Comparison of Classical and Sentinel 2A Satellite-derived Bathymetry of a section of Nun River in Bayelsa State

By
Gerald Ikenna Ugwu, Lawrence Hart, KuroTamuno Peace Jackson

Abstract
The increasing activities of oil and gas sector with associated marine engineering operation in the region, requires a timeous and updated riverbed configuration necessary for scientific analysis and design purposes to match rapid changes on the riverbed topography due to change in river conditions such as storm surges, sea level rise, sediment transport, erosion and accretion. This condition of the riverbed impact on navigation, fishing and allied marine activities. Vessel-based acoustic bathymetric survey, which has been the major method applied in bathymetric survey in the region is constrained by its high operating cost, insecurity and inability to map shallow waters at large scale, with high accuracy. Remote sensing methods offer more flexible and cost-effective means of mapping bathymetry over broad areas. This article seeks to compare classical and remotely sensed bathymetry of a section of Nun River at Gbaran-Ubie in Bayelsa State in terms of correlation. In this paper, a ratio-transform algorithm by Stumpf 2003 was applied on satellite imagery (Sentinel 2A) to derive bathymetry of a Section of Nun River at Gbaran-Ubie in Bayelsa State. Accuracy tests comparing the image-derived bathymetry with reference data from echo sounding confirms 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. The results of this study prove that this remote sensing method can augment the conventional echo sounding method in the Nun River and can be used as a technique for in-fill or rapid response to bathymetry-changing events in quick decision making by hydrographic or marine surveying offices. **(Keywords:** Classical Bathymetry, Nun River, Remote Sensing, Riverbed configuration***)***

IJSER

1.0 INTRODUCTION

The understanding of underwater configuration is considered an essential component for marine applications since several activities and infrastructure are being carried out at the bottom, column and surface of the sea, [1], Evagorou et al [2]. Bathymetry is the foundation of the science of hydrography, which measures the physical features of a water body. Hydrography includes not only bathymetry, but also the shape and features of the shoreline; the characteristics of tides, currents, and waves; and the physical and chemical properties of the water itself [3]. Bathymetry is the measurement of the depth of water in oceans, rivers, or lakes. Bathymetric data, which includes information about the depths and shapes of underwater terrain, has a range of uses: nautical charts, hydrodynamic models, studying changing coastline features and marine life [3] According to Gonçalves et al, [4] bathymetry surveys are essential to provide data necessary to keep navigation charts updated, obtain insights in water body bottom dynamics and processes applicable for hydrodynamic modeling that are particularly important regarding possible climate change effects. Traditional bathymetry data acquisition techniques for large-scale shallow water survey projects are typically inefficient due to hazardous environmental conditions associated with shallow waters like ship wrecks, coral reef, collapse features, and rock outcrops that could damage the equipment, have however, limited the ability to acquire near-shore bathymetry data and makes the process risky and time consuming [5]. New technology such as Light Detection and Ranging (LIDAR), satellite derived bathymetry, vertical datum transformation tool and GPS has given the capacity to acquire and integrate near-shore bathymetric, shoreline and topographic data in large-scale. This has in turn increased the knowledge of the complex near-shore environment by expanding the application of data such as habitat restoration, sea-level-rise assessment, shoreline stabilization efforts, risk assessment and storm-surge warning. The volume of information collected can be used to generate classical nautical products while also providing support for the many applications of coastal zone management. The multibeam echo sounder has been the canonical system for providing swath bathymetry due to significantly wide swath with the increase in water depth [6]. The principle of echo-sounders is basic - by measuring the two-way travel time between the acoustic waves transmitted on sea surface and those reflected at seafloor. Multiple methods can be used for deep water bathymetric surveys including multi-beam and single-beam surveys, Acoustics Doppler current profiler (ADCPs), sub-bottom profilers, and the Ecomapper Autonomous Underwater Vehicle. Bathymetric surveys are useful for many different types of research including flood inundation, contour of streams and reservoirs, leakage, scour and stabilization, water-quality studies, dam removal, biological and spill, and storage and fill in reservoirs and ponds. Many methods are available for the determination of ocean, sea or river bathymetry but some factors are considered when making such choices. Among the factors that can be considered includes accuracy, operating cost, time constraint, manpower, logistic difficulties, space coverage, affordability, risk involved. These new revolution in bathymetric extraction through imagery processing include LIDAR, IKONOS, Worldview, LANDSAT and Sentinel Imagery. The readily downloadable multispectral satellite images include the USGS's LANDSAT-8 and ESA's Sentinel-2 & 3. The commercially available multispectral satellite images include SPOT, GeoEye, IKONOS, Worldview, Pleiades. Sea shore bathymetric data are required almost at the commencement of underwater activity and which necessitates the determination of a method that helps to reduce cost and as well achieve bathymetric accuracy. In this study, a ratio-transform algorithm by [7] was applied on satellite imagery (Sentinel 2A) to derive bathymetry of a Section of Nun River at Gbaran-Ubie in Bayelsa State. This paper focused on the provision of riverbed configuration of a section of Nun River at Gbaran-Ubie in Bayelsa State, Nigeria. In order to achieve this, vessel-based acoustic bathymetry of the study area was retrieved, including bathymetry estimation of the study area from Satellite imagery (Sentinel 2A imagery) using the Ratio Transform Algorithm by [7]. This was followed by comparison of the estimated bathymetry from Satellite imagery with the classically-derived bathymetry in terms of correlation; and finally, bathymetric maps of the study area were produced.

2.0 Study Area

The study area is at Obunagha community in Gbarain Kingdom of Yenagoa LGA of Bayelsa State Nigeria. It harbours multibillion naira facilities and several oil and gas activities are taking place in the location. The Gbaran-Ubie Integrated Oil and Gas facility operated by Shell Petroleum Development Company Nigeria and the ongoing private Modular refinery project under construction by Azikel Petrolume are located on the convex side of River Nun. It is bounded by the coordinates 05° 00' 45''N, 06° 17' 44''E and 05° 01' 31''N, 06° 18' 00''E, WGS'84. The present study makes an attempt to determine the bathymetric mapping of the study area 3.8km by 0.4km at Gbaran-Ubie Nun River, using imagery-derived bathymetry approach. The study area is also a harbour for fishermen and women who settled there to earn some living. The Nun River is a very dynamic river characterized by High River current and flooding and its multiple flow patterns favour bank erosion estimated at 1m per annum and huge scouring of its bed. The Niger-Delta region is dominated by rural communities that depends solely on the natural environment for subsistence living. The Niger Delta is a geographical area covering about 70,000km^2 and the largest in Africa and third in the world. It represents about 12% of Nigeria's total surface area, [8]. The Niger Delta is located on the coast of the Gulf of Guinea and is known as one of the largest and most vital wetlands in the world. The Figure 1 shows the Nun River at Gbaran –Ubie study area.

Fig. 1. Site location clearly shows the ox-bow nature of the River, the study area as circled in red and location of the facility. (Retrieved from [9]).

3.0 MATERIALS AND METHOD

3.1 Data used for the Study; Sentinel-2A optical satellite data

In this study, Sentinel-2A imagery and field data were used to analyze and estimate bathymetry. Sentinel-2A mission is

ISSN 2229-5518

part of the European Space Agency (ESA) with high-resolution multi-spectral imagery. The current research aims to compare the estimated results of bathymetry with the classical bathymetry. Therefore, processed satellite image was acquired through the Copernicus minor site (ESA, 2020), with the proximal timing of referenced data acquisition covering the study area. Table 1 below shows the details of acquired satellite imagery that was used. The acquired package is of Level 2A i.e., orthoimage and bottom of atmosphere corrected reflectance product. At this stage, the product was processed on radiometric, geometric, cloud screening and atmospheric corrections. This multispectral image has 12 bands of spectral range at three different resolutions:

Table 1: Bands of Sentinel-2 satellite image

Sentinel-2 Bands	Central Wavelength (μm)	Resolution
Band 1 – coastal aerosol	0.433	60
Band 2 – blue	0.490	10
Band 3 – green	0.560	10
Band 4 - red	0.665	10
Band 5 – Vegetation Red Edge	0.705	20
Band 6 – Vegetation Red Edge	0.740	20
Band 7 – Vegetation Red Edge	0.783	20
Band 8 - Near Infrared (NIR)	0.842	10
Band 8A – Vegetation Red Edge	0.865	20
Band 9 – Water Vapour	0.945	60
Band 10 - Short-wave Infrared (SWIR) Cirrus	1.375	60
Band 11 - Short-wave Infrared (SWIR)	1.610	20
Band 12 - Short-wave Infrared (SWIR	2.190	20

(Source: [10])

Vessel-based in-situ data

The in-situ data were collected and analysed. Odom Echo-track MK III (33 KHz/210KHz) digital recorder with an over-the-side mounted transducer shoe was used for the survey. The transducer was installed rigidly to its bracket and side mounted on the survey vessel. The transducer shoe was sufficiently deep in water and well positioned not to experience turbulence and aeration from the vessel during data acquisition. The computer receiving GPS derived coordinates in WGS'84 from the GPS system to output the final grid coordinates in Universal Transverse Mercator (UTM) Zone 32N. The navigation system software provides display presentations suitable for navigating predetermined lines and included a visual aid for the Helmsman. Raw depths were recorded in real time and event marking appropriately carried out. The raw depths obtained from Odom Echo-track MK III (33 KHz/210KHz) Multi-Beam Echo-sounder were reduced by considering the depth of the Transducer to the water surface which is known as Draft. A draft of 0.35m was applied to all sounding depth so that the value recorded by the echo sounder is the direct sounding. After the survey, the data was downloaded from the echo-sounder with a removable drive and then transferred to a computer for sorting and elimination of redundancies using Microsoft Excel.

$$D = \frac{1}{2}(vt) \qquad (1)$$

Where:

D = sounded depth,

V = speed of sound in water,

t = two-way travel time of the acoustic Signals.

The Nun River is not affected by sea tide influence of the gravitational forces of the moon and the sun hence, no tidal corrections are required in the measurements of fluctuation.

3.2 Methodology

There are several methods available for the estimation of the bathymetry using remote sensing. This study, gives emphasis in one of the most commonly used methods (ratio transform algorithm) for deriving depths using satellite imagery, [7]. In this method, the approach of Beer's Law was accepted which considers that light attenuation in the water column increases exponentially as depth increases, [11]. The log transformation algorithm is related to the natural logarithm for reflectance of two bands and actual depths. Therefore, the bands used for estimating the bathymetry are the blue (440–540 nm), green (500–600 nm) and near infrared (700–800 nm) bands. The penetration in the blue and green part of the spectrum is higher while the absorption of the electromagnetic radiation is increasing as we move to the red part of the spectrum. The ratio transform algorithm can be applied with bands having different water absorption and

ISSN 2229-5518

appropriate wavelengths of any sensor. Since blue and green bands have lower absorption, their ratio should remain the same despite the different bottom albedos at a constant depth. The values of these bands were implemented on the following Eqation. (2) to estimate bathymetry.

$$Z = m_1 \frac{In(nR_w(\lambda_i))}{In(nR_w(\lambda_j))} - m_0 \qquad (2)$$

Where Z is the satellite derived bathymetry depth, m_1 is a tunable constant to scale the ratio to depth, n is a fixed constant for all areas to assume that the algorithm is positive, and m_0 is the offset for a depth of 0m where $(Z = 0)$. R_w is the reflectance of water, and $(\lambda_{i,j})$ are two different bands (Blue and Green bands).

For this model, the bottom depth is estimated on the basis of light attenuation phenomena, as the attenuation of the incoming shortwave radiation varies spectrally. The ratio transform algorithm was implemented to the multispectral imagery. Initially the multispectral imagery was resampled by a referenced band with a 10m spatial resolution, using the ArcGIS software. Upon the selection of the area of interest, the ArcGIS software was used where the shape-file was created and uploaded on the ArcGIS software to mask satellite imagery. The masked imagery classified the blue, green and near infrared band and then separated land and water. After the pre-processing of satellite data and atmospherically corrected, the median filter, a nonlinear digital filtering technique was used for removing the noise from imagery. Bathymetric algorithm was calculated from the blue and green fix obtained from the imagery. The final bathymetry was derived by calculating the vertical referencing of the bathymetric algorithm. Figure 2 shows the processing steps for deriving bathymetry on the study area.

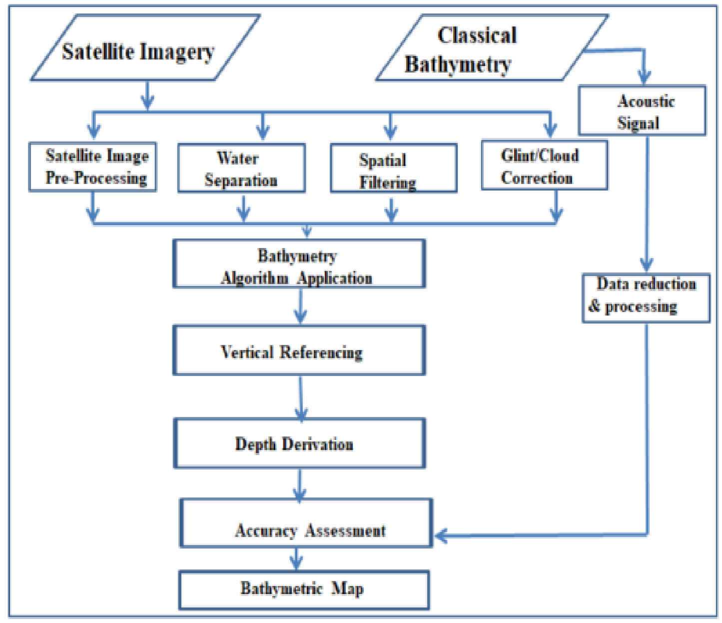

Fig. 2. Flow Chart of Method (Source: Authors' Conceptualisation, 2021)

IJSER

4.0 RESULTS AND DISCUSSIONS

4.1 Results

Table 2. Bathymetry Algorithms Extracted from Sentinel Image.

Bathalg	Reference (Observed) Depth
0.994180501	9.4
0.992700398	8.9
0.993934929	7.8
0.99521178	7.2
0.994326711	7.6
0.994180501	9.6
0.994781077	6.1
0.99541384	7.4
0.994364142	6.8
0.992043436	8.2
0.992151797	7.1

0.993450284	7.2
0.992700398	7.3
0.992151797	6.5
0.992294014	7.9

(Source: Authors, 2021).

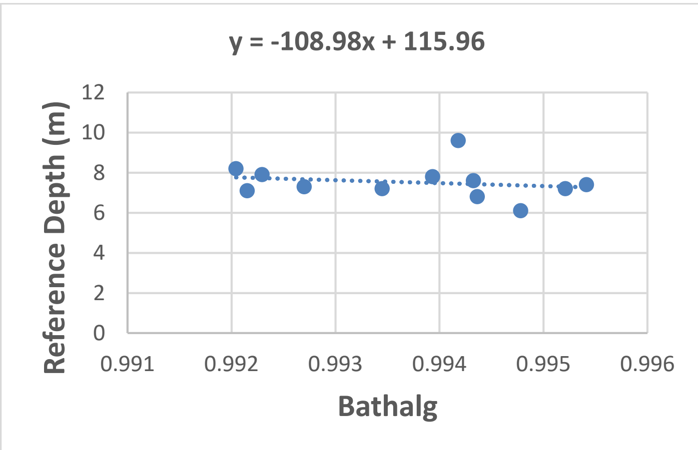

Fig. 3. Values of Gain (m_1) and Offset (m_0) Values Obtained from Sentinel Derived Bathalg

IJSER

Table 3. Estimated Bathymetry (depth) from Sentinel Image

Bathalg	**Observed Depth (m)**	**Estimated Depth (m)**
0.994180501	9.4	9.4
0.992700398	8.9	8.7
0.993934929	7.8	7.7
0.99521178	7.2	7.0
0.994326711	7.6	7.5
0.994781077	6.1	6.1
0.994180501	9.6	9.3
80.99541384	7.4	7.4
0.994364142	6.8	6.8
0.992043436	8.2	7.8
0.992151797	7.1	7.1
0.993450284	7.2	7.6
0.992700398	7.3	7.4
0.992151797	6.5	6.8
0.992294014	7.9	7.7

(Source: Authors, 2021).

Comparison of the Derived Bathymetry results Using Statistical Indices;

The comparison of estimation results of the satellite imagery used in this work were carried out by correlation coefficient (R^2), Root Mean Square Error (RMSE) and standard Error of Mean (SEM). These parameters were used to evaluate the accuracy of results finally obtained.

Direct measurement of sea floor depth was done by echo-sounding from a vessel. The data assessments which serve as the quality assurance were used to evaluate the performance against the estimated satellite derived bathymetry. In this case, bathymetric points were used to assess the accuracy of the satellite-derived bathymetry (Sentinel imagery). The accuracy assessments were done based on the following;

i. Root Mean Square Error (RMSE) test was used to evaluate the satellite-derived bathymetry accuracy. The RMSE was computed using the Equation 3:

$$\text{RMSE} = \sqrt{\frac{\sum(X_{\text{Known i}} - X_{\text{estimated i}})^2}{n}} \qquad (3)$$

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 in the checking area, [12].

ii. The correlation coefficient (R^2) between the estimated depth and check data was calculated, the value normally ranges between 0 and 1. If the R^2 is close to 1, it signifies that there is a positive correlation between the estimated depth and the observed depth. But if the R^2 is close to 0, it signifies that there is a negative correlation between the estimated and observed depth.

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 Eq.4 below:

$$\text{SEM or } \bar{x} = \frac{\sigma}{\sqrt{n}} \qquad (4)$$

σ = Standard Deviation of the Population;

n = Size (number of observations) of the sample

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x-\bar{x})^2}{N-1}} \qquad (5)$$

σ = Standard Deviation of the Population;

N = Number of observations

x = Observed values of a sample mean

$\bar{x}$ = The mean value of the observations

4.2 Discussion of Results

Root Mean Square Error (RMSE) and Correlation Coefficient (R^2)

Sample points of sounded depths using an echo sounder were compared with estimated depths from Sentinel imagery. Root Mean Square Error (RMSE) as explained above including correlation coefficient (r^2) was used to test the reliability of the Sentinel data. The RMSE is stated below in table 4 and correlation coefficient (r^2) in figure 4.

Table 4. The Computed RMSE for Sentinel Bathymetry

S/N	Observed Depth (m)	Estimated Depth (m)	Residual (R)	R^2
1.	9.4	9.4	0.0163	0.0003
2.	8.9	8.7	0.2015	0.0406
3.	7.8	7.7	0.0887	0.0079
4.	7.2	7.0	0.2000	0.0400
5.	7.6	7.5	0.0821	0.0067
6.	6.1	6.1	0.0392	0.0015
7.	9.6	9.3	0.3000	0.0900
8.	7.4	7.4	0.0000	0.0000
9.	6.8	6.8	-0.0300	0.0009
10.	8.2	7.8	0.4000	0.1600
11.	7.1	7.1	0.0000	0.0000
12.	7.2	7.6	-0.3604	0.1299
13.	7.3	7.4	-0.1429	0.0204
14.	6.5	6.8	-0.3000	0.0900
15.	7.9	7.7	0.2059	0.0424
				RMSE = 0.251119m

(Source: Authors, 2021).

From Table 4, (computed RMSE for Sentinel Bathymetry), it was deduced that the RMSE was **0.251119m.** According to [12], the acceptable RMSE recorded ranged between 0.024m and 3.758m for the sites, in which the RMSE for Sentinel derived bathymetry falls within that range, which implies that the estimated depth in this study is reliable. Also, the correlation coefficient (r^2) between the estimated depth and check data was calculated to be 0.9635 (Figure 4), which is close to 1, signifying that there is a positive correlation between the estimated depth and the observed depth.

IJSER

ISSN 2229-5518

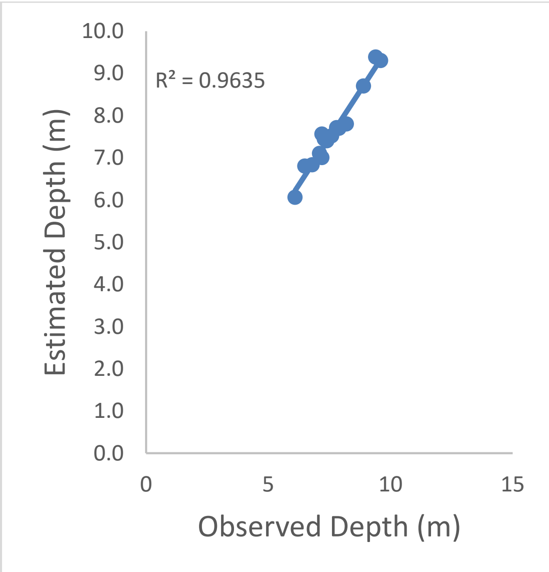

Fig. 4. Correlation Coefficient (r^2) between the Sentinel Satellite-Derived Depth and Observed Depths

Standard Error of the Mean (SEM)

The standard error of the mean is a measure of the dispersion of sample means around the population mean. Standard error provides information on the accuracy of the statistic. It is an important indicator of how precise an estimate of the population parameter, the sample statistic, is. The larger the standard error, the wider the confidence interval about the statistic. The Standard Error (SE) of the estimated depths is shown in Table 5 below.

Table 5: the Computed SEM for Sentinel Derived Bathymetry.

S/N	Observed Depth (m)	Sentinel Depth (m)
1.	9.4	9.4
2.	8.9	8.7
3.	7.8	7.7
4.	7.2	7.0
5.	7.6	7.5
6.	6.1	6.1
7.	9.6	9.3
8.	7.4	7.4
9.	6.8	6.8
10.	8.2	7.8
11.	7.1	7.1
12.	7.2	7.6
13.	7.3	7.4
14.	6.5	6.8
15.	7.9	7.7
Mean		**7.6**
Standard Deviation		0.9
Standard Error of Mean		0.2324

(Source: Authors, 2021).

IJSER

Provision of Bathymetric Maps of the Study Area

After importing the depths into the GIS environment, cartographic enhancement was done to produce the bathymetric maps shown below. Figure 5 below represents the echo sounder bathymetric map of the study area while Figure 6 represents the Sentinel imagery Derived Bathymetric map for the study area. The two maps below showed strong positive correlation.

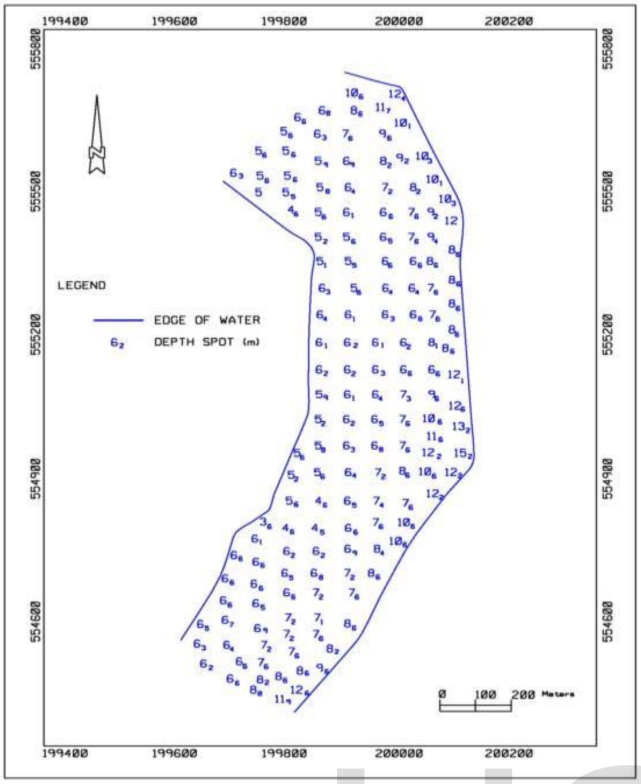

Fig. 5. Bathymetric Map from Echo Sounder (Source: Authors, 2021)

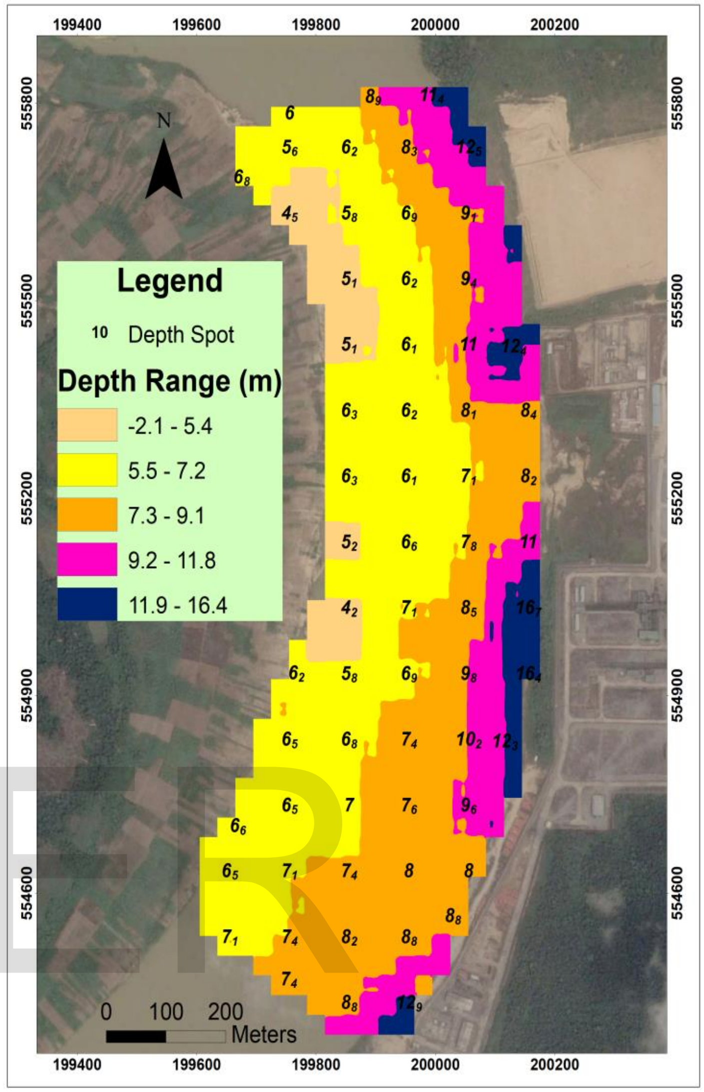

Fig. 6. Sentinel Satellite Derived Bathymetry map for the study area (Source: Authors, 2021)

IJSER

CONCLUSION

An increasing number of studies have shown that bathymetric information can be derived from optical satellite multispectral imagery at the spatial resolution of the source image. Various models have been developed to convert image pixel values into depth estimates. Stumpf's method addresses several issues that have considerable relevance to using passive multispectral imagery to map shallow-water bathymetry. This study applied the [7] ratio transform model to estimate depths from Sentinel imagery. Accuracy tests comparing the estimated bathymetry with reference data show good agreement with standard errors as low as 0.2324 for Sentinel. The results of accuracy tests of the model indicate a very sufficient performance (R^2 = 0.9635, RMSE = 0.251119 for Sentinel imagery). The absolute differences between known depths and estimated depths at the study site varied from 0.01m to 0.40m. Statistical indices obtained in this work indicated that the ratio-transform algorithm can accurately retrieve depths up to 10m. This research has evaluated and shown the potentials of satellite-derived bathymetry. Results showed strong positive correlation with reference depths. In general, the water depths derived from readily downloadable Sentinel satellite imagery (10m spatial resolution) was depicted to be statically accurate and able to provide realistic seabed terrain profiles. This method can be an alternative survey sources to complement the medium resolution (profiling interval 10-30m) surveys. Apparently, it is possible for low-cost, low-accuracy and low-risk bathymetry charting mission. Most of the tiny or small features may not be visible from the low spatial resolution imagery. Therefore, it is not advisable to be applied for jobs that require high accuracy and precision, even though satellite-derived bathymetric mapping is an innovative solution to supplement the traditional vessel-based survey techniques [12]. This study's result is in conformity with the work of [12].

- *Gerald Ikenna Ugwu has a Bachelor Degree in Surveying and Geoinformatics and is currently pursuing his M.Sc Degree in Surveying and Geomatics Department Rivers State University Port Harcourt Nigeria. E-mail: ugwugerald@yahoo.com*
- *Dr. Lawrence Hart and Dr. KuroTamuno Peace Jackson are Research Fellows in the Department of Surveying and Geomatics Rivers State University Port Harcourt Nigeria. co-authors email: Lawrence.hart@ust.edu.ng, kurotamuno@gmail.com*

REFERENCES

[1] A. Bäckström, "A New Bathymetric Model of LakeVättern, Southern Sweden." M.Sc Thesis, Department of Geological Sciences, Stockholm University, SE-106 91 Stockholm, 2018. (Thesis)

[2] E. Evagorou, C. Mettas, A. Agapiou, K. Themistocleous, and D. Hadjimitsis, "Bathymetric Maps from Multi-Temporal Analysis of Sentinel-2 Data: The Case Study of Limassol, Cyprus" *Advanced Geoscience Journal*, vol. *45*, pp. 397–407, Jan. 2019. https://doi.org/10.5194/adgeo-45-397-2019

[3] NOAA (National Oceanic and Atmospheric Administration) U.S. Department of Commerce. Available at https://www.govinfo.gov/content/pkg/FR-2021-02-05/pdf/2021-02431.pdf, Feb. 2021.

[4] J. A. Gonçalves, J. Pinheiro, L. Bastos, and A. Bio, "Combining Low-Cost Sonar and High-Precision GNSS for River and Estuarine Bathymetry" Proceedings of CoastGIS on Spatial Planning and Climate Change, Sept. 2018. Available at https://www.uw.is/haskolasetur_vestfjarda/skraarsafn/skra/865/ ,

[5] L. Brisson, D. A. Wolfe and M. Staley, "Interferometric Swath Bathymetry for Large Scale Shallow Water Hydrographic Surveys" Canadian Hydrographic Conference, pp. 1 – 18, April, 2014. https://hydrography.ca/wp-content/uploads/files/2014conference/29-Brisson-et-al-Interferometric-Swath-Bathy.pdf

[6] K. R. Hogrefe, D. J. Wright, and E. J. Hochberg, "Derivation and Integration of Shallow-Water Bathymetry: Implications for Coastal Terrain Modeling and Subsequent Analyses" *Taylor & Francis Group*, vol. 31 no. (4), pp. 299-317, Dec. 2008. https://doi.org/10.1080/01490410802466710

[7] R. P. Stumpf, K. Holderied and M. Sinclair, "Determination of Water Depth with High-Resolution Satellite Imagery over Variable Bottom Types" *Limnology and Oceanography*, vol. *48* issue 1, part 2 pp. 547-556, Jan. 2003. https://doi.org/10.4319/lo.2003.48.1_part_2.0547

[8] UNDP (United Nations Development Programme). "Nigeria's path to sustainable development through green economy." Country report to the Rio+20 summit). June, 2021.

[9] Google Earth (2020). Landsat imagery. U.S. Navy Data. Retrieved from https://earth.google.com/web

[10] Hatari Labs, "How many spectral bands have the sentinel 2 images?"April, 2017, available at https://www.hatarilabs.com/ih-en/how-many-spectral-bands-have-the-sentinel-2-images.

[11] J. Gao, Bathymetric Mapping by Means of Remote Sensing: Methods, Accuracy and Limitations. *Progress in Physical Geography*, vol. *33*, pp. 103-116. May, 2009. http://dx.doi.org/10.1177/0309133309105657

[12] K. K. Tang and B. Pradhan, "Converting Digital Number into Bathymetric Depth: A Case Study over Coastal and Shallow Water of Langkawi Island, Malaysia." FIG Working Week, Sofia, Bulgaria, May, 2015. Available at

IJSER

https://www.fig.net/resources/proceedings/fig_proceedings/fig2015/papers/ts07a/TS07A_tang_pradhan_7505.pdf

IJSER