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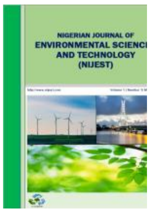

Assessment of Empirical Algorithms for Bathymetry Extraction of Selected Coastal Waters in Nigeria

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ABSTRACT

Several research has justified that the acoustic (vessel based) method of depth determination is the most reliable over other methods, however the satellite bathymetry method which utilizes multispectral images of high-resolution sensors to determine depth has been increasingly deployed as an improved alternative technique for bathymetric derivation. But the accuracy and reliability of the satellite derived depth is of outmost concern as it depends on the derivation algorithm with respect to various conditions of the water bodies. This study is aimed at assessing some empirical algorithms for bathymetric extraction of some selected rivers in Nigeria with the objective of evaluating the depth derived from the Linear Band Model (LBM) and the Band Ratio Model (BRM) with respect to the vessel based in-situ bathymetric depth. The Sentinel-2 satellite imagery in three bands with spatial resolution of 10m was acquired for a section of Opobo River, Orashi River and Badagery creek respectively. Satellite bathymetry of the study areas were extracted using the raster calculator in the ArcGIS 10.2 environment and applying the mathematical algorithms (LBM) and (BRM) after image geo-rectification. Maximum depths obtained are in the range of 16.8m for Opobo River, 6.8m, for Orashi River, and 10.8m for Badagery creek using the (LBM) while 16.9m, 7.8m and 10.9m was obtained using the (BRM) for Opobo River, Orashi River and Badagery creek respectively. Results of accuracy check showed that the (LBM) has the highest correlation coefficient (r^2) value of 0.9824 with RMSE values of 0.4082 for the study areas. This result was validated with the in-situ data which show maximum depth of 16.8m for Opobo River, 6.5m for Orashi River, and 10.5m for Badagery creek respectively.

Keywords: Bathymetry; Acoustic, Algorithms, Empirical, Multispectral

1.0. Introduction

Bathymetry is important to human activities and her ecosystems but despite its importance, depth of most worlds coastal area remains largely unknown (Baba et al., 2021). Bathymetric data have constantly provided knowledge of sea bottom configuration and underwater changes. For a nation like Nigeria, that have a coastal line of approximately 853km facing the Atlantic Ocean (Nwilo and Badejo, 2006); bathymetric data are needed to support diverse applications of human such as marine navigation, management of environmental protection, exploration and exploitation of marine resources, fisheries, marine science research, maritime defense, delimitation of maritime boundaries, tourism and recreation as well as the development of national spatial data infrastructure (International Hydrographic Organization IHO, 2005). Bathymetric information enhances the emergency response to storm surges, sea level rise, changes in coastal conditions and engineering related works (Olusegun et al., 2017). Hence, timely and accurate environmental information such as bathymetry is necessary to support functional policy formulation and management for coastal areas as well as to assure human safety and

welfare (Casal et al., 2019). Bathymetric survey technique has gone through transition (graduated rope attached with a weight, acoustic ship-borne equipped with echo sounder instruments such as single-beam and multi-beam echo sounders and the satellite approach) which is for increase in scope of data acquisition and accuracy required (Jagalingam et al., 2015). The extensive derivation of bathymetry from optical satellite sensors a space-borne technique has brought in the new revolution and considered as a new promising technology in the field of hydrographic surveying (Said et al., 2017).
Gerald et al, (2021) in a study on Comparison of Classical and Sentinel 2A Satellite-derived Bathymetry of a section of Nun River in Bayelsa State posited that satellite derived bathymetry can be used as an alternative where the acoustic (vessel based) technique is impossible due to cost or insecurity. The research conducted an accuracy test comparing the satellite derived bathymetry with the acoustic data from echo sounder which confirmed good agreement at sampled points, with standard error as low as 0.2324, correlation coefficient as 0.9635 and root mean square error as 0.251119 for the Sentinel data. Statistical indices obtained in this work indicated that the ratio-transform algorithm can accurately retrieve depths up to 10m in the Nun River.

However the successful utilisation of the satellite approach in coastal environments of Nigeria requires unique mathematical algorithm which is as a result of complexity of the water column composition, cloud cover, sunlight, turbidity and submerged vegetation that impedes and reduces the accuracy of depth calculation (Cahalane et al., 2018). The choice of any model is to enhance depth penetration and accuracy of estimated depth. Lyzenga, (1978) developed the (LBM) for depth derivation. Extraction of depth must consider the relationship between the water depth and the reflected radiance of a single or multiple spectral bands where the optical properties of that water reflectance and the bottom reflectance are permanent (Casal et al., 2019; Alsubaie, 2012). The (LBM) technique was performed under two assumptions. The first assumption was that if the optical properties of the water and the bottom reflectance are uniform, a single wavelength can be used to describe the relationship between water depth and radiance. However, if the optical properties are not uniform, more than one wavelength must be used in the depth calculation. In another development, Stumpf et al., (2003) developed the mathematical model which was published and adopted as an alternative model for determining bathymetry that preferably accounted for turbid water. Appling a simple linear relationship between the ratio of reflectance in two bands and depth, Stumpf et al., (2003) derived bathymetry. The log transformation algorithm has a relationship with the natural logarithm for reflectance of two bands and insitu depths (Casal et al., 2019).

The main thrust of this work is to assess two different mathematical algorithms: linear band model (LBM) (Lyzenga 1978, 1985; Lyzenga, et al, 2006) and log-transformed band ratio model (BRM) (Stumpf, et al, 2003) to providing accurate bathymetric model for depth extraction in the study areas of Nigeria. The derivation of depth in clear water can successfully mapped up to 25–30m by adopting the remote sensing approach (Eugenio et al., 2015; Lyzenga et al., 2006; Mishra et al., 2005). To determine the depth of water bodies, the blue and green bands (visible bands) of multispectral wavelength are selected for remotely sensing bathymetry.

2.0. Methodology

2.1. Study Area

Opobo River is located in the lower section of Imo River-II, Opobo/Nkoro Local Government Area of Rivers State, Nigeria. It is one of the most stressed Rivers in Niger Delta. The Opobo River is an important water resource for the communities located along its bank, as they depend on the river for recreation, transportation, agriculture and sometimes for domestic water supply. It lies between at latitude 04° 29' 45.52"N, longitude 7° 16' 23.86"E to latitude 04° 31' 49.27"N, longitude 07° 14' 50.41"E within the lower section the river. The Opobo people are mainly farmers and fishermen who historically exchanged their smoke -dried fish and salt with the people of the hinterland for bulk foodstuffs, tools, clothing and domestic gear (MacPepple et al., 2017). It is tidal and links major town which includes Minima, Illoma, Epellema and other Opobo communities to the Atlantic. Numerous creeks and creek-lets are connected to the channel, such as Jaja Creek and FineFace Creek. The soil of the channel consists of clays, silt and sand, with high organic matter characterized by mangrove forest and swampy terrain. The coastal environment is not just dynamic but also prone to flood depending on the season. The river is salt water with unidirectional flow pattern. The dry and wet seasons determines the varying levels and intensity of flow of the river (Ezeugwu et al., 2015).

The second and third locations include Orashi River and the Badagery creek. The River Orashi (aka River Ulasi) is located in Ahoda West Local Government Area of Rivers State, Nigeria. However, the region covered in the study is located between Akiogbologbo and Odieke communities and lies between latitude 05° 01' 09.68''N, longitude 06° 25' 46.32''E to latitude 05° 00' 57.72''N, longitude 06° 26' 09.71''E along the river channel while the Badagery creek is located in Badagery, Lagos State, Nigeria. It lies within geographic longitude 02° 42′ 00"E and latitude 06° 22′ 00" N and geographic longitude 03° 42′ 00"mE and latitude 06° 78′ 42′ 00"mN while part of the Creek under study lies between latitude 06° 25′ 42".07N and longitude 03° 16′ 59.16"E and latitude 06° 25′ 44".77N and longitude 03° 17′ 03.89"E. Most communities within these areas are directly dependent on the river for their agricultural, recreational, and sometimes, domestic water supplies. Fishing, trade, and lumbering is the main economic activities of the people. Fish is a very important component of human food systems in the Niger Delta region and some other parts of Nigeria (Abah, 2013). The study area is represented by Figure 1.

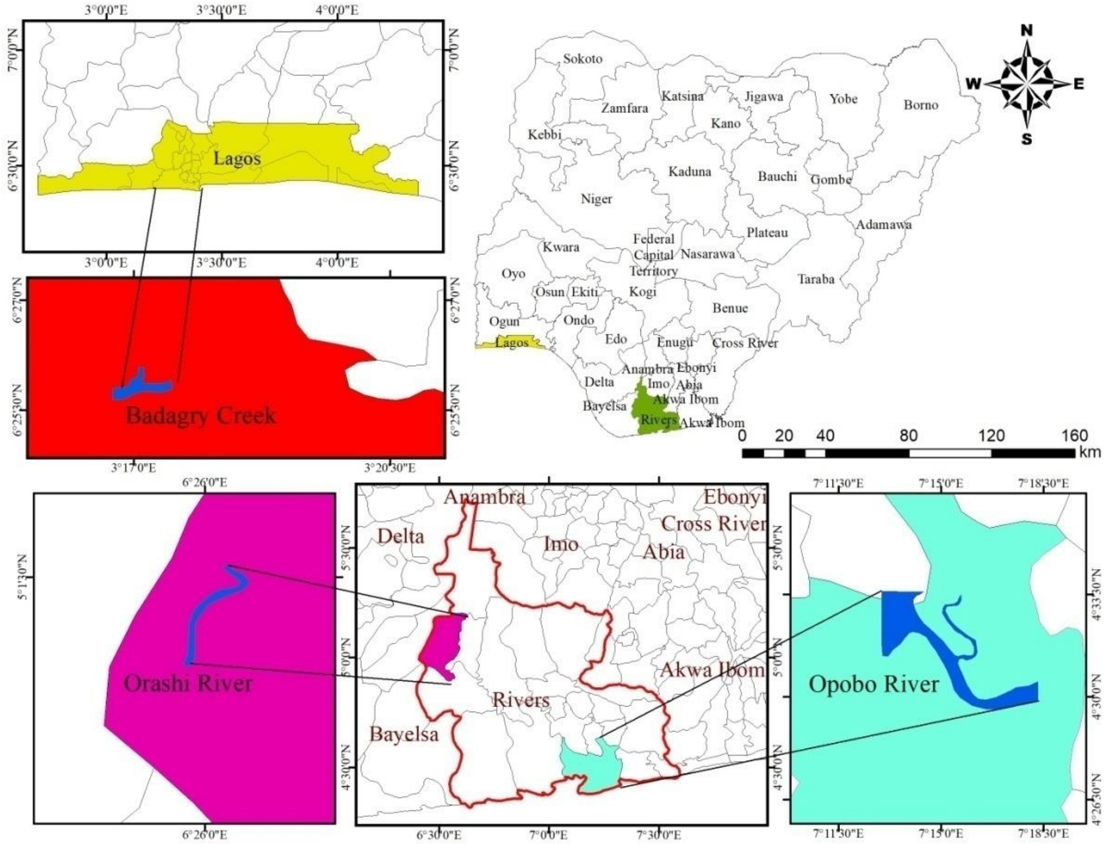

Figure 1: Map of Study Area clearly showing the sections of the location

2.2. Methods

2.1. Materials

2.1.1. Insitu bathymetric data

To assess the bathymetric algorithms, three locations were selected. The insitu bathymetric data for the first study area (Opobo) was acquired in March 2022 using ResonNavisound 210 single beam echo sounder attached with CNAV 2050 DGPS installed on an AHTS JASCON39 survey vessel for Opobo River. The complete system was capable of measuring water depths between 0 and 250m with vertical accuracy of 0.02m at 210 kHz. However 0.02m was obtained during bar check, which was necessary to ascertain the error budget of the instrument. The river is a tidal river; hence vertical tidal corrections were applied in the post-processing stage and reduced to Lowest Astronomical Tide (LAT) using Opobo River Entrance Port (as Port Reference for Tidal Datum). The second and third study area's bathymetric data (Orashi River in Akiogbologbo community and Badagery Creek Imore, satellite town) were obtained through crowd sourcing method. The data were acquired in February 2022 and May 2022. The second study area water depths were acquired using an Odom Hydrographic Systems Echo track model DF 3200 MKII echo sounder instrument with built-in DGPS. The depth range of the echosounder was from 0.2 to 200m and its vertical accuracy was 0.01m of depth. The Orashi River is a tidal river therefore tidal corrections were applied in other to correct for water surface variations. Depths were reduced to LAT (Lowest Astronomical Tide) and deemed suitable for hydrographic charts. Finally, the reference water depths of the third study area were acquired using a single-beam Lowrance LCX-15MT dual frequency (50/200 kHz) transducer and 12-channel GPS antenna. The measuring accuracy was (±0.01m) and depth ranging from 0.3 m to 150m. The resultant data were corrected for tidal fluctuations using predicted tide. The data were recorded once per second, and every measurement point had a corresponding longitude and latitude. After the survey, the data was downloaded from the echo-sounder using a removable drive and then transferred to a computer for sorting and elimination of redundancies using Microsoft Excel. These data were used as the response variable in our study models. The mathematically representation of the acoustic technique is as shown below:

2.1.2. Satellite data and pre-processing

The Sentinel-2A satellite images of the study areas were downloaded from the Copernicus Scientific Data Hub website (https://scihub.copernicus.eu/), as level-1C, Top of Atmosphere (TOA) reflectance in 100 km × 100 km tiles formats and a Universal Transverse Mercator (UTM)/ World Geodetic System 1984 (WGS84) projection. To obtain a relationship between the reflectance of the band and insitu acquired water depth that is reliable, images close to the measured data time and dates were obtained. Images of 10m spatial resolution bands B2 (497 nm) blue, B3 (560 nm) green, B4 (665 nm) red were considered. All the satellite images acquired for the study locations were resized and radiometrically corrected for sunglint/cloud effect and water separated from land using ArcGIS 10.2 software to obtain the radiance physical values from the image digital values and define the study areas. Also a spatial filtering technique called low-pass filter (kernel size of 5 × 5) was applied on the blue, green, and NIR bands of Sentinel 2A imagery to remove the speckle noise and anomalous cells in the images. Specifically for this study Sentinel image bands and the coefficients were extracted from the European Space Agency (ESA) zipped metadata file (XML file) using ENVI 5.3 software. Before the application of the empirical bathymetric models, all sentinel images were segregated.

2.2. Methods
2.2.1. Bathymetric models

The estimation of the bathymetry using remote sensing approach utilises several methods such as Second-order Polynomial of Ratio Transform (SPR), Multiple Linear Regression (MLR), Principle Component (PC), Least Squares Boosting Fitting Ensemble (LSB), Support Vector Regression (SVR), Bagging Fitting Ensemble (BAG) and many more (Manessa et al., 2017). However the choice of any model directly affects the accuracy of depth derivation. For this study, two different bathymetric models were selected and assessed for depth derivation in the study locations because of their capacity in retrieving depth of highly turbid coastal environment, account for heterogeneity in bottom type and water quality and capable of determining depth where the optical properties of the water are not constant which are the conditions of the study area. They include the linear band model (LBM) (Lyzenga 1978, 1985; Lyzenga, et al, 2006) and log-transformed band ratio model (BRM) (Stumpf, et al, 2003).

2.2.1.1. Linear band model (LBM)

Lyzenga, (1978) developed a linear method for determining the bathymetry of water bodies. This method determined water depth by considering the relationship between the water depth and the reflected radiance of a single or multiple spectral bands where the optical properties of that water reflectance and the bottom reflectance are permanent (Casal et al., 2019; Alsubaie, 2012). Lyzenga in his method followed the fundamental principle as derived by Beer Lambert which defines the relationship of observed reflectance to the corresponding water depth and bottom albedo. This method is mathematically written as:

$$R_w = (A_d - R_\infty)e^{-gz} + R_\infty$$
(1)

Where:

R_w is the reflectance of the water,
A_d is the bottom albedo,
R_∞ is the water column reflectance,
z is the depth, and g is the function of the diffused attenuation coefficient for down-welling and upwelling light.

In order to determine the depth, Equation 1 was further expressed as:

$$Z = \frac{1}{g}[In(A_d - R_\infty) - In(R_w - R_\infty)]$$
(2)

Casal et al., (2019) reiterated that since the intensity of light is assumed to be decaying exponentially with depth, radiance can be linearized using natural algorithms. If X_j is transformed radiance for each of the bands 1-N the equation can be written as equation (3):

$$X_j = In[R_w(\lambda_j) - R_\infty(\lambda_j)] \quad (3)$$

Where:

R_w is the above-surface radiance in band λ_j and
R_∞ is the average deep-water signal after atmospheric and sun glint corrections.

2.2.1.2. Log-transformed band ratio model (BRM)

The second bathymetric algorithm used for deriving depth for this study is the log-transformed band ratio model algorithm. Stumpf et al., (2003) developed the mathematical model which was published and adopted as an alternative model for determining bathymetry that preferably accounted for turbid water. Appling a simple linear relationship between the ratio of reflectance in two bands and depth, Stumpf et al., (2003) derived bathymetry. The log transformation algorithm has a relationship with the natural logarithm for reflectance of two bands and insitu depths (Casal et al., 2019). There is a higher penetration in the blue and green part of the spectrum because of the increase in the absorption of electromagnetic radiation. The ratio transform algorithm can be applied with bands having different light absorption rate in water. Since blue and green bands have lower absorption, their ratio to high absorption bands should remain the same despite the different bottom reflective power at a constant depth as:

$$Z = m_1 \frac{In(nR_w(\lambda_i))}{In(nR_w(\lambda_j))} - m_0 \tag{4}$$

Where:

Z is the Estimated Depth,
m_1 is a tunable constant to scale the ratio to depth,
n is a fixed constant for all areas to ensure that the algorithm is positive,
And, m_0 is the offset for a reference depth of 0_m where (Z = 0),
R_w is the reflectance of water, and ($\boldsymbol{\lambda}_{ij}$) are two different bands (Blue and Green bands).

The ratio between the two bands will increase as depth increases (Casal et al., 2019). This concept effectively removes the error associated with varying albedo since both bands are affected in the same way.

2.3. Accuracy evaluation

The satellite derived depths obtained from linear band model (LBM) and log-transformed band ratio model (BRM) were assessed using different statistical methods such as Root Mean Square Error (RMSE), Correlation Coefficient (r^2) and Standard Error (SE). In order to determine the level of accuracy of LBM and BRM derived depths, 500 sample points of the study locations were used to calibrate the algorithm, the statistical indicators include:

i. Root mean square error (RMSE): The use of RMSE is very common, and it is considered an good general purpose error estimator for numerical predictions. For this research, the (RMSE) test was conducted to measure the accuracy of satellite-derived bathymetry. The RMSE can be mathematically expressed as shown in Equation 5.

$$RMSE = \sqrt{\frac{\sum(X_{Known\ i} - X_{estimated\ i})^2}{n}} \tag{5}$$

Where:

$X_{known,i}$ is the previously sounded data;
$X_{estimated,i}$ is the estimated depth; while,

n is the total number of test points (Tang and Pradhan, 2015).

ii. Correlation coefficient (r^2): For this research, the correlation between the estimated depth and insitu data was calculated. Tang et al., (2015) asserted that if the r^2 is close to 1, it signifies a positive correlation between the estimated depth and the observed depth. The correlation coefficient gives a validity of prediction of the dependent variable.

iii. Standard error (SE): is the standard deviation of its sampling distribution of an estimate of that standard deviation. The Standard Error of Mean (SEM) was computed using the Equation (6) below:

$$SE = \frac{\sigma}{\sqrt{n}} \tag{6}$$

Where:

σ is standard deviation of the population,
n is size (number of observations) of the sample.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x-\tilde{x})^2}{N-1}} \tag{7}$$

Where:

x is observed values of a sample mean,
$\tilde{x}$ is the mean value of the observation,
N is the number of observation.

3.0. Results and Discussion

3.1. Acoustic ship borne bathymetry

The measured channel on the Opobo River covered a length 902km with an average width of 695.5m, with 1.12m being the shallowest bathymetric point and 17m being the deepest. After sorting a total number of 524 points were left. The least range of depth (1.12m to 1.5m), which are located in the North Western part of the river channel, while the deepest part of the channel (15m to 17m) were located at the South Eastern axis of the river. While a total of 1896 depths points were acquired for Orashi River and 545 for Badagery Creek respectively. After filtering of outliers, 1858 was deemed fit as reference depth for the Orashi River while 500 for Badagery Creek. The length of the surveyed section was 1432km and 166.21m having an average width of 220m and 54.66m for both Orashi River and Badagery Creek. The observed depth of Orashi River showed that the depth ranged from 2.45m to 8.99m. The least range of depth (2.45m to 3.5m), which are located along the Eastern area of the River, while the deepest part of the River (7.23m to 8.99m) were located along the Western axis of the section of Orashi River. Also the observed depth of Badagery Creek section showed that the depth ranged from 1.4m to 11.89m. The least range of depth (1.4m to 2.35m), which are located in the Southern area of the creek, while the deepest part of the channel (15m to 17m) were located at the Northward axis of the Creek.

3.2. Bathymetric estimation from satellite imagery

In order to achieve this, the above surface radiance (Rw) in the bands (λj) and the average deep-water signal (R∞) after atmospheric and sun glint corrections were calculated; this was used for referencing the bathymetric algorithm (LBM) result to the chart datum hence obtaining the depth of sample points across the study area, which were previously acquired through the acoustic approach within the study area. Then extracting mathematical algorithms linear band model (LBM) (Equation 3) applied using the raster calculator in ArcGIS 10.2 environment. Likewise the depth estimation from sentinel 2A satellite imagery for log-transformed band ratio model (BRM) involves calculating the gain m1 and offset m0 needed for referencing the bathymetric algorithm (bathalg) result to the chart datum by obtaining the depth of sample points across the study locations, which were previously acquired through the acoustic approach, before inputting into the mathematical algorithms (BRM) (Equation 4) and estimation using the raster calculator in ArcGIS 10.2 environment. The values of (m1) and (m0) were derived by plotting a scatter plot graph on Microsoft Excel, using sample points from observed or insitu depth (reference depth) against the values obtained from bathalg (Bathalg obtained from Sentinel) of the same points as shown in (Figure 2-4).

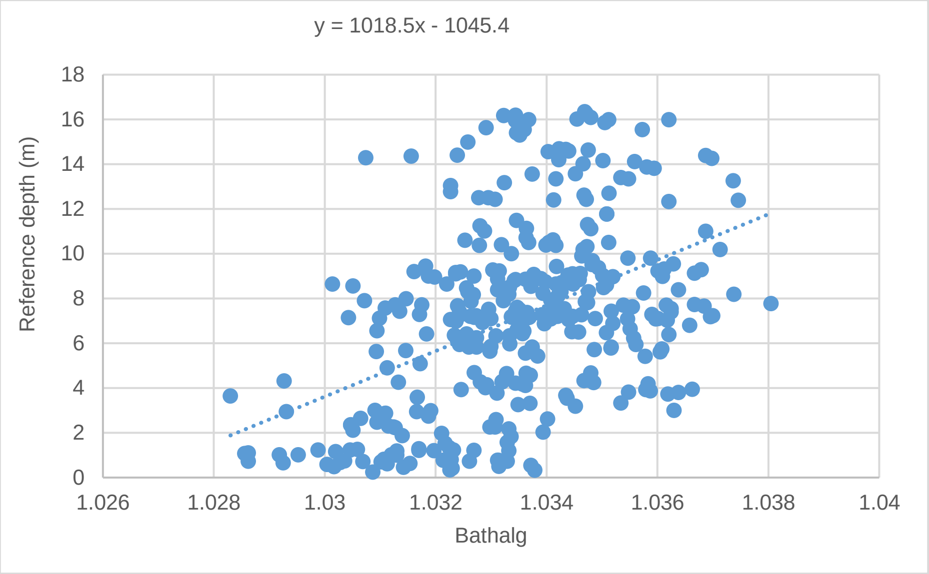

Figure 2: Values of Gain (m_1) and Offset (m_0) Values Obtained for Opobo River.

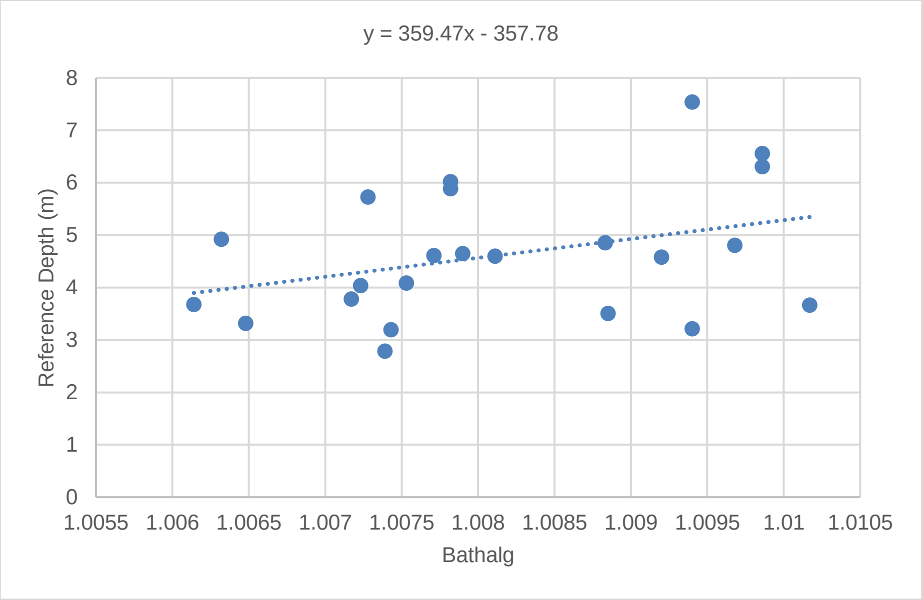

Figure 3: Values of Gain (m_1) and Offset (m_0) Values Obtained for Orashi River

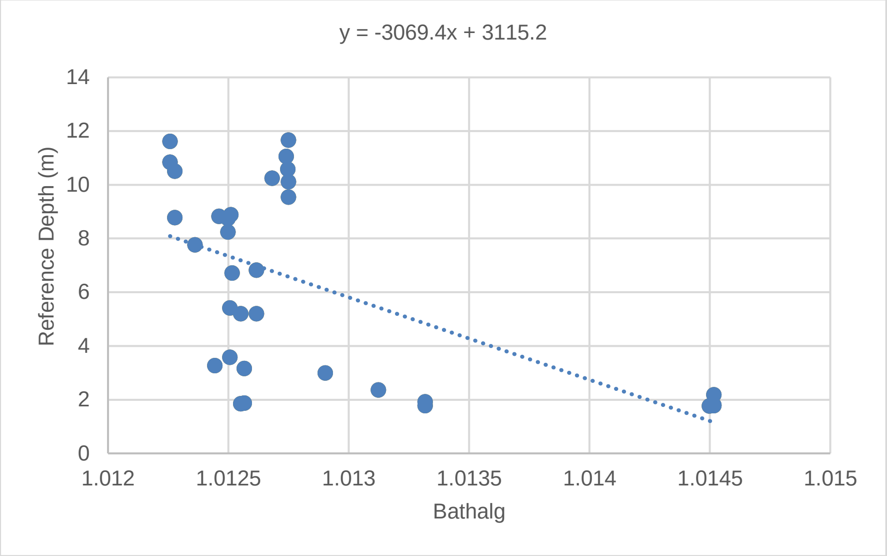

Figure 4: Values of Gain (m_1) and Offset (m_0) Values Obtained for Badagry Creek.

Table 1: Satellite derived water depth for various locations samples

Locations	Bathymetric algorithms Linear band model (m)	Log-transformed band ratio model (m)	No of sample points	Least depth range (m)	Highest depth range (m)
Opobo River	0.14 – 0.17	0.13 - 17	500	0.13 -1.6	16 - 17
Orashi River	2.03 - 8.91	2.09 - 9.9	500	2.09 -3.28	7.76 -9.91
Badagery Creek	1.01 - 11.87	1.01 - 11.96	500	1.01 - 1.91	10.34 - 11.96

As shown in Table 1 the least depth range for the study locations were observed around the North Western axis of the river channel, while the highest range of depth were around the South Eastern axis of the water, which is similar to the depth obtained from acoustic method.

3.4. Assessment of bathymetric models

Root mean square error (RMSE) of extracted points was calculated for (LBM) and (BRM) using Equation 6 for the three study locations. The deduced RMSE for Opobo River was 0.4082m and 0.4442m, Orashi River 0.4361m and 0.4427m and 0.3983m and 0.4192m for Badagery creek respectively.

According to Tang and Pradhan, (2015) RMSE values greater than 0.5 reflects the poor ability of the model to accurately predict the data, in which the RMSE results obtained for Opobo River, Orashi River and Badagry Creek were less than 0.5, which signified that the LBM and BRM models accurately predict the observed depth data. This also implies that the RMSE for Sentinel derived bathymetry falls within the range of bathymetric extraction indicating the reliability of the depth estimation models. Also the correlation coefficient (r^2) between the estimated depth and insitu data was calculated for (LBM) and (BRM). This was calculated by plotting the observed depth against the estimated depth as shown in (Figure: 5-7). The value of (r^2) obtained for LBM and observed depth was 0.985, 0.881 and 0.984 while 0.982, 0.882 and 0.983 for BRM and observed depth see (Figure: 8-10).

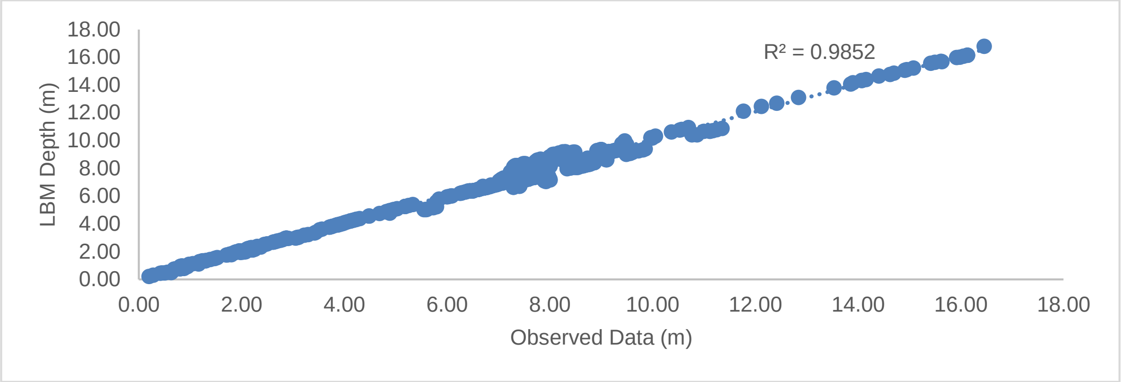

Figure 5: Correlation Coefficient (r^2) between LBM derived depth and Observed Depth, for Opobo River

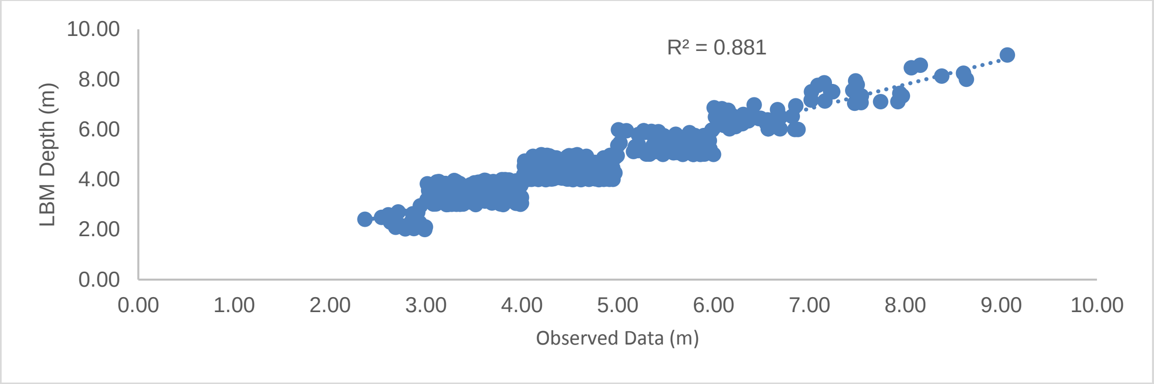

Figure 6: Correlation Coefficient (r^2) between LBM derived depth and Observed Depth, for Orashi River

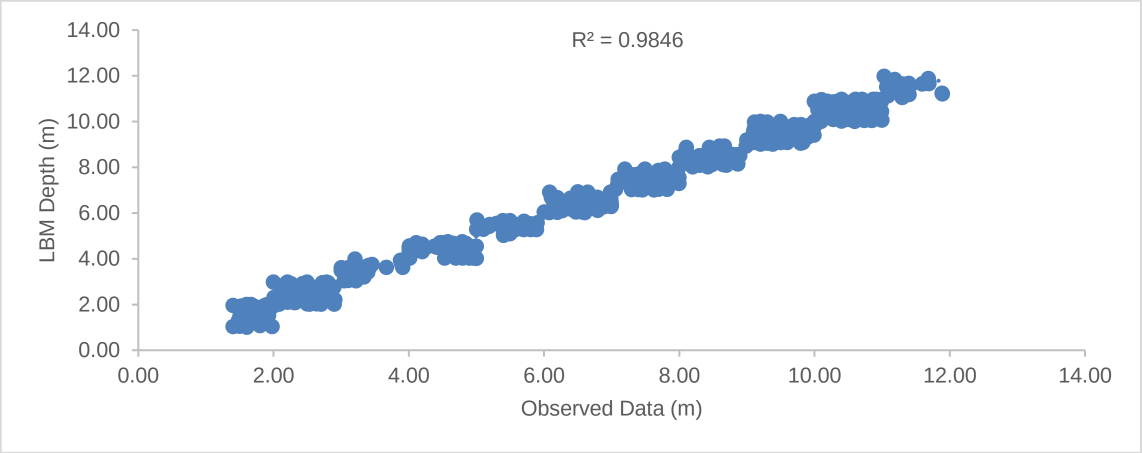

Figure 7: Correlation Coefficient (r^2) between LBM derived depth and Observed Depth, for Badagery creek.

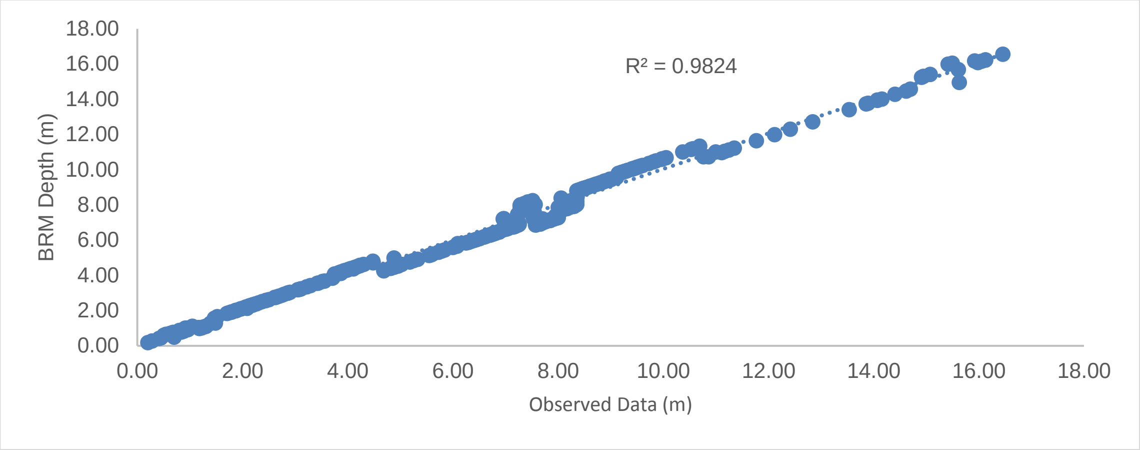

Figure 8: Correlation Coefficient (r^2) between the BRM derived depth and Observed Depth for Opobo River

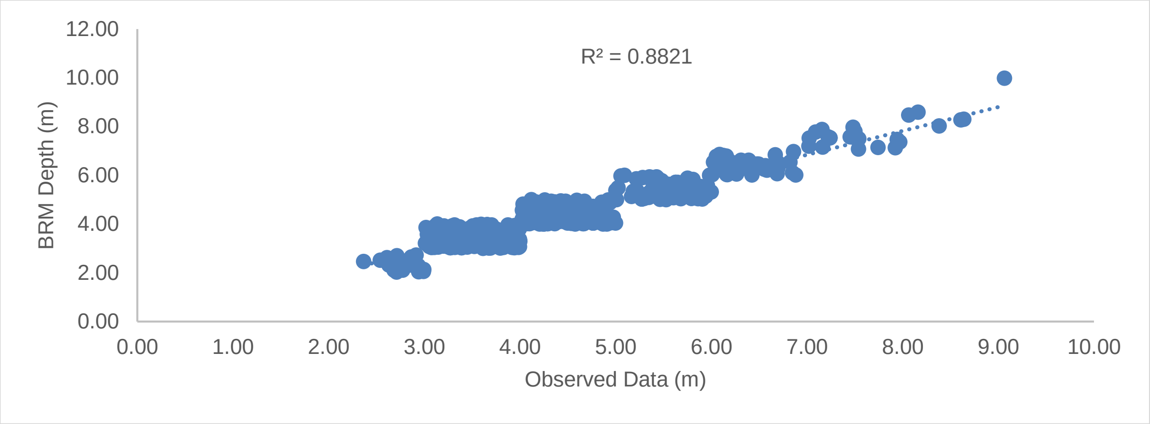

Figure 9: Correlation Coefficient (r^2) between the BRM derived depth and Observed Depth for Orashi River

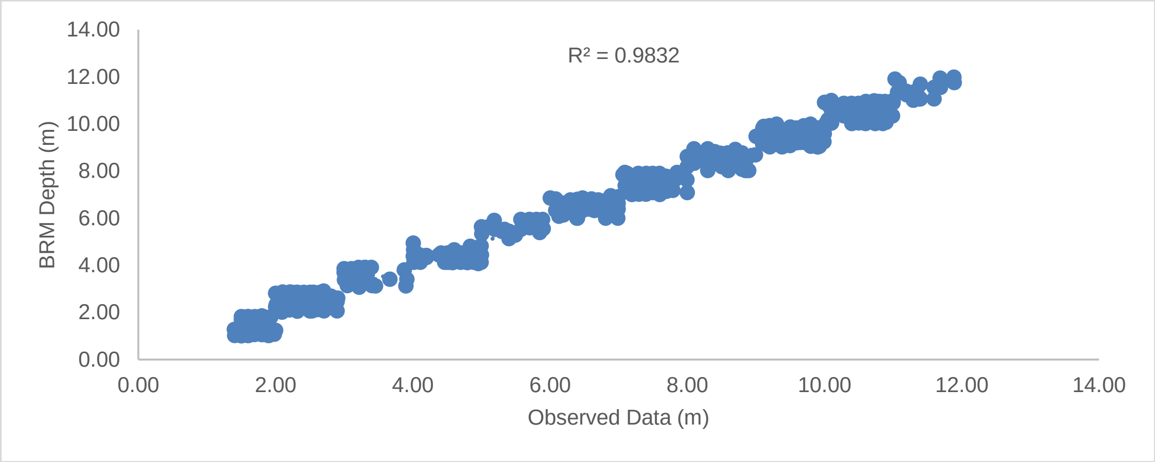

Figure 10: Correlation Coefficient (r^2) between the BRM derived depth and Observed Depth for Badagery creek

The r^2 values were close to 1, which signified that there is a positive and very strong correlation between the estimated depth and the observed depth for the study areas. Using Equation 7, standard error was calculated for linear band model and log-transformed ratio band model. Table 2 shows summary of the standard error.

Table 2: Summary of standard error

S/N	Locations	Standard Error	
		LBM	BRM
1	Opobo River	0.1488	0.1494
2	Orashi River	0.0551	0.0559
3	Badagery Creek	0.1431	0.1443

The SE deduced for the LBM and BRM was assessed with the observed / sounded data were 0.1488 and 0.1494 for Opobo River, 0.0551 and 0.0559 for Orashi River and 0.1431 and 0.14444 for Badagry Creek, respectively. From the results, it could be deduced that Orashi River had the least SE value, followed by Badagry Creek then Opobo River. It could also be deduced that SE results of the depth values derived from LBM and BRM were small which signified good result, because the smaller the standard error, the less the spread of error and the more likely it is that any sample mean is close to the population mean.

Generally, we have shown that the water depths determined from Sentinel 2A satellite imagery (10m spatial resolution) were statically accurate and capable of producing an estimated sea bottom depth. The selection of blue band for bathymetric retrieval in clear water is due to its high penetration level into the water column, in turbid waters the optimal bands shifts to longer wavelengths such as green-yellow spectral regions (Vahtmae and Kutser 2016; Casal et al., 2019). This was confirmed in some part of our study areas where the green band (560nm) demonstrated the highest correlation with the insitu depth same as the blue band (497nm). We assessed two depth retrieving models (LBM) and (BRM) and the measured water depth values in the study areas. The LBM applied to the Sentinel-2 data demonstrated good and better results to the in-situ bathymetry data in the three bands of image in comparison to BRM. These results are in concordance with other works carried out in turbid coastal waters that reported the same findings. The r^2 values obtained in this study were similar to the ones obtained in studies that applied the same empirical methods to sensors of higher spatial resolution indicating that empirical models applied to Sentinel-2 data can provide a good correspondence with bathymetry. Nevertheless, this study has demonstrated that this method can be utilised an alternative survey technique to complement the medium resolution (depth interval 10-30m) surveys and can be used for low-cost, low-accuracy and low-risk bathymetry charting mission.

4.0. Conclusion

Increasing number of studies has shown that bathymetric information can be obtained from multispectral satellite imagery at varying spatial resolution of the sensor image. This study demonstrates that bathymetric data derived from sentinel 2A satellite imagery can be utilised as an alternative data source in mapping unmapped rivers in the Nigeria. This study assessed Lezenga’s linear band model and the Stumpf's log transformed ratio band model in estimating depths from Sentinel 2A imagery along Nigeria's coastal area. Accuracy test assessing the bathymetry derived from both models confirms that Lezengs's model indicated sufficient performance ($r^2 = 0.9824$, RMSE = 0.4082m) for Sentinel imagery. Atmospheric correction and bottom reflectance as well as water quality conditions were proven to be critical factors to be considered in the use of the bathymetric models within the Nigeria coast.

References

Alsubaie, N. M. (2012). The Potential of using Worldview-2 Imagery for Shallow Water Depth Mapping, (Master's thesis, Prism University of Calgary, Calgary, AB). Retrieved on February5th, 2022 from
https://prism.ucalgary.ca/bitstream/handle/11023/353/Universitu_of_Calgary_2012_Alsubaie_Naif.pdf?sequence=2&isAllowed=y

Baba, M. W., Thoumyre G., Bergsma E. W. J., Daly C. J. and Almar R. (2021). Deriving Large-Scale Coastal Bathymetry from Sentinel-2 Images Using an HIGH-Performance Cluster: A Case Study Covering North Africa's Coastal Zone, Journal of Remote Sensing, No. 21: 7006. Retrieved on October 11th, 2021 from https://doi.org/10.3390/s21217006.

Cahalane, C., Hanafin, J. and Monteys, X. (2016). Improving Satellite-derived Bathymetry Using Spatial Regression Algorithms. HydroInternational, 16–19. Retrieved on March 03rd, 2022 from https://www.hydro-international.com/content/article/improving-satellite-derived-bathymetry.

Casal, G., Monteys, X., Hedley J., Harris P., Cahalane C. and McCarthy T. (2019). Assessment of Empirical Algorithms for Bathymetry Extraction using Sentinel-2 data. International Journal of Remote Sensing, Vol. 40, No. 8, 2855–2879. Retrieved on October 13th, 2021, from https://doi.org/10.1080/01431161.2018.1533660.

European Space Agency (2021a) "ESA Sentinel 2 Orbit Description." Retrieved on October 13th, 2021. https://sentinel.esa.int/web/sentinel/missions/sentinel-2/satellite-description/orbit.

European Space Agency (2021b) "Sentinel-2 MSI Technical Guide." Retrieved on October 13th, 2021. https://earth.esa.int/web/sentinel/technical-guides/sentinel-2-msi.

Eugenio, F. Marcello, J. and Martin, J. (2015). High-Resolution Maps of Bathymetry and Benthic Habitats in Shallow-Water Environments Using Multispectral Remote Sensing Imagery. Geoscience and Remote Sensing, Vol. 53, No. 7, pp. 3539-3549. Retrieved on November 20th, 2021 from doi: 10.1109/TGRS.2014.2377300.

Ezeugwu, M. U., Idhoko, K.E., Nnamah, P.O. and Ofuenyi, J. O. (2015). Application of GIS in Evaluation of Coastal River Bathymetry: A Case Study of Opobo Channel, Rivers State, Nigeria. International Journal of Engineering Science Invention 4(11): pp. 54-59. Retrieved on March 24rd, 2022 from http://www.ijesi.org/papers/Vol(4)11/J411054059.pdf.

Gao, J. (2009). Bathymetric Mapping by Means of Remote Sensing: Methods, Accuracy and Limitations. Progress in Physical Geography, 33, 103-116. Retrieved on June 16th, 2021 from http://dx.doi.org/10.1177/0309133309105657.

Gerald, I. U., Hart, L. and KuroTamuno P. J. (2021). Comparison of Classical and Sentinel 2A Satellite-derived Bathymetry of a section of Nun River in Bayelsa. International Journal of Scientific & Engineering Research Volume 12, Issue 8, ISSN 2229-5518 Retrieved on March 24rd, 2022
https://www.researchgate.net/publication/354638584

International Hydrographic Organization IHO, (2005). Manual on Hydrography (M-13) - First Edition May 2005, International Hydrographic Bureau MONACO. Retrieved on December 22rd, 2021 from https://iho.int/uploads/user/pubs/cb/c-13/english/C-13_Chapter_1_and_contents.pdf.

Jagalingam, P., Akshaya, B. J. and Hegde, A. V. (2015). Bathymetry mapping using Landsat 8 Satellite Imagery. Procedia Engineering (116) 560–566. Retrieved on September 12th, 2021 from http://creativecommons.org/licenses/by-nc-nd/4.0/.

Lyzenga, D. R. (1978) Passive Remote Sensing Techniques for Mapping Water Depth and Bottom Features. Applied Optics, 17, 379-383. Retrieved on December 04th, 2021 from http://dx.doi.org/10.1364/AO.17.000379.

Lyzenga, D. R. (1985). Shallow-Water Bathymetry Using Combined Lidar and Passive Multispectral Scanner Data. International Journal of Remote Sensing 6 (1), 115-125, Retrieved on December 11th, 2021 from https://doi.org/10.1080/01431168508948428.

Lyzenga, D.R., Malinas, N.P. and Tanis, F.J. (2006) Multispectral Bathymetry Using a Simple Physically Based Algorithm. IEEE Transactions on Geosciences and Remote Sensing, 44, 2251-2259. Retrieved on December 11th, 2021 fromhttp://dx.doi.org/10.1109/TGRS.2006.872909.

MacPepple, E., Okereke, N., Egwuonwu, C. and Igoni, A. H. (2017) Effect of Raw Sewage on Surface Water Quality in Opobo Town, Nigeria. Environment and Ecology Research 5(3): 220-226. Retrieved on April 4th, 2022 from http://www.hrpub.org DOI: 10.13189/eer.2017.050307.

Mishra, D.R., Narumalani, S., Rundquist, D., and M. Lawson. (2005). Characterizing the Vertical Diffuse Attenuation Coefficient for downwelling Irradiance In Coastal Waters: Implications for Water Penetration by high Resolution Satellite Data. Photogrammetry and Remote Sensing. 60: 48–64. Retrieved on April 22rd, 2022 from DOI:10.1016/j.isprsjprs.2005.09.003.

Nwilo, P.C. and Badejo, O.T. (2006) Impacts and Management of oil Spill Pollution along the Nigerian Coastal Areas. Administering Marine Spaces: International Issues. A Publication of FIG Commission 4 and 7 Working Group 4.3. Retrieved on February 04th, 2022 https://www.fig.net/resources/publications/figpub/pub36/chapters/ chapter_8.pdf

Olusegun A., Sankey B. L., Chukwuma J. O. and Olutosin C. A. (2017) Assessment of the Changing Underwater Topography of Commodore Channel, Lagos. Journal of Geo-information Science (LJGIS). An International Journal of the Department of Geography University of Lagos, Nigeria. Volume 4, pp 27-44. Retrieved from on January 18th 2022 https://www.researchgate.net/publication/331742257.

Said, N. M., Mamud, M. R. and Hasan, R. C. (2017). Satellite-Derived Bathymetry: Accuracy Assessment on Depths Derivation Algorithm for Shallow Water Area. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences Vol XLII-4/W5. Retrieved on November 24th, 2021. https://doi.org/10.5194/isprs-archives-XLII-4-W5-159-2017

Stumpf, R. P., Holderied, K. and Sinclair, M. (2003). Determination of water depth with high-resolution satellite imagery over variable bottom types. Limnology and Oceanography, 48 (1), 547-556. Retrieved on November 6th, 2021 from https://doi.org/10.4319/lo.2003.48.1_part_2.0547

Tang, K.K., and Pradhan, B. (2015). Converting digital number into bathymetric depth: A case study over coastal and shallow water of Langkawi Island, Malaysia. FIG Working Week 2015. Sofia, Bulgaria. Retrieved on September 17th, 2021 from https://www.researchgate.net/publication/320304312.

Vahtmae, E. and Kutser, T. (2016). Airborne Mapping of Shallow Water Bathymetry in the Optically Complex Waters of the Baltic Sea. Journal of Applied Remote Sensing 10 (2): 025012. Retrieved on November 6th, 2021 from doi:10.1117/1.JRS.10.025012.

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