SHALLOW WATERS DEPTH ESTIMATION USING EMPIRICAL SATELLITE DERIVED BATHYMETRY AND SENTINEL-2 DATA, CASE STUDY: EAST COASTAL WATERS OF JAVA ISLAND

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ABSTRACT:

Hydrographic survey is an activity to provide spatial information in the marine sector. To produce accurate data, hydrographic surveys require very large costs. With the vast sea area in Indonesia, this becomes a very big challenge. In addition, there are some areas that cannot be reached by survey vessels (limited to a depth of > 25 m). Therefore, an alternative method is needed to provide bathymetry data in Indonesia. There is a new technique that is being developed and does not require high costs to obtain water depth data, by using remote sensing technology, especially by using passive sensor image technology. This technique or method is known as Satellite Derived Bathymetry (SDB) which can estimate depths of up to 30 meters. The SDB technique which is often used is empirical SDB. The empirical SDB has the principle of connecting the spectral value of the image with the measured depth. With the use of Sentinel-2 satellite imagery which has high temporal and spatial resolution, the SDB capability is expected to be improved. East coastal waters of Java Island are in the Bali Strait. This strait separates the island of Java from the island of Bali. In the Bali Strait there is a busy ferry shipping lane and there are also underwater cables used to supply electricity to Bali Island from Java Island. On the Java side, there are also many beaches and underwater tourism that must be preserved. Therefore, it is very important to be able to know the hydrographic data such as bathymetry data in the east coastal waters of Java Island. The objective of this work is thus to estimate shallow water depths using empirical SDB and Sentinel-2 images in the east coastal waters of Java Island. With two band combinations applied in the algorithm, best combination to produce the best depth map for the study area can be obtained. Comparing with reference data, the results show Band 1&3 combination give the better correlation and RMSE (0.76 and 0.026) than Band 2&3 combination (0.64 and 0.075).

1. INTRODUCTION

Hydrography is a branch of applied science concerned with the measurement and description of the ocean, coastal areas, lakes, and rivers physical features, also the prediction of their changes over time. This field has the primary purpose of navigation safety and to support all other marine activities, including economic safety development, security and defence, scientific research, and environmental protection. (International Hydrographic Organization, 2008).

Hydrographic survey is an activity to provide spatial information in the marine sector as a basic requirement in planning and decision making in the marine sector. The purpose of the hydrographic survey is to collect georeferenced data related to shoreline configuration, water depth or bathymetry, exploration, and exploitation of existing resources in marine and coastal areas. (Ramadhan, Sasmito, and Hadi, 2021).

In general, hydrographic surveys have a long series of activities, ranging from positioning to provide georeferenced bathymetric data, generalization to obtain sea depth values to tidal observations to determine vertical datums. To produce accurate data, hydrographic surveys require very expensive costs. With the vast sea area in Indonesia, of course this is a very big challenge. In addition, there are some areas that cannot be reached by survey vessels (limited to depths > 25 m) (Arya et.

Al., 2016; Nuha et. al., 2019). Therefore, an alternative method is needed to provide bathymetry data in Indonesia.

Nowadays, there is a technique or method called Satellite Derived Bathymetry (SDB) being developed and does not require high costs to obtain water depth data (Bobsaid & Jaelani, 2017). This method uses remote sensing technology either passive or active sensor image (Aji et. Al., 2020). The SDB technique can estimate depths of up to 30 meters. The SDB technique which is often used is empirical SDB. The empirical SDB has the principle of connecting the spectral value of the image with the measured depth (Syaiful et. Al., 2019).

These years, the availability of Sentinel-2 optical data with high temporal and spatial resolution, can provide time series and multi-source data which are important in providing further information to improve capabilities in Satellite Derived Bathymetry.

East coastal waters of Java Island are in the Bali Strait. This strait separates the island of Java (in the west) and the island of Bali (in the east). In the Bali Strait there is a busy ferry shipping lane that connects Gilimanuk Harbour (in Bali) and Ketapang Harbour (in Java). In addition, there are also underwater cables in the Bali Strait which are used to supply electricity to the island of Bali from Java. On the Java side, there are also many beaches and underwater tourism that must be preserved. Therefore, it is very

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important to be able to know the hydrographic data in the east coastal waters of Java Island.

The main goal of this study is thus to estimate shallow water depths using empirical Satellite Derived Bathymetry and Sentinel-2 images in the east coastal waters of Java Island. The ability of Sentinel-2 multispectral satellite imagery and empirical SDB in estimating and mapping shallow waters in the east coastal waters of Java Island will be tested. In the future, it is hoped that the results of this research can provide consideration in the use of Satellite Derived Bathymetry technology to provide water depths data.

2. METHODOLOGY

2.1 Data and Study Area

In this paper, study area is focused on the east coastal waters of Java Island. This area located in the west part of Bali Strait, as visualized in the Figure 1.

Figure 1. Study Area.

One scene of Sentinel-2 Level 2A Imagery in 2019, covering study area, is used in this research for Satellite Derived Bathymetry processing. As for reference data, to be used for test data in validation process, Multibeam Echosounder (MBES) Data obtained from field surveys in 2019 is also used.

2.2 Method

Sentinel-2 Level 2A imagery is data which has been radiometrically and geometrically corrected (TAS team, 2021). Before the data is used as input in the SDB, masking must be performed. Masking is carried out to separate between waters and land areas. Thus, land area does not affect the waters when shallow water bathymetry algorithms is applied. NDWI (Normalized Difference Water Index) is used to separate land and waters in this masking step (Gao, 1996).

$$NDWI = \frac{(RRS(\lambda_{Red}) - RRS(\lambda_{NIR}))}{(RRS(\lambda_{Red}) + RRS(\lambda_{NIR}))} \qquad (1)$$

where $RRS(\lambda_{Red})$= Red band
$RRS(\lambda_{NIR})$= NIR (Near Infrared) band

After focused only in waters area, sun glint correction must be applied (Evagorou et.al., 2022). Using Sen2Coral toolbox in SNAP, this process is being called as deglint. Sun glint refers to the specular reflection of the sun on water surfaces. This phenomenon is common in satellite images. Due to the reflection of direct sunlight on the air-water interface (sun glint) in the direction of the satellite, the water-leaving reflectance can be difficult to observe. The viewing geometry of Sentinel-2 satellite makes it vulnerable to sun glint contamination. In order to be able to observe bathymetry, a glint removal algorithm must be applied to remove the presence of sun glint (Serco Italia SPA, 2019).

There are several available sun glint removal or correction methods. The algorithm implemented as part of the Sen2Coral toolbox was developed by Hedley et al., 2005. The algorithm can be explained as follows. A regression is conducted between the NIR brightness and the brightness in the visible band using a sample set of pixels, which would be homogeneous if not for the presence of sun glint (e.g., deep water) in order to deglint a visible wavelength band. For other pixels, the slope of the regression is then used to predict the brightness in the visible band that would be expected if those pixels had a NIR value of MinNIR (equation (2)). MinNIR is the NIR value expected from a pixel with no sun glint, which can be estimated by the minimum NIR value found in the sample.

$$R'_i = R_i - b_i (R_{NIR} - Min_{NIR}), \qquad (2)$$

where R'_i = the deglinted pixel in band i
R_i = the reflectance from visible band i
b_i = the regression slope
R_{NIR} = the NIR band value
Min_{NIR} = the minimum NIR value of the sample

Multibeam Echosounder (MBES) data in the form of points will be used as test data (for validation). The data provides information about depth data from field survey. The data used as test data are depth data less than 26-meters. This is because SDB can only estimate the water depth to a depth of around that number. About 4000 points are used for test data. The points were selected by random sampling method.

Empirical SDB in this study used the Stumpf algorithm (Stumpf, 2003). The algorithm discovered by Richard Stumpf and Kristine Holderied in 2003 has the principle that the water attenuation coefficients differ between wavelengths (bands). It is approximately inverse exponential with water depth. Therefore, the ratio between the two bands which will change with depth can be determined (Serco Italia SPA, 2019). The algorithm tries to simplify the calculation operation in extracting the value of water depth using a comparison of two water reflectance factors in the blue band and green band. The algorithm to estimate the depth z is stated in the following equation:

$$z = m_1 \frac{ln(nR_w (\lambda_i))}{ln(nR_w (\lambda_j))} + m_0 \qquad (3)$$

where m_1 = a tuneable constant to scale the ratio to depth
n = a fixed constant for all areas
R_w = the reflectance of water for bands i or j

m_0 = the offset for a depth of 0 m (z = 0).

The fixed value of n is chosen to assure both that the logarithm will be positive under any condition and that the ratio will produce a linear response with depth.

Most commonly the bands 2 and 3 are used for Sentinel-2 as these offer the best combination of penetration depth and spatial resolution (Serco Italia SPA, 2019). Therefore, in this study, Band 2 as the blue band and Band 3 as the green band combination is used. However, using Sentinel-2 imagery, there is two blue bands. First Band 2 as the blue band and Band 1 as the light blue band. Band 1 is the coastal aerosol band which good for coastal monitoring. Band 1 is one of significant importance in the remote sensing of coastal waters (Mouw et al., 2015 in Poursanidis et al., 2019). Accordingly, we will also try another band combinations using Band 1 and Band 3. We try to substitute Band 2 (Blue) with Band 1 in Stumpf algorithm.

In this study, two band combinations are tested, e.g., Band 2 and 3, also Band 1 and 3. The results of each band combination from the methods are then validated using test data. From the results of the validation, it will be known which band combination produces the best depth map for the study area.

In order to compare the band combinations and validate the results, correlation and RMSE (Root Mean Square Error) between the results and test data are calculated. Correlation is a very easy method to calculate and interpret the relationship between two variables (Mukaka, 2012). This close relationship can be used to see how accurate the results are when compared to field data. Table 1 show the guidelines which can be used to interpret correlation values (Hinkle et al, 2003).

Correlation value	Interpretation
0.9 – 1 (-0.9 – -1)	Very high correlation
0.7 – 0.9 (-0.7 – -0.9)	High correlation
0.5 – 0.7 (-0.5 – -0.7)	Moderate correlation
0.3 – 0.5 (-0.3 – -0.5)	Low correlation
0 – 0.3 (0 – -0.3)	Negligible correlation

Table 1. Interpretation of Correlation Values

RMSE also the common technique to test the result. The equation used for RMSE is as follows (Walpole, 1968; Manessa et al, 2017 in Prayogo and Basith, 2020):

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(At-Ft)^2}{n}} \qquad (4)$$

where F_t = depth measured from MBES
A_t = depth estimation from SDB
n = number of measured depth points

3. RESULTS AND DISCUSSIONS

Sentinel-2 imagery which has been separated between land and waters, and through a deglint process is then entered into the SDB algorithm using two combinations, namely a combination of Bands 2&3 and a combination of Bands 1&3. The output of the algorithm is the estimated depth of the satellite image. Figure 2 and Figure 3 show results visualization of the water depth estimation.
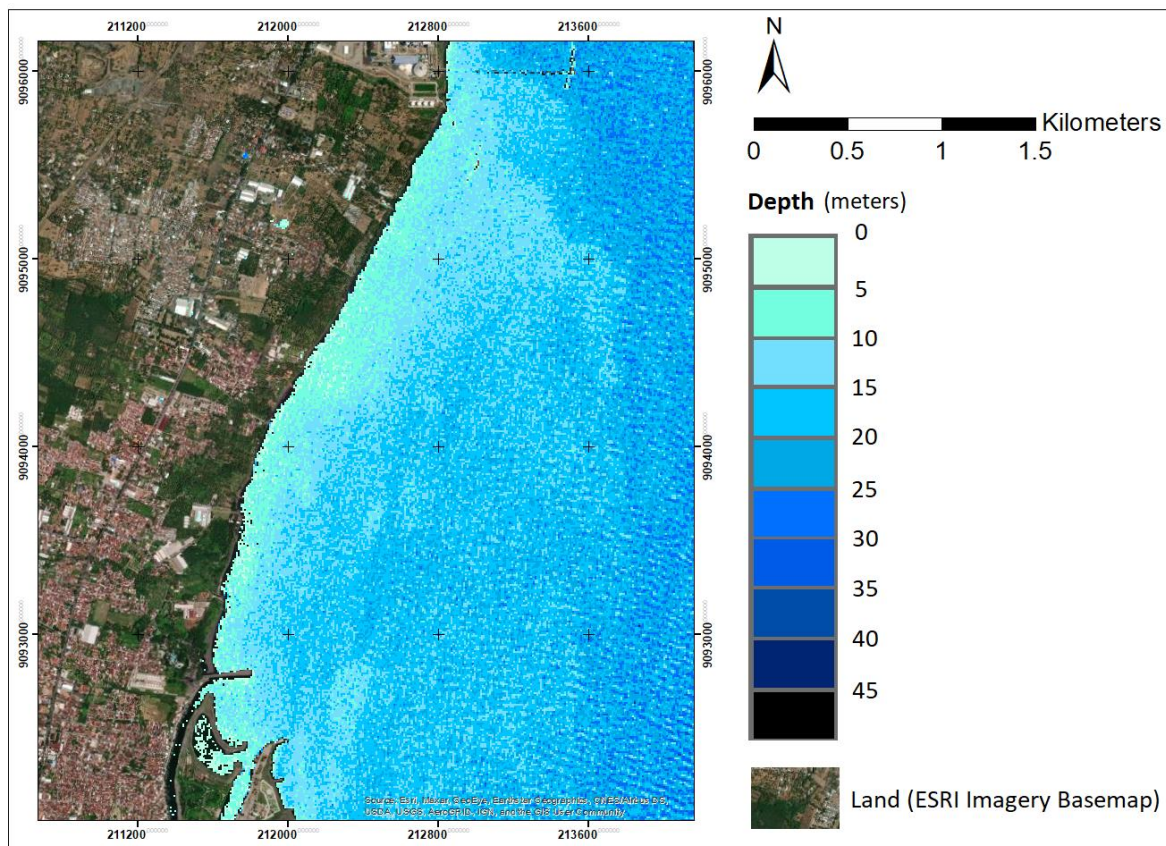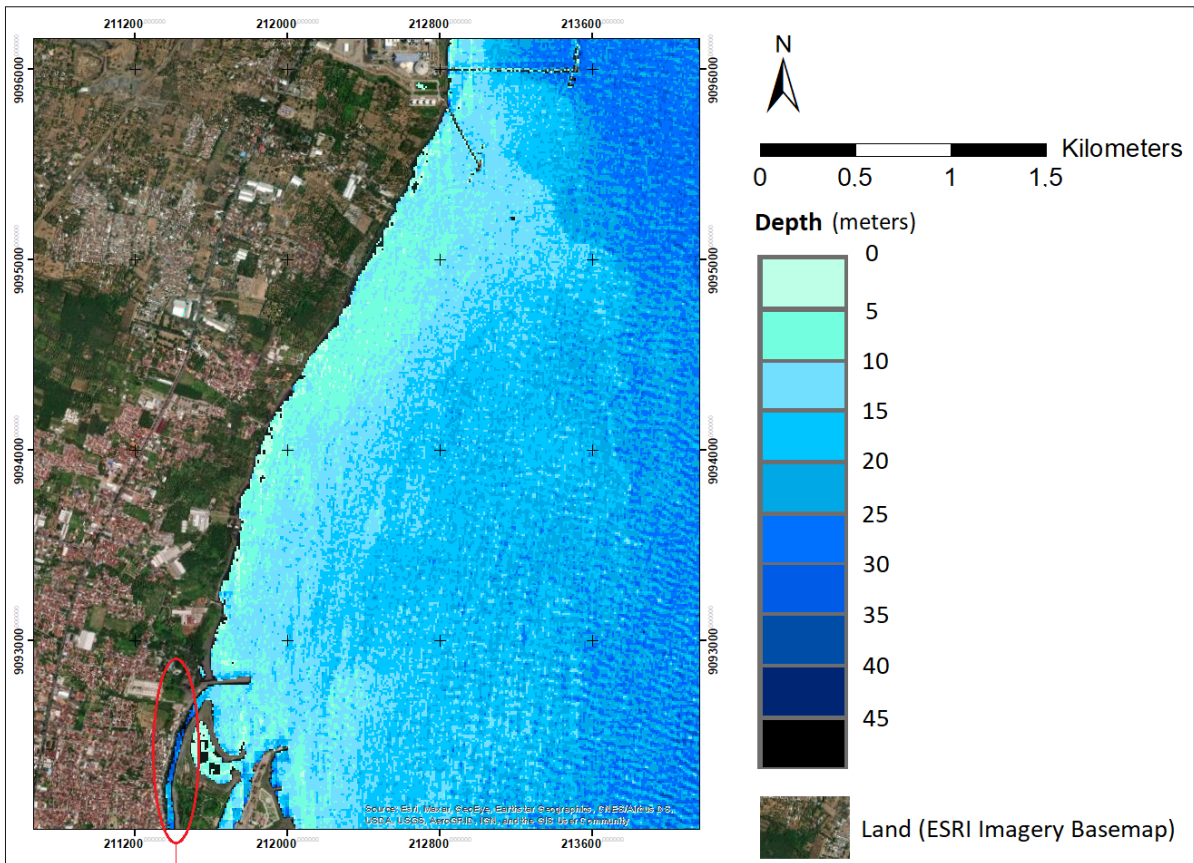

Figure 2. Water Depth Estimation Result from SDB, Band 2 and Band 3 Combination.

Depth estimation in part of river

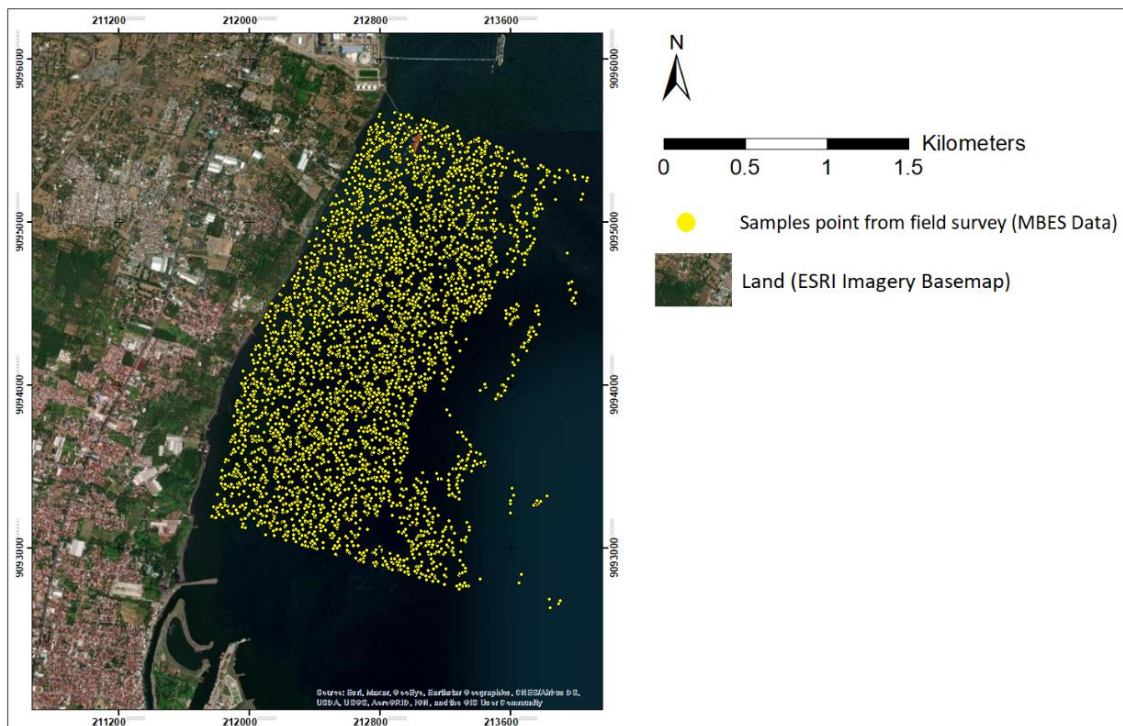**Figure 3**. Water Depth Estimation Result from SDB, Band 1 and Band 3 Combination.

Figure 4. The Points Distribution of Test Data.

From Figure 2 and Figure 3, we can see that the darker the blue that appears, the higher the depth. From the visualization, it can be seen that the color from those two results show the same pattern. It can be concluded that there is no big difference between the results of those two combinations. Yet, Band 1&3 combination can estimate part of river at the bottom left of the image (Figure 3, red circle), while Band 2&3 combination cannot do that.

Table 2 presents statistic values of depth estimation from SDB. From the statistic, it can be seen that the depth varies from 0 meters to more than 45 meters for both of the combinations. Depth estimation from Band 2 and Band 3 combination produces depths varying from 0.0003 meters to about 42 meters. On the other hand, depth estimation from Band 1 and Band 3 combination generates depths varying from 0.0031 to more than

50 meters. Judging from its statistic values, the Band 1&3 combination resulting deeper values of waters than the Band 2&3 combination.

Band Combination	Minimum Depth Value (m)	Maximum Depth Value (m)	Average Depth Value (m)
2&3	0.0003	41.9600	15.5870
1&3	0.0031	51.1061	16.8341

Table 2. Statistic Values of Depth Estimation from SDB.

Those two results are then compared and validated using test data. Test data is reference data from field survey MBES data. The points distribution for test data can be seen in Figure 4.
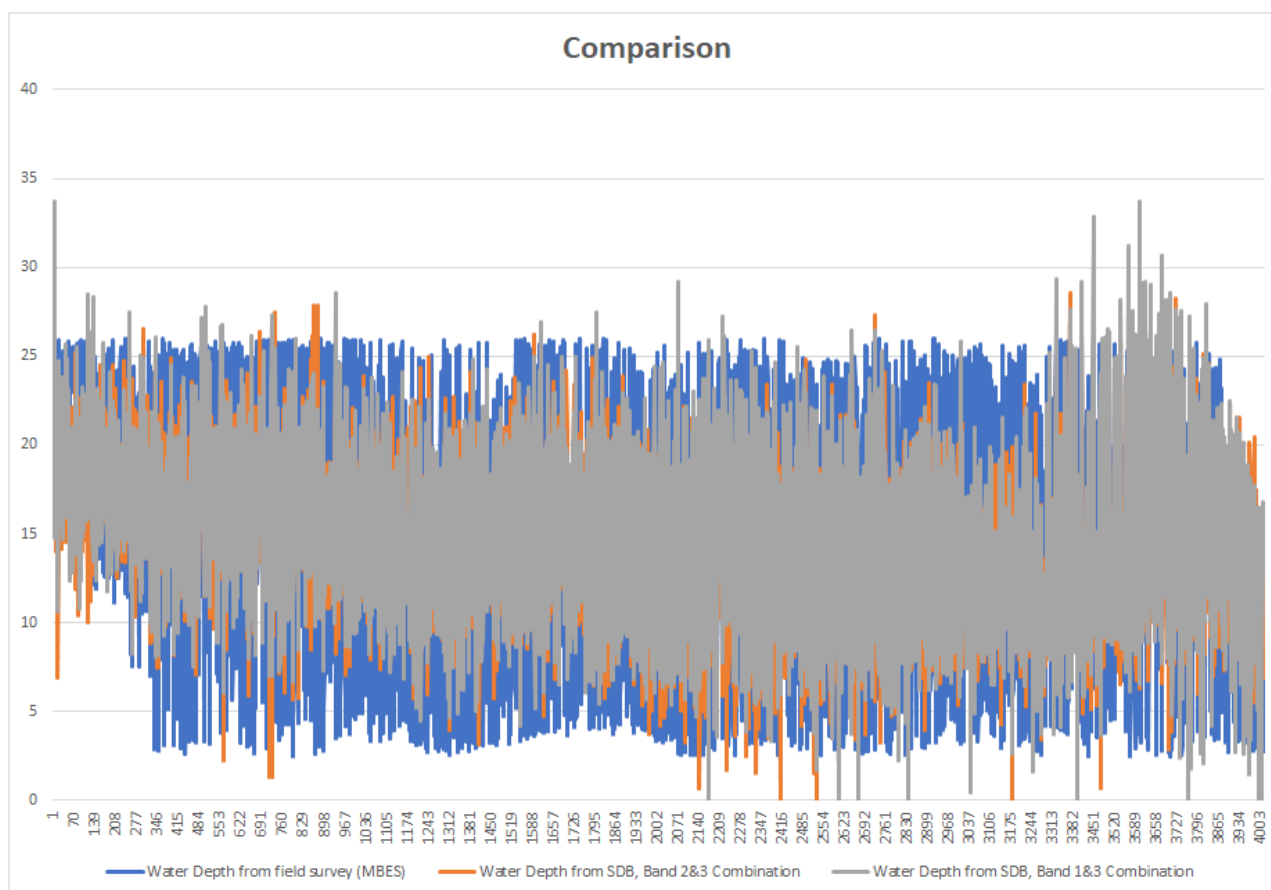

Figure 5. Comparison between Water Depth Estimation Result from SDB and Field Data.

Comparison of depth estimation from SDB values with depth data from MBES can be seen in Figure 5. It can be seen that water depth estimation values from SDB have almost same values with field data. Only some points values are different from the field data.

In Figure 6, there are comparison from each combination with field data. From those comparisons, we can get linear regression models and coefficient of determination values. Correlation values are then can be calculated. Figure 6 show that correlation

value between Band 1&3 combination with field data (0.76) is higher than correlation value between Band 2&3 combination with field data (0.64). Based on Table 1, correlation value between Band 1&3 combination with field data can be categorized as High Correlation. Whereas, correlation value between Band 2&3 combination with field data fall on Moderate Correlation class. Therefore, based on correlation values, it can be concluded that Band 1&3 combination give better result than Band 2&3 combination.
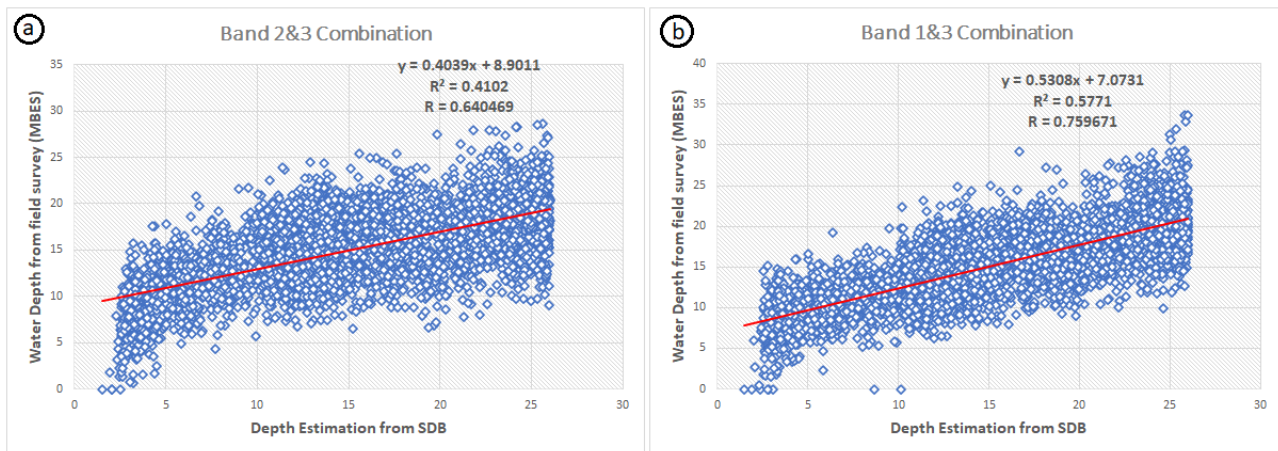
Figure 6. Comparison from Each Combination with Field Data, (a) Band 2&3 Combination, (b) Band 1&3 Combination

The correlation results are also presented in Table 3 along with RMSE results. The smaller the RMSE value, the better the results From Table 3, it can be seen that RMSE from Band 1&3 combination gives smaller value than Band 2&3 combination. This confirms the correlation results which state that Band 1&3 combination give better result than Band 2&3 combination.

Band Combination	Correlation	RMSE
2&3	0.64	0.075
1&3	0.76	0.026

Table 3. Interpretation of Correlation Values

4. CONCLUSSION

In this research, two band combinations are applied in SDB algorithm in order to get depth estimation in the study area. Both of those combinations give good correlation, moderate to high, compared to referenced data and small RMSE values. Nevertheless, Band combination 1&3 gives better result with higher correlation and smaller RMSE than Band 2&3 combination. Thus, for this research, it is better to use Band 1&3 combination to estimate shallow waters depth with empirical SDB method. The results also provide that not only Band Combination 2&3 of Sentinel-2 can estimate shallow waters depth with empirical SDB method, but also Band Combination 1&3, even with better results. The results from this research are encouraging for rapid bathymetry mapping to provide hydrography data.

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