The bathymetry of coral reef area at Bonetambung Island (optical and hydroacoustical comparison to nautical chart)

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Abstract. Base-on time efficiency, cost, and wide coverage area, bathymetry mapping with a hydroacoustic measurement on a small island were avoided; only remote sensing surveys were conducted. Therefore, comparing the bathymetry map of Bonetambung Island, from Hydroacoustic data with that from Landsat 8 OLI images, is essential. Hydroacoustic measurements were carried out in September 2013, while Landsat 8 Satellite Imagery was recorded on April 25, 2018. After being corrected, Kriging (K) and Natural Neighbor (NN) interpolations methods were performed on both data. The 95% ANOVA test, conducted in a previous study, showed that the average depth for the two interpolation results did not differ significantly for the depth range of 0-5m. However, for the 0-30m depth range, this study shows that the accuracy of interpolation hydroacoustic data is much better with the range of RMSE = 0.8-1.2m, ME = 0.4-0.7m, and range of RMSE = 0.8-1.3, ME = 0.4-0.7 for each K and NN interpolation methods. On the other hand, only in the depth range of 0-5m, the accuracy of interpolation Landsat 8 OLI data shows a relatively good value with RMSE = 1.1m, ME = 0.8m, and RMSE = 1.1m and ME = 0.8m for the K and NN Methods respectively. The results of hydroacoustic data interpolation and Landsat 8 OLI were then visually compared with Dishidros Nautical chart number 124. It was concluded that although Landsat data can produce bathymetry maps with a wider coverage area, its accuracy is still unreliable compared to bathymetry maps from Hydroacoustical measurements.

1. Introduction

Over an extended period, the bathymetry of coral waters around small islands can only be obtained from nautical charts. But along with the progress of development in the small island region to support maritime policy, the need for depth information around the small islands is increasing. Information on the depth of water around coral waters is needed for the determination of protected areas, mariculture areas, marine tourism sites, disaster mitigation, and other marine applications.

The bathymetry data can be obtained in several ways, such as measuring depth with lead lines, or by using echo-sounding devices, digitizing contours or depth spots from nautical maps, and water depth modeling using multispectral satellite imagery. Due to time and cost efficiency considerations, bathymetry surveys are often ignored in fulfilling water depth information. The commonly chosen is by map digitation or by other options, such as estimating the water depth by using satellite imagery. Satellite imagery is a popular option because it is freely available now. In addition, the wide-area coverage of the data makes the costs incurred very cheap [1].

Water depth detection using multispectral satellites in principle is to connect several depth values from known points to the reflectance values of those points on one or more visible light bands [2]. Light energy will be absorbed and reflected when entering the water column. Blue-ray wavelengths can transmit deeper into the water column, while longer ray wavelengths will be absorbed shortly. The bottom substrate and water depth contribute to the attenuation of this light. Sand is the most
reliable type of bottom substrate for bathymetry estimation using satellite imagery compared to seagrass and coral [3, 4].

This study aimed to compare the bathymetry map of Bonetambung Island, Makassar produced by remote sensing method (Landsat image), hydroacoustic measurements, and nautical charts. This study result may help the environmentalist to choose the proper method to fulfill their need for bathymetric data on coral reef waters.

2. Methods

A water depth sounding survey was carried out at Bonetambung island, in September 2013 and get a total of 9,004 depth values. Tidal observations conducted simultaneously along with sounding surveys and continued to obtain 16 days of data in 24 hours a day. Landsat 8 OLI (Operational Land Imager) data was gaining from the USGS website on April 25th, 2018, with path number is 114, and the row number is 64. IDRISI Terrset 18.1 was operated to process this satellite image along with Microsoft Excel and QGIS 3. The location study is shown in Figure 1. The general flow data is presented in Figure 2. Data processing and analysis were conducted at Physical Oceanography and Coastal Geomorphology Laboratory at the Faculty of Marine Sciences and Fisheries Hasanuddin University.

Figure 1. Bonetambung as the location of the study in nautical chart number 124.

Figure 2. Data flow in this study.
2.1. Water depth data collection and processing

The water depth data collected using GPS-map-sounder 420, which works in a single beam and two frequency 200 kHz and 50 kHz. The sounding frequency is interchangeable automatically depend on the range of the depth. Track of depth sounding recorded on the log file containing some information, date and time of the acquisition, water depth, position in latitude and longitude, leg time, leg speed, and leg course. This sounding log file is referenced to the mean sea level then exports to Microsoft excel for tidal correction and formatted to making depth grid in the interpolation process. The sounding tracks overlaid to Natural Color Composite of Landsat image are shown in Figure 3.

![Figure 3. Water depth sounding point (white dot) at Bonetambung, September 2013.](image)

2.2. Landsat data collection and processing

Landsat 8 OLI image data was downloaded from https://earthexplorer.usgs.gov/. The raw pixel corrected to Top of Atmospheric (TOA) and then Dark Object Subtraction (DOS) to obtain pixel in reflectance. The atmosphere can affect the nature of remotely sensed images in several ways. At the molecular level, atmospheric gases cause Rayleigh scattering that progressively affects shorter wavelengths (causing, for example, the sky to appear blue). Further, major atmospheric components such as oxygen, carbon dioxide, ozone, and water vapor cause absorption of energy at selected wavelengths. Aerosol particulates are the primary determinant of haze and introduce a Mie scattering that affects all wavelength equally [5].

The effect of haze is usually a relatively uniform elevation in spectral values in the visible bands of energy. One means of reducing haze in imagery is to look for values in areas of known zero reflectance, like deep water. Any value above zero in these areas is likely to represent an overall increase in values across the image and can be subtracted from all values. Dark Object Subtraction model compensates for variations in the solar output according to the time of year and the solar elevation angle. To do this, it requires the same estimate of the Digital number (Dn) of haze (e.g., the Dn of deep clear seawater), the date and time of the image, the central wavelength of the image band, the sun elevation, and radiance conversion parameters. These additional parameters are normally included with the documentation for remotely sensed images [6].

Further, to get sand positions along with the image, the sounding data were overlaid to RGB composite, and then sand pixel extracted for all visible wavelength bands. The relationship between water depth and sand reflectance was build based on three assumptions: they have an exponential relationship; the water quality was relatively constant, and the sand color was uniform on its depth [7]. Landsat image specification is shown in Table 1. This study only uses band 1 to 4 to evaluate and use band 2 to 4 for water depth estimation.
Table 1. Landsat 8 OLI and TIRS bands (µm) [8].

| Bands | Landsat 8 OLI and TIRS bands (µm) |
|-------|----------------------------------|
| 30 m Coastal/Aerosol | 0.435-0.451 | Band 1 |
| 30 m Blue | 0.452-0.512 | Band 2 |
| 30 m Green | 0.533-0.590 | Band 3 |
| 30 m Red | 0.636-0.673 | Band 4 |
| 30 m NIR | 0.851-0.879 | Band 5 |
| 30 m SWIR-1 | 1.566-1.651 | Band 6 |
| 100 m TIR-1 | 10.60-11.19 | Band 10 |
| 100 m TIR-2 | 11.50-12.51 | Band 11 |
| 30 m SWIR-2 | 2.107-2.294 | Band 7 |
| 15 m Pan | 0.503-0.676 | Band 8 |
| 30 m Cirrus | 1.363-1.384 | Band 9 |

2.3. Interpolators
Kriging and natural neighbor method are both used in this study to interpolate water depth data from hydroacoustic surveys and multispectral satellite images. The data frame and its interpolation parameter that was used to make a grid in the contouring process are shown in Table 2. Gridding is the procedure in the contouring process that provides interpolation at fixed intervals across the data display. Interpolation needs to be performed at close space intervals, but for a practical reason, a coarser size of the grid is usually adequate to achieve smooth curves [9]. Contouring is the inference of surface shape that is assumed to be representative of a data set. It interprets the spatial variations and influences the accuracy of the resulting map.

Point kriging generates an interpolated grid and estimates the values of the points at the grid nodes. Block kriging estimates the average value of the rectangular blocks centered on the grid nodes. The blocks are the size and shape of a grid cell. Block kriging generates smoother contours but not a perfect interpolator. That is, even if an observation falls precisely on a grid node, the estimate for that node does not accurately reproduce the observed value. When a standard deviation grid is generated with block, the generated grid contains the block kriging standard deviations and not the point kriging standard deviations. The numerical integration required for point-to-block variogram calculations necessary for block kriging is carried out using a 3x3, two-dimensional Gaussian-Quadrature [10].

Table 2. The parameter used in the interpolation process using Kriging and Natural Neighbor.

| Attributes         | Kriging              | Natural Neighbor |
|--------------------|----------------------|------------------|
| Type               | Point                | -                |
| Drift              | Ordinary (no drift) | -                |
| Variogram          | linear               | -                |
| Spacing interval   | 20 m                 | 20 m             |
| Anisotropy         | -                    | 1                |
| Angle              | -                    | 0                |
| X minimum          | 751549.082           |                  |
| X maximum          | 752974.917           |                  |
| Y minimum          | 9441782.88           |                  |
| Y maximum          | 9443453.11           |                  |
| Number of Columns  | 86                   |                  |
| Number of Rows     | 199                  |                  |

The Kriging method has several advantages, among others as an interpolator, the Kriging method combines spatial correlation data, which is not done by standard statistical procedures. The power of Kriging compared to other contourization techniques is its ability to quantify variance from estimated values so it can be known [11]. The Kriging method can still be used even if it is not a spatial correlation between data was found on independent observations, processes.
2.4. Accuracy Measurements

The accuracy of interpolation results from both kriging and natural neighbor method measured by using Root Mean Square Error (RMSE) and Mean Error (ME). ANOVA test previously runs to conclude that the average depth for the two was not significantly different from the field data. The formula uses to calculate RMSE and ME is as follow:

\[
RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - x)^2}
\]  
\[
ME = \frac{1}{n} \sum_{i=1}^{n} |y_i - x|
\]

\(n\) = number of sample  
\(y_i\) = water depth estimated  
\(x\) = actual water depth

Visual judgment then completes the bathymetric contour map comparison between existing nautical charts to hydroacoustical and satellite image maps, to do that, each interpolation map, both from hydroacoustical and satellite images are displayed inline contour with the same depth interval and scale.

3. Results and discussion

3.1. Bathymetry from hydroacoustic data interpolation and from multispectral image interpolation

The results of depth interpolation with the Kriging and Natural Neighbor interpolation methods can be seen in Figure 4. It can be seen that the interpolation with the kriging method is also carried out in areas outside the measurement boundary. In contrast, the Natural Neighbor interpolation method is limited and only carried out in the measurement area. This causes the RMSE and ME values of the two ways to be different.

The RMSE and ME values of these two methods can be seen in Table 3. This difference is caused by Kriging producing depth estimation based on the average weighting of its known depth in a particular area. On the other hand, the concept of Natural neighbor interpolation is the weight defined by the overlap proportions between new Voronoi polygons (Thiessen Polygons) that are formed between interpolation points with the initial Voronoi polygons that connect adjacent points [12].

![Figure 4](image-url)

**Figure 4.** The water depth contour as a result of hydroacoustical data interpolation using Kriging (left) and natural neighbor (right).

The water depth and pixel reflectance plot on the scatter diagram shows that the light energy does attenuate the natural log (ln) relationship, Figure 5.
Figure 5. Light energy attenuation on each Landsat band.

Figure 5 shows that the highest attenuation occurs in band 4, while the lowest attenuation occurs in band 2, followed by band 3 and band 1. The highest attenuation in bands 2, 3, and 1 occurs at depths above 5 meters.

Figure 6. The relation function between the water depth with a specific band of Landsat.

Figures 5 and 6 show clearly the close relationship between reflectance and depth. The deeper the water, the smaller the reflectance value. Figure 6 also shows the estimated depth with regression modeling with band 2 better than other bands with $R^2 = 98.62\%$ followed by band 1, band 3, and band 4 with $R^2$ respectively 96.88%, 92.52%, and 64.51%. This shows that depth estimation can be done better with band 2.
Figure 7. Interpolation result of estimated water depth using Landsat image by Kriging (left) and natural neighbor (right).

Visually the results of interpolation by the kriging method and natural neighbors to hydroacoustic and Landsat data are not different. Prominence is only visible at the boundary of the measurement area. Extrapolation performed by the kriging method has the potential to cause a higher bias in terms of measured depth and estimation results. Kriging assumes data spread normally while most field data do not meet these conditions; besides, the semivariogram calculated for a data set does not apply to other data sets. Thus, the semivariogram estimation will be difficult if the sample points used are insufficient.

3.2. Hydroacoustics and satellite image derived contour compare to nautical chart

Figure 8. Cross-section profile comparison between hydroacoustical and Landsat water depth.

Cross-section of Figure 8 (A-B) shows that in general, the results of Landsat 8 interpolation can only be done in shallow waters, less than 6 meters. Meanwhile, at a depth range of 0-3 meters, the depth value obtained is quite adequate. This is related to Figures 5 and 6, where the deeper the water, the higher attenuation of the energy of light waves.
Figure 9. The comparison of the bathymetric map from hydroacoustical, Landsat, and nautical map of the Bonetambung coral reef area.

Table 3. Comparison of RMSE and ME values and depth range from a depth of hydroacoustic methods and Landsat imagery.

| Methods of interpolation       | Range depth (m) | RMSE (m) | ME (m) |
|--------------------------------|----------------|----------|--------|
| Hydroacoustics Kriging         | 0-5            | 0.8      | 0.4    |
|                                | 5-10           | 0.9      | 0.4    |
|                                | 0-30           | 1.2      | 0.7    |
| Hydroacoustics Natural Neighbor| 0-5            | 0.8      | 0.4    |
|                                | 5-10           | 1.3      | 0.6    |
|                                | 0-30           | 1.3      | 0.7    |
| Landsat 8 OLI Kriging          | 0-5            | 1.1      | 0.8    |
|                                | 5-10           | 3.5      | 3.1    |
|                                | 0-30           | 5.5      | 3.1    |
| Landsat 8 OLI Natural Neighbor | 0-30           | 1.1      | 0.8    |
|                                | 5-10           | 3.5      | 3.1    |
|                                | 0-5            | 5.2      | 2.9    |

The 95% ANOVA test results that have been done in previous studies show that the average depth of the measurement results of the hydroacoustic and remote sensing methods are not significantly different in the depth range of 0-6 meters.

Meanwhile, Table 3 shows a significant difference between the depth accuracy values obtained using the hydroacoustic and remote sensing methods. The RMSE and ME of depth obtained using Kriging, and Natural neighbor interpolation methods for Landsat 8 data appears to be much lower than the same value from hydroacoustics data. Only in the 0-5m depth range, the value of RMSE and ME interpolation of Landsat 8 data is close to the value of RMSE and ME hydroacoustic data interpolation results. This is mainly related to the effect of attenuation when determining the estimated value, as shown in Figures 5 and 6, and is also associated with the sizeable spatial resolution of Landsat data, 30 x 30m².

The significant difference in depth between the two methods is mainly seen at depths of more than 6 meters, as shown in Figure 8. This is because, at greater depth, the effect of attenuation is more significant than at smaller depths. The result of attenuation is measured at depths of more than 6 meters. Visually, the difference in depth is also seen in Figure 9. This figure shows the similarity of depth patterns between the nautical chart and the bathymetry map of the hydroacoustic method.
contrast, it shows the difference between the nautical chart depth pattern and the Landsat 8 image depth pattern.

4. Conclusion
Although the measurement of depth interpolation using the Landsat satellite imagery method can be carried out over a wider area, the accuracy of the depth resulting from these measurements is much lower than the accuracy of the depth measurement with the hydroacoustic method. Therefore, every activity near coral waters around small islands, which require high depth accuracy, are recommended to obtain depth reference from the result of hydroacoustic method measurement.

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