Near Shore Bathymetry Evaluation using Remote Sensing Method*

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ABSTRACT

This study explores the application of satellite remote sensing technique in near-shore bathymetry. The study area is a section of Cross River which lies between Akwa Ibom State and Cross River State, as well as Bakassi Peninsula. The extensive coastal waters of Nigeria have remained uncharted due to constraints imposed by government policy, funds and technological limitations. The applications of conventional technique of bathymetry such as echo sounders or swath sounding systems are inadequate for mapping very shallow areas due to sensor fouling or prohibitive cost in attempt for full sea floor coverage. The data employed include multispectral Landsat-7 ETM+ image set of year 2000, sounded depth for 2012, tidal data and extract from Admiralty tide tables. Tidal prediction was carried out for 2012 and in retrospect for 2000. The sounded data and Landsat-derived depth were reduced to the same Chart datum for ease of evaluation. Atmospheric correction of the satellite image was accomplished using Improved Image-Based Dark Object Subtraction (DOS) Model, while Stumpf's Ratio Model was employed to estimate the bathymetric depths. The depths derived from the ratio of blue/red bands reveal better bathymetric depths than the ratio of the blue/green bands when compared with the sounded/ground truth data. The results obtained agree with the specifications for under-keel clearance in shallow water navigation and therefore showed that this technique can be adopted for safe mapping of the Nigerian Coastal waters. This is an efficient and cost-effective technique for near shore bathymetry and is therefore strongly recommended for mapping and monitoring of sea floor changes in our coastal waters.

Keywords: *Coastal waters, near-shore bathymetry, remote sensing technique, navigation*

INTRODUCTION

Bathymetric survey of shallow waters is of fundamental importance to coastal areas which are often characterized by high population density, heavy maritime traffic and vulnerable natural ecosystems like mangrove, creeks, lagoons or coral reefs. Minghelli-Roman *et al* (2007) observe that in many regions, sea depth changes because of erosion and sedimentation processes and bathymetry must often be accurately updated. All these attributes spur up environmental investigation of the seabed morphology, and monitoring

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of navigational channels for safety, to ensure proper management of resources in the coastal zones. Though these are common exercises in developed countries, there are still myths in developing countries such as Nigeria. It is interesting to know that many coastal environment of the world have not been fully surveyed, and many that have been surveyed are seriously outdated (Fisher, 1999). But nations who have made maximum utilization of their marine resources have properly charted and updated their charts on regular basis. In Nigeria, the scenario is different because there is no central body to provide accurate bathymetry data for the numerous in-land and coastal waters. Therefore, lack of comprehensive up-to-date navigational charts is a strong factor as to why most marine environments in Nigeria have not been properly harnessed. To this end, charting of waters were undertaken by the Nigerian Ports Plc, the Inland Water ways, the Nigerian Navy and some other Private Organizations, with each concentrating within the limits of her specific areas of operations (Ojinnaka, 1997). Economically, activities in the marine environment, such as, transportation of goods, commercial fishing, and tourism, etc, have adversely been affected within the country. Consequently, this has militated against rapid development, and accruable revenue to government is low or lost in some cases.

Some of the factors hindering charting of water-ways in Nigeria are mostly due to possibility of grounding in shallow (>5m) waters, and inaccessibility of some marine environments by the conventional ship-based sonar systems. Other associated problems with this technique are high cost of equipment, personnel and rigorous field survey procedure, etc. The aftermath is that monitoring of changes on the seabed topography is unattainable because the extensive areas of water bodies near the coast are either uncharted or un-updated for a long time. These unfortunate situations have made it difficult for most developing nations of the world to pay serious attention to the charting of their waters.

All these deficiencies need to be addressed and arrested by opting for a technique and data type that will make for fast and effective production of the charts and other navigational essentials being that the orthodox boat/ship-based systems and techniques are fraught with problems. As a result of these setbacks, satellite remote sensing technology in the 70s was gradually adopted as an alternative in clear water bathymetry mapping to minimize field work. The synoptic view, easy access, and dynamic nature made remote sensing approach a rather cost effective way to provide quick solutions to bathymetry mapping for studies of the fast-changing coastal environment (Zhongwei and Minhe, 2008); and also provide a faster and cost effective alternative to ship-borne sonar bathymetric mapping in shallow waters (Melsheimer and Chin, 2001). Hence, it is expedient to explore satellite remote sensing technique, using multispectral satellite image of Landsat 7 ETM+ to estimate bathymetric depths of Nigerian coastal shallow waters for the purposes of monitoring possible changes of seabed topography in coastal shallow waters.

The Study Area

Cross River demarcates the coastal boundaries between Akwa Ibom State on the west and Cross River State on the north-east, both in the South-South region (Niger Delta region) of Nigeria; and Bakassi Peninsula on the east. The Northward channels of the sea lead to Calabar Port (Export Processing Zone (EPZ)) in Cross River State, and discharges into the Atlantic Ocean in the South. The cross-sectional distance of the downward part of the river is about 16 kilometers. The sea has the potential of being influenced by hydrological dynamics from the Atlantic Ocean. The sea is shown on the Admiralty Chart (Sheet No. 3433) from the Atlantic Ocean and it is entitled "Approaches to Calabar". The physical relief of the coastal lands of Akwa Ibom State is characterized by deltas, estuaries, lagoons, creeks and swamps. The swamps are tidal mudflats in nature. The vegetations on the coastal lands are generally made up of flood plain mangrove, brackish or saline mangroves and salt-water swamp forests. The economic significance of the river and its environs comprise of abundant oil and gas reserves, fishing, marine transportation and the proposed site for seaport in Akwa Ibom State.

MATERIALS AND METHOD

The data used included historical multispectral Landsat-7 ETM+ image set of 2000, tidal datasets, bathymetric datasets of a section of the river, and Admiralty Chart data of Calabar Channel published in 1994. The blue, green, red and Near InfraRed (NIR) bands of the Landsat-7 ETM+ were used to carry out this study. The Spectral Bands of 1-5 and 7 atmospherically uncorrected Landsat-7 ETM+ image set with path/row number 187/057 acquired at 09 : 29 :11 (GMT) on December 10, 2000 is shown in figure 1. The stages involved in the preparation of the spectral and bathymetric data include geometric correction, atmospheric correction, water reflectance determination, tidal correction of image and bathymetric depths values to chart datum, the extraction of water depths using Stumpf's Model from the image. The algorithm for these steps is as shown in Figure 2.

Geometric Image Correction: Landsat-7 ETM+ image is a Level 1G fully processed product that is geometrically standardized and the image coordinate system in the Universal Transverse Mercator (UTM) Projection System with WGS 84 (Zone 32) as the datum. Coordinates of the selected known points on the ground were charted on the image, and they corresponded without much difference. Hence, geometric correction was not performed on the image.

Atmospheric Correction: The objective of atmospheric correction was to convert remotely sensed DN to ground surface reflectance. The processes employed are Conversion of DN to Surface Reflectance and Water Reflectance Determination.

Conversion of DN to Surface Reflectance: The methods for atmospheric calibration are classified into two main groups – absolute calibration and relative calibration (Thome et al., 1997 cf. Lu, Mausel, Brondizio and Moran, 2002), which can be further simplified into three model groups, namely:

i. Physically- Based Calibration Models
ii. Image-Based Calibration Models
iii. Relative Calibration Models.

The choice of a particular model depends on the requirement of the research and data available for atmospheric correction. This study used an historical Landsat-7 ETM+ image set acquired on December 10, 2000, hence, Image-Based Calibration Models was suitable.

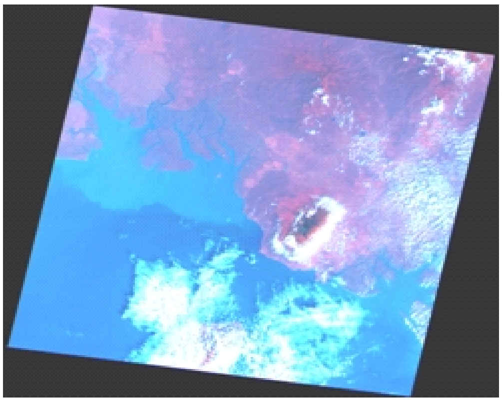

Figure 1: Lansat-7 ETM+ Image of Band 1 - 5 and 7

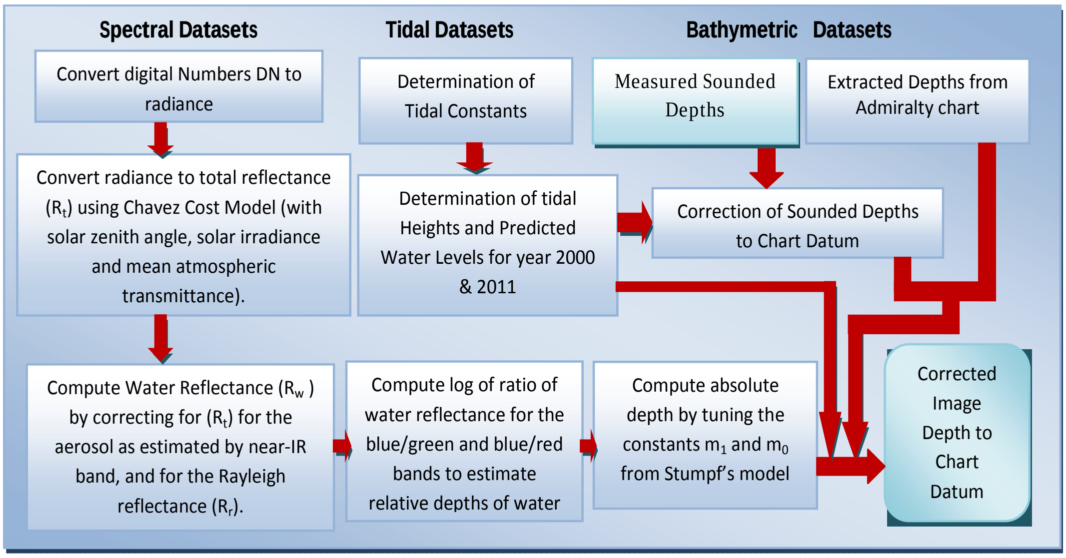

Figure 2: Algorithm for Data Preparation

The different methods of image-based models include the Apparent Reflectance Model, the Dark Object Subtraction (DOS) Model and the Improved Image-Based DOS model (Chavez, 1996). The Improved Image-based DOS model was employed to carry out atmospheric correction. This model makes use of calibration parameters from the header file of the image. The parameters include sun zenith angle, date of acquisition of the image, as well as the specifications for either "high" (H) or "low" (L) coefficients. Based on the "high" or "low" specifications for gain and offset (bias) coefficients, including exo-atmospheric solar irradiance, these parameters were extracted from Chander, Markham and Helder (2009). The Improved Image-based DOS model is given as:

$$R_T(\lambda)=\frac{\pi\left((DN_\lambda \times Gain_\lambda + Bias_\lambda)-(H_\lambda \times Gain_\lambda + Bias_\lambda)\right)\times D^2}{E_{SUN\lambda}\times\left[\cos\left((90-\theta)\times\frac{\pi}{180}\right)\right]\times\tau}$$

(Chavez, 1996) (1)

Where, R_T = is the total reflectance for spectral b and λ

π = Mathematical Constant 3.1415926

= Sun Zenith Angle (θ is the Solar Elevation)

D^2 = Square of Normalized Earth-Sun Distance

= $[1 – 0.01674 \text{ x Cos } (0.9856 \text{ x } (JD-4))]^2$ (Nurlidiasari, 2004).

To convert the units to radians is simply to multiply by ð/180.

= Exo-atmospheric Solar Irradiance for Spectral B and λ

$H\lambda$ = Digital Number representing Dark Object for Spectral B and λ

= Atmospheric Transmittance expressed as

for COST Model (Chavez, 1996)

This model was accessed through a Web-Based tool and processed in ERDAS Imagine 9.1 software.

Digital Number representing Dark Object for spectral Band, $H\lambda$ in Equation (1) was used to estimate the atmospheric path radiance under clear atmospheric condition. Minimum DN values were presumed to represent dark objects in the image (Skirvin, 2002) and the selection of minimum DN values was based on Mauz (2002) approach. The atmospherically corrected (surface reflectance) image from the COST model is shown in Figure 3.

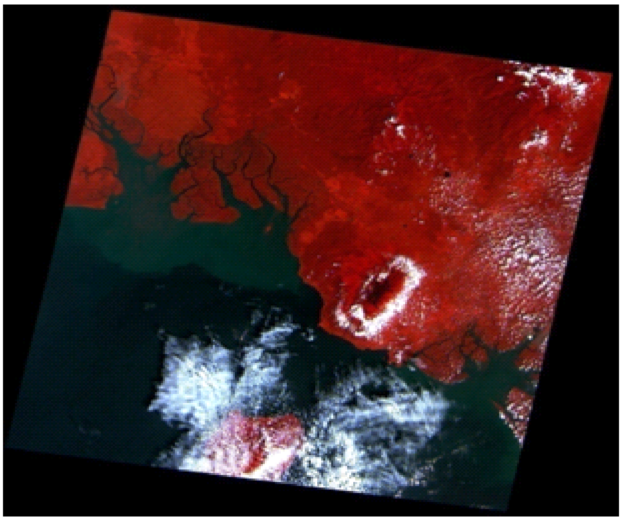

Figure 3: Surface Reflectance Image
(Using Improved Image-Based Model)

Water Reflectance Determination

The water reflectance, R_w, of a particular spectral band is defined as:

$$R_w = \frac{\pi L_w(\lambda)}{E_d(\lambda)} \quad (2)$$

Where: L_w = the water-leaving radiance

E_d = the downwelling irradiance entering the water

λ = the wavelength of the spectral band.

This model requires that the water-leaving radiance, L_w, and the downwelling irradiance, E_d, be measured physically using a spectroradiometer. In the absence of this equipment, an alternative approach was explored. Stumpf, Holderied and Sinclair (2003) and Zhongwei and Minhe (2008) show that due to inherent complexities in obtaining certain physical quantities, Reflectance of Water, $R_w(\lambda)$, could be determined using the model:

$$R_w(\lambda_i) = R_T(\lambda_i) - Y(\lambda_i) R_T(\lambda_{IR}) - R_r(\lambda_i) \quad (3)$$

Where: R_T = is the total reflectance for spectral band λ.

Y = the constant to correct for spectral variation (equivalent to the Angstrom exponent in Gordon et al. (1983) as cited in Stumpf, Holderied and Sinclair, 2003).

$R_r(\lambda)$ = Rayleigh Reflectance is estimated by the deep water reflectance of the wavelength (λ) (Stumpf, Holderied and Sinclair, 2003).

Subscript *i* and *IR* denote the wavelengths of the visible and near -*IR* spectral bands. The reflectance of water (R_w) was to be found by correcting the total reflectance, R_T for the aerosol and surface reflectance, as estimated by the near-IR band, and for the Rayleigh reflectance, R_r (Stumpf, Holderied and Sinclair, 2003). This step was achieved by employing the Erdas Imagine modeler tool to obtain water reflectance images for the three Bands (blue, green and red) as shown in figures 4a, 4b and 4c respectively.

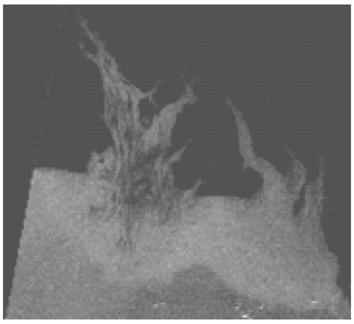

Fig. 4a: Water Reflectance Image of Blue Band

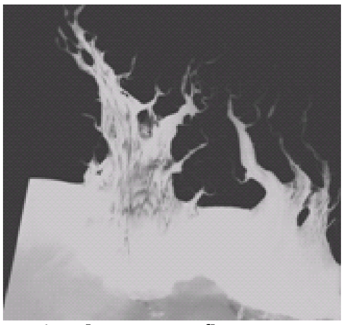

Fig. 4b: Water Reflectance Image of Green Band

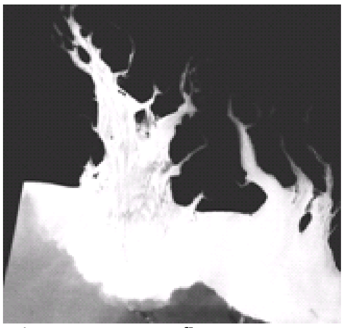

Fig. 4c: Water Reflectance Image of Red Band

Processing of Tidal Data and Sounded Data Reduction

In the absence of tidal information for the area, tabulated harmonic tidal constants for 29 constituents which include $\mathbf{M_2, S_2, K_1}$ **and** $\mathbf{O_1}$ were extracted from the Admiralty Manuals for Hydrographic Surveyors for this location. These constants were processed using University of Nigeria Tidal Analysis and Prediction Program (UNITAPP) to predict reduced water levels at chart datum for the years 2000 (image acquisition year) and 2011 (sounding operation year) respectively. Sounding operation for a section of the river was carried out between 11.50am - 12.40pm on September 22, 2011 using SDE 28 Echo Sounder, alongside Ashtech ProMark™ 3DGPS to fix the positions of the sounded depths. The result of the predicted water level (for the date of sounding operation) was used to reduce to the sounded depths to chart datum.

Extraction of Water Depths

Stumpf, Holderied and Sinclair's (2003) Ratio Model was used to estimate water depths from the image by employing the blue/green and blue/red ratios of image wavelengths. The model is given as:

$$z(depth) = m_1 \frac{\ln[nR_w(\lambda_i)]}{\ln[nR_w(\lambda_i)]} - m_0 \qquad (4)$$

Where m_1 = a tunable constant to scale the ratio to depth

n = a constant for all areas to ensure that the algorithm is positive under all circumstances

m_0 = offset for a depth of 0m

The first steps to determine bathymetry from the image was to determine relative bathymetry using natural log transform of the reflectance values below:

$$\frac{ln\ [1000 * R_W(\lambda_i)]}{ln\ [1000 * R_W(\lambda_j)]} \qquad (5)$$

Where, the water reflectance values were multiplied by 1000 (the value of n) to ensure that the logarithms remain positive for all reflectance values. This was followed by scaling the relative bathymetry to absolute bathymetry. Series of points from the Admiralty Nautical chart were extracted as in-situ data. These points were then regressed against the relative bathymetry values to obtain absolute bathymetry for the entire image. After the conversion to absolute bathymetry, the predicted water level value on December 10, 2000 was used to reduce the Landsat-7 ETM+ derived water depths to chart datum.

RESULTS AND DISCUSSION

The results of the Landsat-7 ETM+ derived bathymetric depths generated by employing the ratios of blue/green and blue/red wavelengths were good and acceptable as shown in figures 5 and 6. The Ratio Model could estimate water depths over variable bottom types (muddy and sandy) that were not classified. The depths of Cross River ranged within 0m – 14m. The derived bathymetry from the combination of blue/red wavelengths ratio, depicted the seabed topography of the entire area better when compared to the blue/green ratio. This is because the blue/red ratio captures depths more accurately in shallow water regions than the blue/green ratio. From the analyses, the coefficients of determination showed good correlation between the derived depths and extracted depths from the Admiralty Nautical Chart as well as sounded depths from the section where investigation was done. For the area where sounding investigation was carried out, Coefficient of Determination, R2 = 0.821, was achieved by regressing extracted image depths (generated from the blue/ red ratio) against sounded depths (Figure 7). It also yielded a standard error of 0.246m, root mean square (rms) error of 0.346 and percentage relative error of 11.44%.

Similarly, extracted image depths values from three Sections for 29 points were used in the evaluation with chart depths. These depths points were randomly selected ensuring that both shallow and deep areas were captured. The Coefficients of Determination, R2, of the image depths were 0.716 and 0.667 for blue/red and blue/green ratios respectively (Figure 8 and 9). Evaluation of the accuracy of the derived image depths (from blue/red ratio) in relation with the chart depths showed a standard error of 0.236m, root mean square (rms) error of 0.556, and percentage relative error 11.672%. Similarly, for the derived image depths from blue/green ratio, a standard error of 0.198m, root mean square (rms) error of 0.542, and relative percentage error of 11.167% were obtained.

The remote sensing approach adopted in this study has proved effective for depth extraction in shallow coastal water. It is thus considered an important tool being that the shallow characteristics of Cross River could have been a strong impediment to adequate accessibility of survey vessels during field data collection. The tidal constants provided in the Admiralty Tides Tables (2008), were used to predict tides and water levels for the reduction of sounded depths (2011) and derived image depths (2000) to chart datum. From the analyses, it was observed that the coefficient of determinations, R2, of the estimated image depths obtained from blue/red algorithm was 72%, while that of blue/green algorithm was 67%, when regressed against chart depths. This result was remarkable, based on the 29 depths points randomly selected from three cross sections on the nautical chart.

The rationale for these numbers of sample points was based on the fact that the seabed topography of the study area was relatively flat. A particular expanse of the seabed could have the same height value with slight differences in decimal values; hence, efforts were made to select varying depths values along the three cross sections. The results of the coefficient of determination signified that in the regression of image depths against chart depths, the numbers of variations from image depths obtained from blue/red ratio were more than those obtained from blue/green ratio. The reason for this stemmed from the fact that blue/red ratio captured more accurate depths information than blue/green ratio in the shallow areas. However, the accuracies of the derived image depths of (blue/red and blue/ green ratios) did not indicate much difference. For the blue/green derived image depths, the standard error was 0.198m, root mean square (rms) error of 0.542, and relative percentage error of 11.167%.

The blue/red derived image depths revealed a standard error of 0.236m, root mean square (rms) error of 0.556, and percentage relative error 11.672%. On the whole, it was believed that with increased number of sample points in the analyses, the accuracy of the derived bathymetry would have improved. This argument was also validated by Camacho (2006), who observes that in an environment with multiple bottom types and depths variations, the standard error is amplified with limited data. A comparison of the extracted and derived depths values with chart depths reveals that there were some over-estimated and under-estimated depths. This phenomenon could have been caused by noise or variable seabed within the study area, which must have been characterized by sandy and muddy substrates. Camacho (2006) also observes that sandy seabed produces higher reflectance values than other bottom types especially in very shallow water areas.

These high reflectance values caused the ratio model to overestimate the depth values. Bearing this in mind, it could justify why higher depths values were seen in the extracted image depths when compared to corresponding reduced chart depths. This proved the assertion by Stumpf, Holderied and Sinclair (2003) that the ratio algorithm is robust even when ground truth data about variable bottom types were unavailable. It also affirms the claim that the blue/green ratio algorithm mostly was not suitable for depths estimation in shallow areas where depths were less than 5m.

The specifications for minimum dynamic Under Keel Clearance (UKC) of 10% vessel's draft is allowable for approaches to ports in coastal shallow waters, 0.6m minimum UKC needed for berthing; while in open coastal waters, 20% of the draft should be maintained. From these specifications, it was safe to say that the accuracy of the estimated absolute bathymetric depths were reliable for navigational purposes, based on the analyses of the blue/green generated image depths and the blue/red generated image depths discussed above. From the foregoing, depending on the specification for vessel sizes, the errors associated with the derived bathymetric depths met and even exceeded these minimum standards for safe navigation of vessels through coastal waters. In addition, the application of the Ratio Model in remote sensing technique, to estimate bathymetric depths, was found to be a reliable tool to rapid monitoring of changes on the seabed topography of coastal waters.

The results further show that reliable depths estimates can be derived by using Stumpf's Model over unclassified variable bottom types of coastal waters because they compare favourably with those obtained in similar studies. For instance, Abdullah, MatJafri and Din (2000), in an attempt to employ satellite imagery of Landsat TM and SPOT as an aid to bathymetric charting of Strait of Penang, Malaysia, obtained root mean square errors of 4.7 and 6.5 using second-degree polynomial transformation equation for calibration and validation respectively. Minghelli-Roman *et al.* (2007), in validating the use of MeRIS image with 300m spatial resolution to map bathymetry of large areas of the Gulf of Lion in France, obtained a relative percentage error of 16% and rms error of 9.36 for depth range of 20m - 50m. In another comparative study by Pennucci, Grasso and Trees (2008), three methodologies - Lyzenga, Jupp and Stumpf's Models were employed on hyperspectral and multispectral imagery for bathymetry estimation. The results show that Stumpf's (Ratio) Model gave the best fit in terms of Coefficient of Determination, $R^2 = 0.869$, standard error = 0.99m and percentage relative error = 7.46% considering the complexities of the area, which was classified as a non-homogeneous environment.

Though the Ratio Method proved to be a sound technique to derive water depths in the coastal waters, there were still some possible limitations. One was that coastal waters are categorized as Case II waters; which are characterized by dissolved organic matter (DOM), suspended (particulate) material derived from river inputs, re-suspended bottom sediments, sewage-sludge dumping, and land drainage, particularly off estuaries, embayments, and shallow tidal seas (Robinson, 2004). The major effect of the Case II waters, as observed by Sipelgas *et al.* (2004), was that at short wavelengths regions of 440 - 550 nm, irradiance transmission for coastal waters were much less than oceanic waters. Therefore, the variations of the optical properties (loss of blue light traditionally) in coastal waters could cause reduction of the blue/green reflectance and subsequent introduction of error in the estimation of bathymetric depths. This effect must have apparently influenced the result of blue/green algorithm as seen in Figure 5.1, since the water column properties were not taken into consideration. Howbeit, the effects of coastal waters characteristics on the estimation of bathymetric depths of the coastal/estuarine shallow waters have not yet been empirically proven. Hence, it is thus a research area for further studies. Worthy of mentioning here is the cost and time required for bathymetric depth derivation with spectral imagery. Also, despite the fact that the algorithm basically employed satellite imagery, field measured bathymetric depths were pre-requisites for the scaling of the relative bathymetry to absolute values. Therefore, ground-truth exercise remains an important element of remote sensing analyses. In actual fact, it requires proper planning to carry out the ground-truth measurement considering the cost implications, safety and security. The peculiarity of the study area located in the volatile Niger Delta region and also being part of territorial water was an issue of concern. Hence, security assistance was obtained from the Nigerian Navy, Forward Operating Base, Ibaka in Mbo Local government Area of Akwa Ibom State, Nigeria to enable ground-truth measurements. On the whole, the overall cost of deriving bathymetric depths with remote sensing approach is far more economical and effective than the ship-based sonar method in terms of field operations, time, cost, equipment, and personnel.

CONCLUSION AND RECOMMENDATIONS

The possible influence of Case II waters, generalization of depths by 30x30m pixel values, and variable bottom types were the factors of concern. These may have had some effects on the accuracy of the derived bathymetric depths. Howbeit, it is important to note that the depths values produced in this research are good indicators of the actual bathymetry of Cross River, but further research is needed for validation purposes. A derived Landsat-7 ETM+ bathymetry of Cross River was generated using Stumpf's Ratio Model. The strength of this Model to estimate bathymetric depths of coastal shallow waters with limited ground-truth depths, over unclassified variable bottom types was also validated. The ratio of blue/red wavelength employed in the model produced better depths values compared to the depths derived from the ratio of blue/green wavelength. Analyses of the results of the derived image depths revealed that the remote sensing technique was a dependable tool for rapid estimation of water depths. Thus, it is suitable for monitoring of possible changes on the seabed topography of near shore shallow waters using Landsat-7 ETM+ satellite image set.

i It is pertinent for a National Hydrographic Office (NHO) to be made functional in the country so that comprehensive bathymetry of in-land and coastal waters could be obtained for the up-dating of the navigational charts. Frequent updates of the navigational charts and availability of the charts electronically will be a great asset to users and navigators.

ii To effectively harness the marine environment to boost economic developments, agricultural growth, tourism, and marine transportation, etc, there must be adequate and available up-to-date information. Such information include, tidal heights and range (electronically), water currents, water compositions, sedimentations, the nature and stability of the seabed, height of swells, atmospheric pressure, changes in the density of sea and inland waters, seabed soaring, etc. These data could be acquired for the creation of an efficient database for proper management if the NHO is made functional.

iii Functional tidal stations should be established on the in-land and coastal rivers of the country to generate tidal data for the management and monitoring of the marine environment. In recent years, rise in sea levels have constituted enormous dangers to the marine and coastal environments in Nigeria. Thus, it is very essential that continuous and accurate data about marine environment needs to be generated. This will also encourage regular researches/studies on this environment so as to avert possible dangers that are associated with it.

iv It is imperative to note that the high resolution multispectral NigeriaSat-2 satellite imagery with similar wavelengths ranges to multispectral Quickbird satellite imagery, is very suitable for the mapping and charting of the in-land and coastal waters to produce reliable up-to-date navigational charts for Nigeria. NigeriaSat-2, an Earth Observation Satellite (EOS), with very high resolution of 2.5m and 5m ground sample distance (GSD) was designed to boost scientific researches in Nigeria. In addition to other functions, this system was built to support the NGDI (National Geospatial Data Infrastructure) project. Its wavelengths for the four multispectral bands (blue, green, red and NIR) are as shown below.

Table 1: Multispectral Bands of NigeriaSat-2

Band	Wavelength Range	Colour
1	450 nm ± 10 nm to 520 nm ± 10 nm	Blue
2	520 nm ± 10 nm to 600 nm ± 10 nm	Green
3	630 nm ± 10 nm to 690 nm ± 10 nm	Red
4	760 nm ± 10 nm to 900 nm ± 10 nm	Infra red

The applications of NigeriaSat-2 included mapping, water resources management, agricultural land use, population estimation, health hazard monitoring, disaster mitigation and management. Having seen the specifications and expected applications of the Nigeriasat-2 system, it is worthy of note to point out that the National Space Research and Development (NASRDA) should provide assistance for researchers, to develop application software for the use of these images. This would enhance the mapping and charting of the in-land and coastal waters, in order to produce up-to-date navigational charts for the country. Obviously, the tool will certainly provide an alternative approach that is easier and cheaper to obtain bathymetric depths when compared with the conventional ship-based sonar methods. Government is therefore urged to explore this technique to obtain bathymetric depths of the extensive in-land and coastal shallow waters that are uncharted and un-updated.

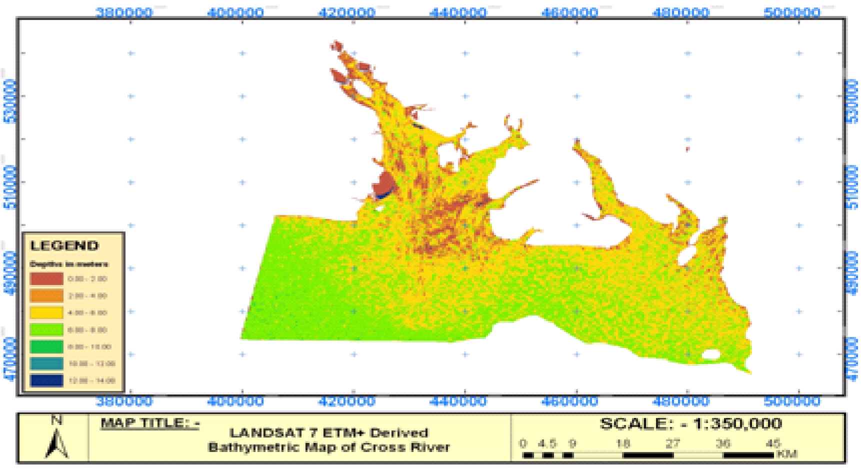

Figure 7: Landsat-7 ETM+ Depths Coloured Chart of Cross River using Blue/Green Ratio

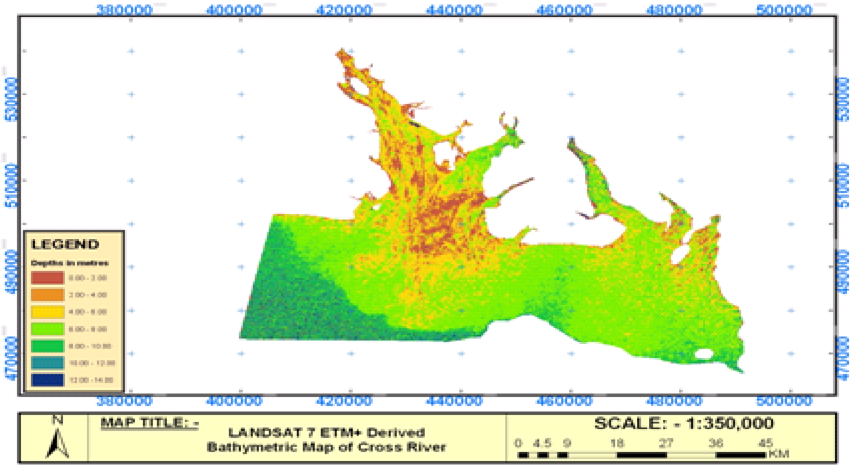

Figure 8: Landsat 7 ETM+ Depths Coloured Chart of Cross River using Blue/Red Ratio

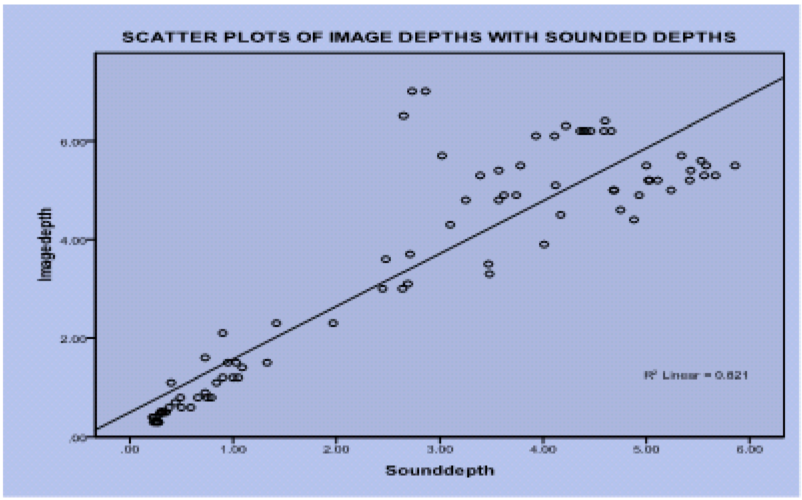

Figure 9: Derived Image Depth and Sounded Depth Correlation using Blue/red ratio

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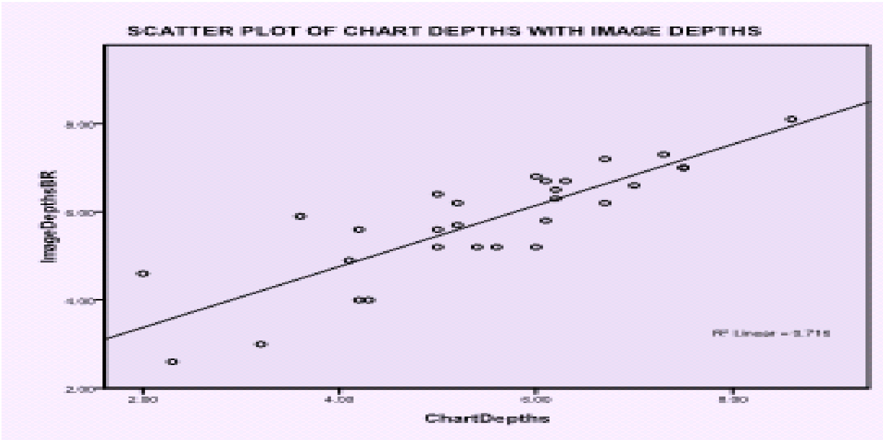

Figure 10: Scatter Plot of Chart Depths with Image Depths generated from Blue/Red ratio

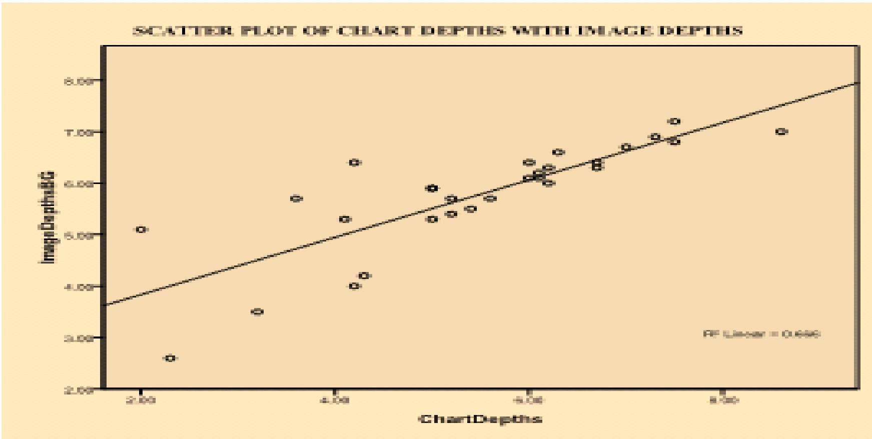

Figure 11: Scatter Plot of Chart Depths with Image Depths generated from Blue/Green ratio

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