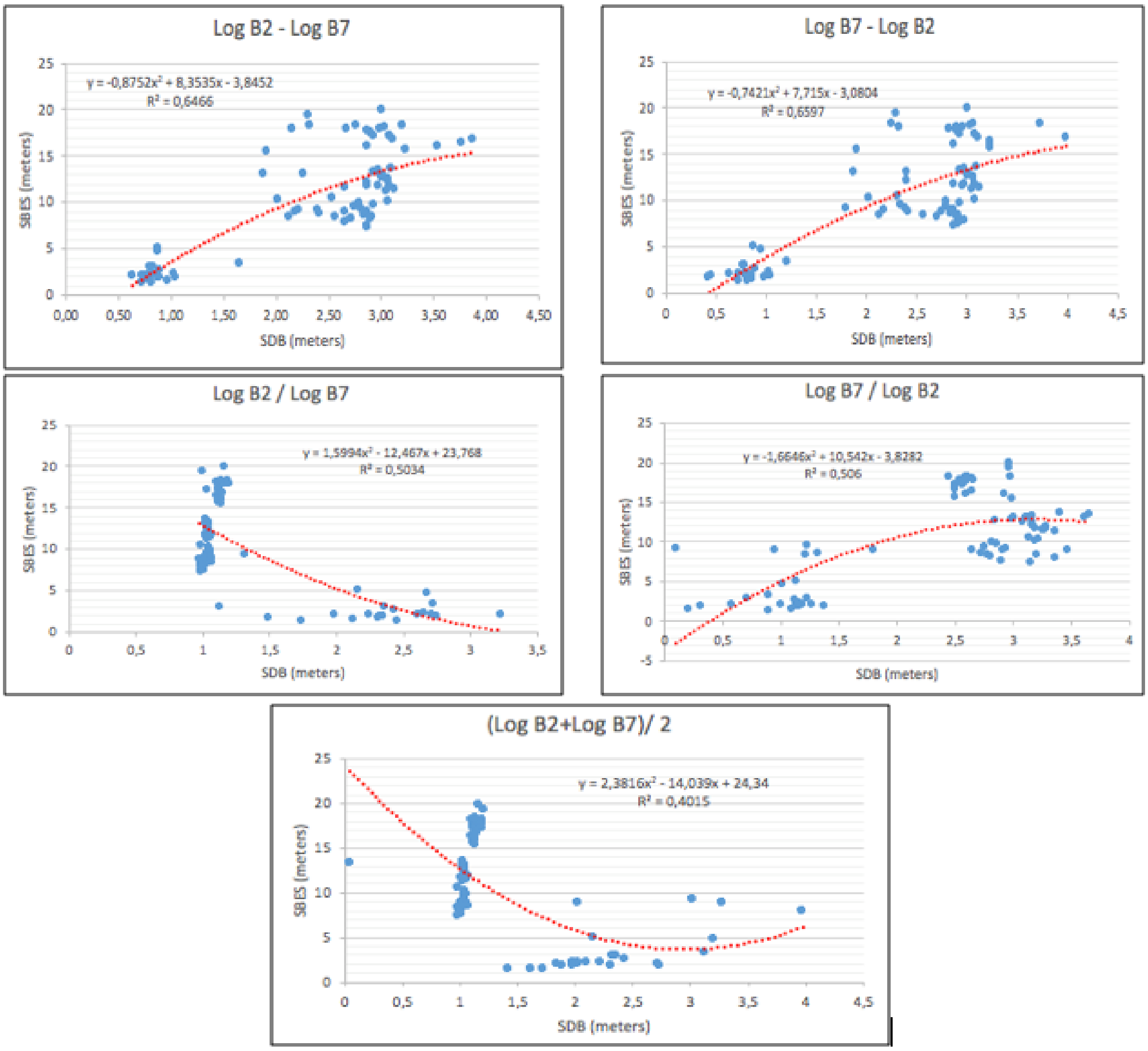


Figure 7. The Relationship Graph between Estimated Depth Values Without Sunglint's Correction

Using Sunglint Correction

The second approach in this study is to use Sunglint's correction. From this trial, it can be concluded that the Thresholding approach (B2-B7) produces R2 of 0.7364 with an upward curved regression line. This line shows that the increasing the depth value, the greater the value from the SDB extraction. The same thing also happened to Thresholding (B7-B2), where the resulting R2 value was 0.7351 with the same form of the regression line. Besides, the Rationing approach uses two types of ratios, namely (B2 / B7) and (B7 / B2). At Rationing (B2 / B7), the R2 value is 0.6288, with an upward curved regression line. This curve shows that the increasing depth results in a more excellent SDB estimation value.

Furthermore, Rationing (B7 / B2) produces R2 of 0.6214 with an upward curved regression line. The graph shows that as the depth value increases, the depth estimation results using SDB also get more significant. Then, the last approach is to use Mean Value ((B2 + B7) / 2)) to produce R2 of 0.5268 with an upward curved regression line. This curve shows that as the depth value increases, the estimated value results are getting bigger. So this approach produces a low correlation. The three approaches that have been done, the Thresholding approach produces the best correlation. On the other hand, the lowest correlation is the Mean Value approach, resulting in an upward curved polynomial line. The following is a graph of the three approaches to the Sunglint correction:

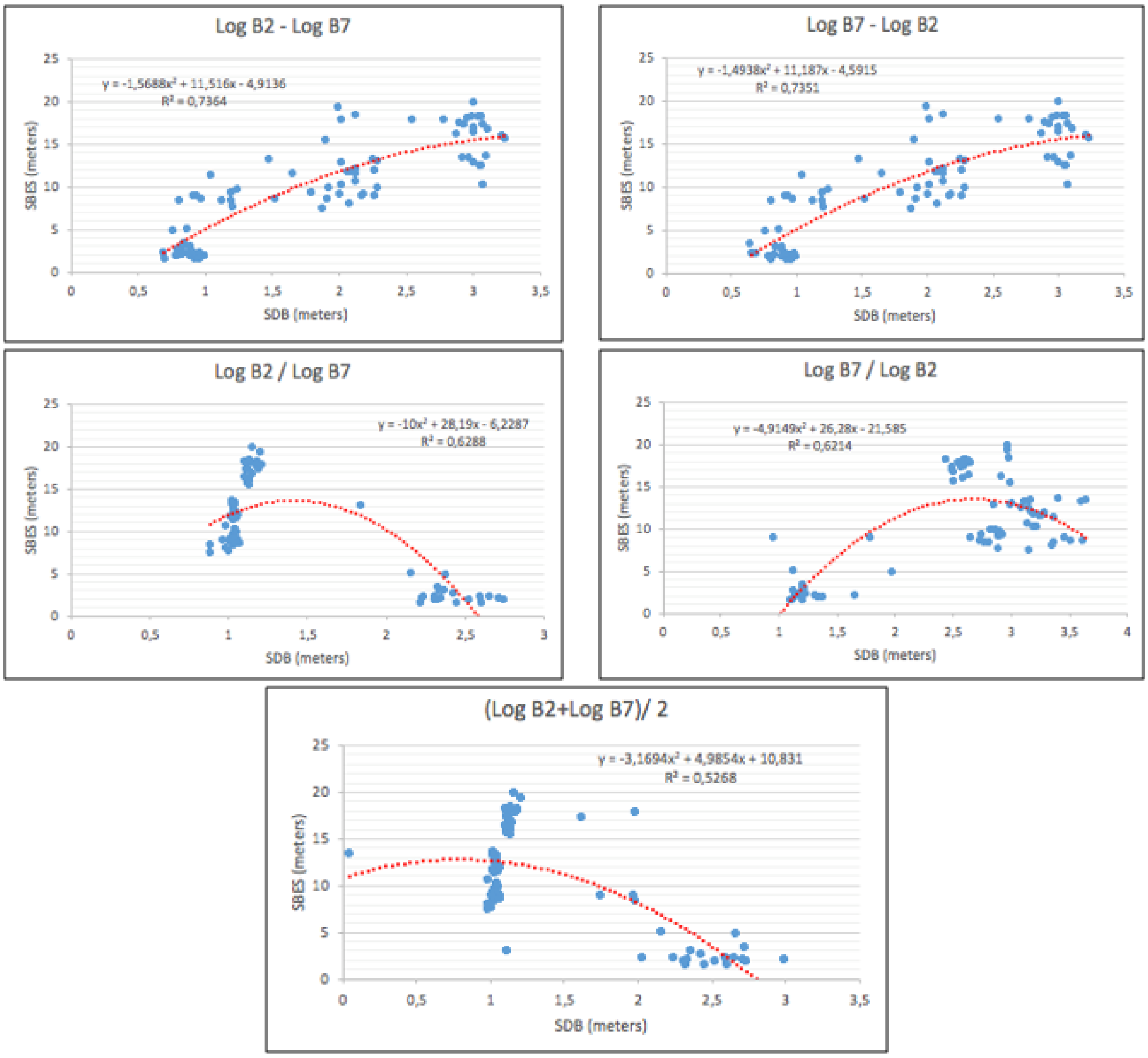


Figure 8. The relationship graph between the estimated depth and Sunglint's correction

CONCLUSIONS

In this study, it can be concluded that the SDB estimation results in Karimunjawa Islands, Central Java with three approaches, namely Thresholding, Rationing, and Mean Value, show that the Sunglint correction on Worldview 3 imagery significantly affects the depth extraction results. The best results are shown by Sunglint's correction using the Thresholding approach (B2-B7), which produces the best correlation with R2 of 0.7364 and (B7-B2) with R2 0.7351. This approach aims to separate land and ocean objects so that the land value does not affect the process's depth extraction results. Contrastingly, the lowest correlation is generated using the Mean Value ((B2 + B7) / 2) approach without Sunglint's correction with R2 of 0.4015. Thus it can be concluded that the Worldview 3 imagery with Sunglint correction has the potential in providing bathymetry data, especially in shallow waters.

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