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Shallow-water bathymetry using Landsat 8 imagery – example of Ibafon and Badagry Creeks, Lagos Nigeria

Chukwuma Okolie, Emmanuel Ayodele Oluwatobi Raji, Waliyah Adedokun, Olagoke Daramola, Samuel Akinnusi, Hamed Olanrewaju

University of Lagos, Faculty of Engineering, Department of Surveying and Geoinformatics, Lagos, Nigeria

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ABSTRACT

There is high demand for the seabed topography of water bodies. The shallow nature of some waterbodies makes it difficult to deploy the conventional bathymetry method, that is the use of echo-sounders on a vessel. Under these conditions, remote sensing methods thrive with significant advantages in terms of costs, coverage area and delivery time. In this study, Stumpf's algorithm was applied on Landsat imagery to derive bathymetric data in parts of Ibafon Creek and Badagry Creek in Lagos, Nigeria. In the findings, the depths were generally shallow with depth range between 0.7 m and 13.3 m and an average depth of 4.84 m. In several instances, the remote sensing method of bathymetry can serve as an alternative to the conventional methods in shallow waters, and can as well be used as a reconnaissance tool to obtain change in depth over several epochs.

1. Introduction

The majority of methods for estimating bathymetry are based on the concept of using time to infer distance (Dierssen et al., 2011). The fundamental physical principle underlying the retrieval of bathymetric information from optical remote sensing images is that when light passes through water it becomes attenuated by interaction with the water column (Raj et al., 2013). Deep areas appear dark on the image since the water absorbs much of the reflected light. Shallow areas appear lighter on the image since less light reflected from the seabed is absorbed in the passage through the water column. For survey of bathymetry at synoptic scale, the remote sensing method may be a viable alternative to the conventional bathymetric mapping using echo sounders.

Several techniques for estimating bathymetry from satellite imagery have been developed and applied at numerous sites in different parts of the world. This is evident in the high yearly turnover of scientific articles on satellite derived bathymetry (SDB) published in journals and conference proceedings. Despite this increased global awareness, there has been a very slow uptake of SDB by hydrographic researchers, professionals and agencies in Africa. The present study demonstrates the potential of SDB for estimating the bathymetry of shallow water bodies in Lagos, Nigeria.

Satellite derived bathymetric information, if well-utilized can support safety of navigation by providing up-to-date grids of the shallow water zone. This is paramount in areas with outdated charts in Nigeria. In addition to the bathymetric information, it can aid the identification of obstacles, which are hazardous to safe navigation. Therefore, this study applies the Stumpf's bathymetric algorithm to derive bathymetry in parts of Ibafon and Badagry Creeks of Lagos State Nigeria, and compares the depth values with the data obtained from the conventional means using an echo sounder.

Stumpf et al. (2003) model is robust and works well over variable bottom types. It also accounts for water turbidity. The algorithm requires only two tunable parameters which could be computed using the linear regression method between the ratio result and ground truth (Alsubaie, 2012).

$$Z = m_1 \frac{\ln(nR_W(\lambda_i))}{\ln(nR_W(\lambda_j))} - m_0 \qquad (1)$$

Where 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.

* Corresponding Author

*(rajitobi27@gmail.com) ORCID ID 0000-0002-0812-4273

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This study aims to assess the overall adequacy of Landsat 8 satellite data for the derivation of shallow water bathymetry cost and timely benefits.

2. Methods

2.1. Study area

Ibafon creek is an inlet into the Badagry creek and opens into the Atlantic Ocean. It covers a length of 5.45 km from Ibafon to the Festac Lagoon and is bounded between 6°26'57.82" N and 3°19'01.31" E, and 6°26'57.82" N and 3°19'01.31" E. It also extends centrally towards Amuwo-Odofin and Okota. Badagry Creek is a creek that flows from Benin Republic into Commodore Channel in Lagos. These creeks can be described as very turbid; this is partly due to the human activities near the coastal area. The turbid nature of these water bodies presents a significant case study for investigation.

2.2. Datasets

The satellite image used is Landsat 8 imagery, which was downloaded from the United States Geological Survey (USGS) website. The in-situ bathymetry data used was collected from the Department of Surveying and Geoinformatics University of Lagos, Nigeria. The summary of the datasets collected are shown in Table 1.

Table 1. The summary of the datasets used

Data	Publisher/Source	Year	No. of Points
Bathymetric data	Field data acquired by the Department of Surveying and Geoinformatics.	2020	698
Landsat 8 Imagery	US Geological Survey (USGS)	2020	

2.3. Image processing

The downloaded Landsat 8 imagery was processed to generate the satellite-based bathymetry using ArcGIS software tools. The key processes carried out which were used to generate the bathymetry include: (i) water-land separation using threshold value (ii) spatial filtering (iii) generation of bathymetric raster using Stumpf's model. Further analyses were done to assess the relationship between the satellite-derived bathymetric values and field bathymetric values using statistical tools in Microsoft Excel software.

2.3.1. Land/water separation

The water body was separated from the land areas on the raster data using the threshold value of the point of transition between the water and land area. Profile graph and Pixel inspector tools in the ArcMap toolbox were used to determine the threshold value to separate the waterbody from the land areas.

2.3.2. Spatial filtering

A low-pass filter was used to enhance the imagery. Before performing spatial filtering, the float tool was used to convert the value of each pixel of the raster derived from the water-land separation into a floating-point representation. This was necessary to improve the precision of the pixel values.

2.3.3. Derivation of bathymetry

The final step to determine the satellite-based bathymetry involves the application of Stumpf's model. This model compares the bathymetry algorithm values and the in-situ bathymetric depth values to build a regression model to generate the satellite-derived bathymetric raster. Consequently, it is necessary to determine the bathymetry algorithm (bathyalg) model, which is the coefficient of m_1 in Stumpf's model. The bathyalg is the ratio of the filtered blue band (band 2) and green band (band 3). The sample in-situ depth points were plotted on ArcMap and the layer was used to extract bathyalg values for the same sample points with the "Extract Value to Point" tool in Arc Toolbox. The resulting attribute table was exported in txt format for further analysis on Microsoft Excel.

Equation 2 can be likened to a straight-line equation of $y = mx + c$. Hence, a regression-line graph of the bathymetric algorithm versus the true depth is plotted. The equation was inputted in the Raster Calculator tool on ArcMap to calculate the satellite-derived bathymetry.

$$Z = m_1(\text{Bathymetry algorithm}) - m_0 \ldots\ldots (2)$$

2.4. Quantitative analysis

A depth difference maps (ΔDepth) was calculated by subtracting the in-situ depth values from the imagery-derived depth values. This was also done to show the agreement of the SDB depth with the echo sounding data. The calculation was done in Microsoft Excel and exported with their respective coordinates into ArcGIS for plotting.

3. Results

Table 2 presents the summary statistics of the datasets, which showed consistent higher values in the field data than in the imagery-derived values. On the other hand, Figures 1 and 2 present the bathymetric charts from the two datasets and the difference in depths respectively. Further discussion of the results is presented in Section 4.

Table 2. Summary statistics of the depth comparison

	Landsat depth (m)	Echo sounding depth (m)	Difference (m)
Min	0.68	0.89	0.21
Max	9.84	12.16	2.32
Range	9.16	11.27	2.11
Mean	5.68	5.78	0.10
SD	2.51	2.97	0.46
Variance	6.28	8.82	2.54
SE	0.46		

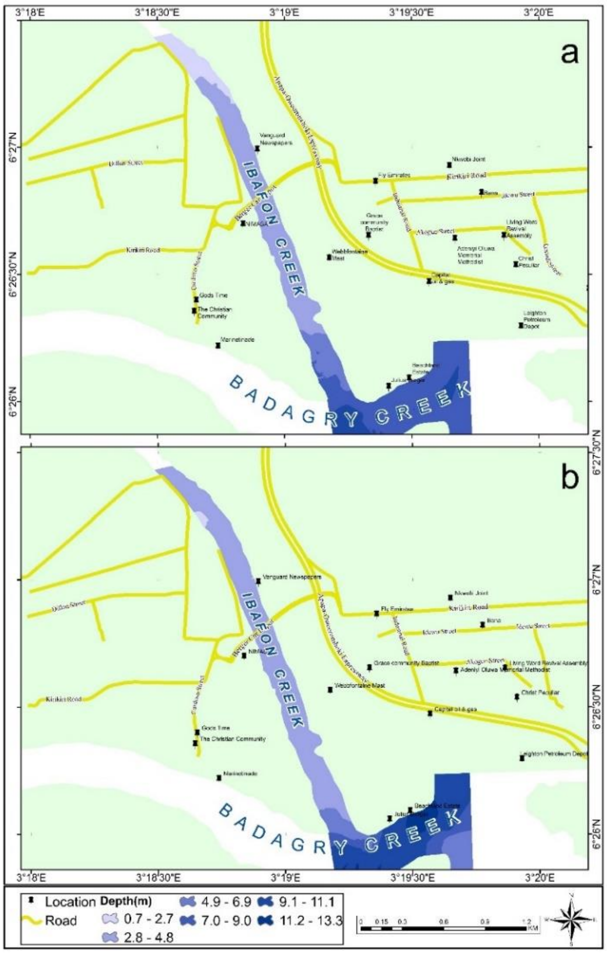

Figure 1. Bathymetric charts produced from (a) Landsat imagery (b) Echo sounding

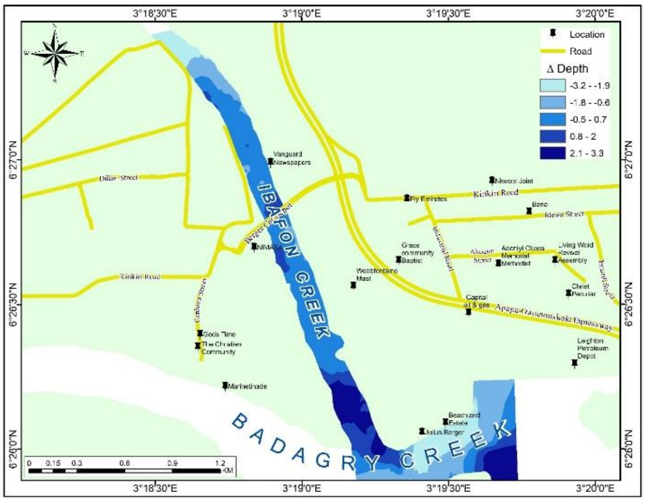

Figure 2. Map showing changes in depth

4. Discussion

The depths are generally shallow with depth range between 0.7 m and 13.3 m and an average depth of 4.84 m. Badagry Creek is the deepest part of the study area. Generally, the depth in Ibafon Creek is fairly uniform with most of the depth values between 2.7 m and 4.5 m compared to the Badagry Creek. In Figure 1b, the bathymetry of the narrow strip of the study area appears to be uniform. In Figure 2, the changes in depth ranged from -3.2m to 3.3m. The Landsat depths were very close to the in-situ depths along the narrow strip in Ibafon Creek. This confirms the claims that SDB is a promising technology for shallow water bodies.

5. Conclusion

This study has examined the application of satellite derived bathymetry (SDB) in a shallow water environment consisting of two creeks in Lagos Nigeria to understand applicability based on Stumpf model. The study found that the technology performed favorably well when compared with the echo-sounding approach. Accordingly, it can be deduced that the technology can be used to monitor beach erosion, sea level rise and general changes in coastline features. A set of time series maps can be generated to this effect. The data can also help scientists to study the habitats of bottom-dwelling aquatic organisms. Maps of coral habitats can also be generated to assist on conservation and monitoring. In a future study, the method of linear regression with statistical tests such as the coefficient of determination (R^2) will be used for validating the imagery-derived bathymetry. Also, a more detailed analysis on the correlation between the Landsat bathymetry and the echo-sounding data will be presented. Exploring the potential of this technology under a fit-for-purpose concept is a welcome idea.

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