Lyzenga Algorithm for Shallow Water Mapping Using Multispectral Sentinel-2 Imageries in Gili Noko Waters

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Abstract. Bathymetric survey is an essential approach for gathering marine geospatial information. The use of an echosounder can provide highly accurate bathymetric data, yet it is expensive and time-consuming. To achieve an accurate chart of shallow water areas is challenging as they are difficult to access by large survey vessels due to their draft limitation. Bathymetric survey can also be carried out by using an Unmanned Surface Vehicles; however, it is restricted to small and calm areas. Thus, a Satellite Derived Bathymetry (SDB) come as a solution to take the place of bathymetric survey using an echosounder, especially in a shallow water with many natural or man-made obstacles. This study utilises Sentinel-2 image data, an optical satellite imagery to determine depth values of shallow water area using SDB approach. Several algorithms have been developed to collect depth values using the SDB. One of the algorithms is Lyzenga algorithm which aims to simplify the process of extracting water depths by comparing water reflectance factors using three bands of panchromatic sensor imagery. This study applied the Lyzenga algorithm to determine water depths using multiple linear regression and it is validated using an in-situ data. The RMSE and MAE values is 1.711m and 1.254m, respectively whilst the correlation coefficient is 0.946.

1. Introduction

Bathymetric survey is an approach for providing underwater geospatial information in the marine sector. One of bathymetric survey method is performed by using an echosounder to measure the water depth and depict the seabed topography [1]. The important thing that should be prepared to create bathymetric maps is georeferenced data of sounding points followed by tidal monitoring to establish the vertical datum [2]. This in-situ approach of using an echosounder for bathymetric mapping is time-consuming, costly, and resource intensive.

Bathymetric mapping is utilized to acquire the seabed topography information [3]. Bathymetry plays an important role in coastal engineering, maritime safety and security, resource development, the fishing industry, ocean shipping, environmental protection, and the management of coastal zones on islands [4]. The dynamic nature of waters especially in shallow areas may alter bathymetric conditions rapidly, therefore it is required depth measurements periodically [5]. An accurate bathymetric mapping in shallow water areas is arduous to achieve for large survey vessels due to their draft limitation [6]. An Unmanned Surface Vehicles (USVs) equipped with acoustic sensors (bottom and sides) can be a solution to map shallow waters [7]. USVs have high nonlinear dynamics that operate autonomously [8]. USVs is sensitive to strong currents and high waves. This disturbance affects the transducers, resulting in less dense sounding points and inaccurate water depth mapping [6].

Along with technological advancements, researchers have explored an economical and rapidly approach to determine water depth data and information across a wide and diverse region. This approach is known as Satellite Derived Bathymetry (SDB), and it employs a remote sensing technology, utilizing a passive sensor imagery [9]. SDB is a mathematical modelling technique that utilises multispectral imagery to divide the wavelength spectrum into multiple bands [10]. This approach presents an alternative to field surveys [11] and minimalize the environmental risks and lousy impacts on personnel or equipment. The depth of the water can be determined without the need of direct access to water areas [3].

SDB can be approached using either analytical or empirical methods [12]. The analytical approach is based on modelling the behaviour of light penetration in water. Whereas the empirical approach relates reflected radiation to in-situ depth without taking into account light transmission in water [3]. One of the most used empirical methods is the Lyzenga linear transformation [13]. The relationship between water reflectance and depth is assumed to be linear but may be affected by species variation and random noise. Red (665 nm) is less able than the blue (490 nm) and green (560 nm) bands to pierce the water column in the Sentinel 2-A Level 2 optical satellite image used [15].

The study is located in Sangkapura waters of Gili-Noko Island, Gresik Regency, East Java Province. These waters separate Bawean Island and Gili-Noko Island. Due to its clear water conditions, the beach and underwater tourism in this area are being developed very intensively [16]. Thus, it is important to understand the hydrographic information in this area. The study attempts to determine the shallow water depths in Sangkapura Waters, Gili-Noko Island, using empirical bathymetry data acquired from satellite and Sentinel-2 imagery. The capability of Sentinel-2 and SDB multispectral satellite imagery to empirically predict and map shallow waters in Sangkapura Waters, Gili-Noko Island were also examined.

2. Methodology

This study was conducted in Sangkapura Waters, Gili-Noko Island, Gresik, East Java. Geographically, it is located at 112°45' East Longitude and 5°45' South Latitude. A Sentinel-2A imagery provided a comprehensive view of the research site on the acquisition date of 23 May 2021 with a yellow square indicating the study area, as illustrated in Figure 1.

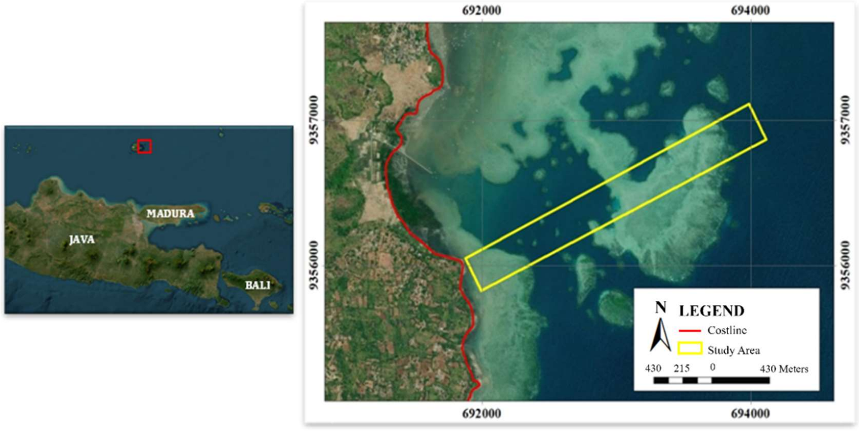

Figure 1. Area of study

This study processed Satellite Derived Bathymetry using Sentinel-2 Level 2A scene imagery from 2021 that covers the study area. In the validation process, reference data will be used for test data, Single Beam Echosounder (SBES) data from a field study on May 2021 is also used. The SBES points visualization from the in-situ survey can be seen in Figure 2.

The purpose of this study is to estimate the depth of shallow water areas of Gili-Noko Island using multispectral Sentinel-2 imagery with seven stages including resampling Sentinel-2 Level 2A imagery, masking water and land areas, masking cloud areas cloud, sun glint correction, filtering of image reflectance data and SBES data field survey, shallow water depth mapping with the Lyzenga algorithm, and accuracy and correlation test which was performed consecutively.

2.1.1. Resampling Sentinel-2 Level 2A Imagery.

Data from Sentinel-2 Level 2A images must be geometrically and radiometrically corrected [17]. Resampling the entire Sentinel-2A image band Level 2 ROI Sangkapura Waters, Gili-Noko Island, Gresik East Java with the acquisition date of 23 May 2021 to a resolution of 10m. This step was performed as the entire image bands have a different spatial resolution. After the resampling process, the image subset is in accordance with the ROI of the research area.

2.1.2. Masking Water and Land Areas

Masking must be conducted before using the data as input to the SDB. Water masking is used to separate water from terrestrial areas. The Normalized Difference Water Index (NDWI) is used to separate land from water [18]. The following in equation (1) describes the NDWI.

$$NDWI = \frac{R(\lambda_{green}) - R(\lambda_{NIR})}{R(\lambda_{green}) + R(\lambda_{NIR})} \tag{1}$$

Where:

$R(\lambda_{green})$: the reflectance from green band

$R(\lambda_{NIR})$: the reflectance from NIR band

2.1.3. Masking Cloud Areas Cloud

Cloud masking is used to separate the cloud cover contained in the image [19]. Normalized Difference Cloud Index (NDCI) describes the difference in the ratio and sum of the two zenith emission measurements measured in two spectral bands around the wavelengths and the wavelengths are chosen based on the optical parameters of clouds, which are similar but have different surface reflectance values. with reflectance values between 0.65 m and 0.86 m. Sentinel-2A images have a range of reflectance values in the red band and the NIR-2 band. The following in equation (2) describes NDCI:

$$NDCI = \frac{R(\lambda_2) - R(\lambda_1)}{R(\lambda_2) + R(\lambda_1)} \tag{2}$$

Where:

$R(\lambda_1)$: the reflectance from red band

$R(\lambda_2)$: the reflectance from NIR-2 band

2.1.4. Sun Glint Correction

After separating water areas and cloud cover, it is necessary to apply sun glare correction [20]. This process, called de-glint, is performed using the Sen2Coral toolbox in SNAP. Sunlight refers to the refraction of sunlight on the water surface, which is common in satellite imagery. This reflection is difficult to observe because sunlight reflects directly from the air-water interface to the satellite. The Sentinel-2 satellite's observing geometry is susceptible to solar contamination. To be able to observe the depth of the waters, the sun glare removal algorithm must be employed to eliminate the sun glare effect [21].

2.1.5. Filtering of Image Reflectance Data and SBES Data Field Survey

The in-situ water depth data of 273 points obtained through the SBES survey with an acquisition time of 10:00 a.m. until 11:00 a.m. on 23 May 2021 serves as validation test data. The data obtained during testing consisted of depth measurements less than twenty meters in length. This is because SDB is limited to estimating the water depth to this depth or less. Each depth point is mapped geographically into Sentinel-2A level 2 imagery, which has been processed using the import point tool in SNAP. The reflectance values of bands 1–12 of the image is obtained. Depth data and reflectance bands 1–12 is then exported as data labels. Several consecutive points are mapped to the same pixel in a satellite image due to the difference between the sampling resolution and the image's spatial resolution. So, it is necessary to remove the preprocessing data to remove some of the noise from the measured depth points. Two or more consecutive depth points within one pixel are deleted to leave a single pixel image with only one depth point. In the region illustrated in Figure 2, 203 in-situ samples were collected.

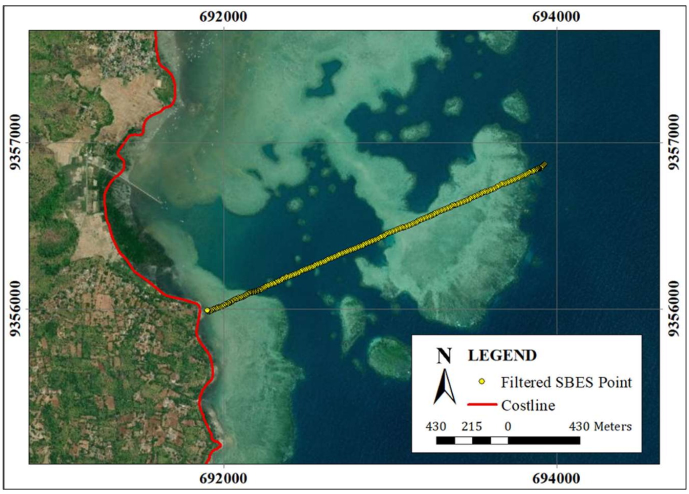

Figure 2. In-situ Depth Sample Distribution

2.1.6. Shallow Water Depth Mapping with the Lyzenga Method

The Lyzenga algorithm was applied to empirical SDB in this investigation [22]. The premise behind the method developed by David R. Lyzenga in 1985 is that different wavelengths (bands) have different water attenuation coefficients. With increasing water depth, it approximates an inverse exponential. Consequently, it is feasible to calculate a ratio between the three bands that varies with increasing depth. The technique contrasts three water reflectance characteristics in the red, blue, and green band to streamline the process of calculating water depth. The following in equation (3) represents the algorithm used to estimate depth:

$$z = a_0 + \sum_{i-1}^{N} a_i \ln(R(\lambda_i) - (R_\infty(\lambda_i)) \quad (3)$$

Where:

z	:	Depth of Water
$a_i(\dot{l} = 0,1,\ldots,N)$	:	N is the constant coefficient representing the number of spectral bands
$R(\lambda_i)$	:	Spectral band reflectance after atmospheric correction λ_i
$R_\infty(\lambda_i)$	:	Average deep-sea reflectance in the spectrum λ_i

2.1.7. Accuracy and Correlation Test

The Root Mean Square Error (RMSE) is used to determine the accuracy of the resulting water depth prediction. RMSE is the average root of the sum of squares of the ratio between the actual depth value of field measurement outputs and the predicted depth value of Satellite Derived Bathymetry image processing. In addition to RMSE, the accuracy of predicted water depth calculations is also measured through the Mean Average Error (MAE). MAE is the calculation of the average absolute error between the difference in the actual depth value of field measurements and the predicted depth value of Satellite Derived Bathymetry image processing. The following equations (4) and (5) are the equations used in the accuracy test [22].

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(z_i - \hat{z}_i)^2}{n}} \tag{4}$$

$$MAE = \frac{\sum_{i=1}^{n}|z_i - \hat{z}_i|}{n} \tag{5}$$

Where:

z : Measured depth survey results with SBES
$\hat{z}$: Estimated depth value of pixels
n : Amount of depth measurement points

Correlation makes it simple to calculate and comprehend the connection between two elements [23]. Field data can be compared with calculated results. Methods that can be used to understand correlation values are presented in Table 1 [24].

Table 1 Statistical Analysis of Correlation Values

Size of Correlation	Description
0.9 to 1 (-0.9 to -1)	Highest
0.7 to 0.9 (-0.7 to -0.9)	High
0.5 to 0.7 (-0.5 to -0.7)	Moderate
0.3 to 0.5 (-0.3 to -0.5)	Low
0 to 0.3 (0 to -0.3)	Lowest

3. Results and Discussion

Using three band combinations, namely bands 4, 3, and 2, the Lyzenga algorithm is then fed to Sentinel-2 imagery in which land and water, clouds, and de-glint have been distinguished from one another. The depth estimate from the satellite picture is the algorithm's output. Figure 3 shows the results of the water depth estimation.

Water depth mapping with this method is done with multilinear regression analysis. After obtaining the multilinear regression value, the next step is to apply the value to the Lyzenga algorithm equation formula (equation 3). This process, called depth extraction (vertical referencing), aims to convert pixel values (relative depth) into in situ depth values (field depth). The equation for the extraction of sea depth from the above coefficients derived from equation (3) is followed by equation (6)

$$z = 28.32 * X1 - 36.25 * X2 + 9.42 * X3 + 16.35 \tag{6}$$

Where:

X1 : Blue Band

https://doi.org/10.1051/bioconf/20248907006

X2 : Green Band
X3 : Red Band

Figure 3 demonstrates that the deeper the blue hue looks, the darker it seems. The image demonstrates that there are parts of the ocean where it is impossible to anticipate the depth. This is because of the local cloud cover or cloud shadow. To prevent an accurate depiction of the Lyzenga algorithm's findings in the red, green, and blue bands. The Lyzenga method can be utilized, nevertheless, in places with no clouds. Between 0 and 23 meters of depth can be surveyed in the research region and its environs.

The predicted depth is then compared to test data and validated. Figure 2 depicts the point distribution of the test data, which is derived from the field survey SBES data. Field data and SDB water depths estimation values are nearly identical.

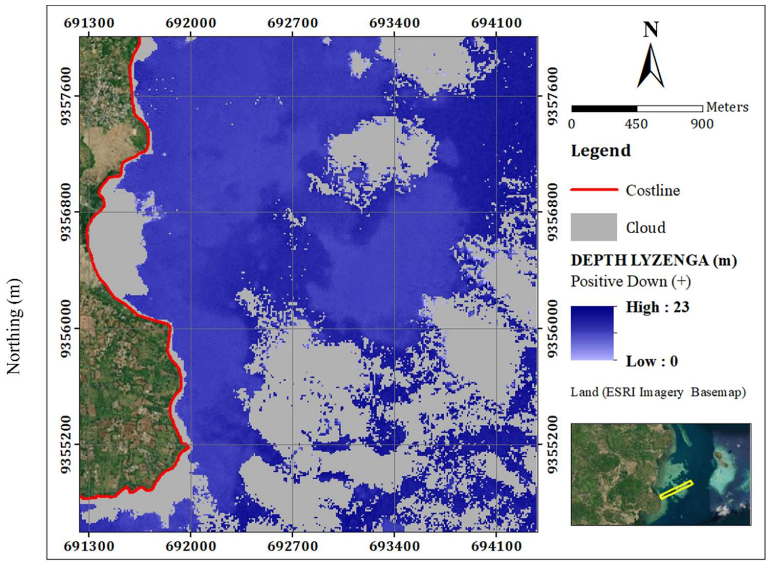

Figure 3. Estimation of Water Depth from the SDB using Lyzenga Algorithm

After the application of equation (6), the coefficient of determination and linear regression model can be determined from the comparison of the In-Situ data with the resulting estimated depth. The correlation coefficient may then be determined. Figure 4 displays the correlation coefficient of the depth data obtained from both the Lyzenga algorithm and the field survey data. Table 1 shows a clear association between the depth findings and the field data. Therefore, it can be inferred from the correlation value that the Lyzenga Algorithm produces highly accurate results when estimating shallow water depth**.**

In addition to the RMSE results, Table 2 also displays the correlation outcomes. From Table 2, the RMSE and MAE of the Lyzenga algorithm is small. This confirms the correlation results which are included in the highest interpretation.

Table 2 Statistical Analysis of Correlation Values

SDB Method	Correlation (m)	RMSE (m)	MAE(m)
Lyzenga Algorithm	0.946	1.711	1.254

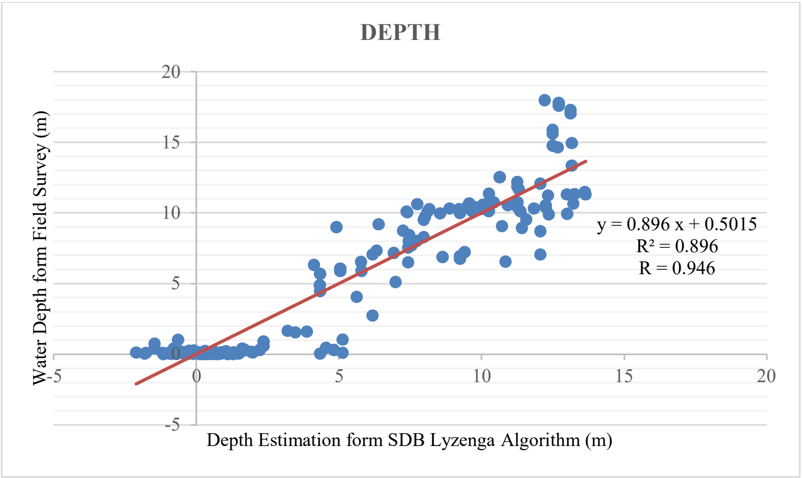

Figure 4. Coefficient of Determination and the Linear Regression of the Depth

4. Conclusion

Gili Noko's waters are valuable for tourism, particularly for underwater activities. The area has been developed for this purpose, and Sentinel-2 imagery is available with good spatial and temporal resolution to estimate shallow water depth. Our study focused on the shallow waters of Gili-Noko Waters in Gresik, where we used visible reflectance images from Sentinel-2 to predict water depth. The first step is to resample the Sentinel-2 Level 2A imagery to ensure that each image band has the same spatial resolution. Then, use the NDWI Algorithm to mask water and land areas to separate water from land areas. Next, use the NDCI Algorithm to mask cloud areas and separate the cloud cover contained in the image. Then, correct the Sun glint to remove the refraction of sunlight on the water surface. Next, filtering of image reflectance data and SBES field survey data. Finally, use the Lyzenga method to obtain shallow water depth mapping in the study area.

The result indicated that using the Lyzenga method on the three reflectance bands (Red, Green, Blue) of Sentinel-2A level 2 imagery obtained a correlation value of 0.946, which is categorized as 'Very High' for predicting shallow water depth in the study area. This finding supports the use of rapid bathymetry mapping to provide hydrographic data. The Lyzenga method can be used to promote rapid bathymetry mapping in the provision of hydrographic data. However, the map's accuracy is limited due to the presence of cloud cover, which hinders the optimal estimation of water depth. Therefore, it is necessary to consider the selection of image acquisition dates and in-situ data for future research.

5. Acknowledgements

The authors wish to express their gratitude to the European Space Agency for providing Sentinel-2 data. Additionally, we would like to thank The Directorate of Business Cooperation and Management and the Directorate of Research and Community Service at Institut Teknologi Sepuluh Nopember for providing this study's reference data.

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