Journal of Geosciences and Geomatics, 2020, Vol. 8, No. 1, 25-34
Available online at http://pubs.sciepub.com/jgg/8/1/4
Published by Science and Education Publishing
DOI:10.12691/jgg-8-1-4

Navigational Hazard Analysis of Part of Bonny River, Rivers State Nigeria

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Received February 16, 2020; Revised March 18, 2020; Accepted March 25, 2020

Abstract Bonny River is arguably the most important river in Rivers State because it registers per season high volume of vessel traffic compared to other rivers in the state and also has infrastructures, major cities, companies and institutions along its banks. This high vessel traffic on the channel comes with mishaps that can render a once navigable channel unsafe which can lead to loss of property, resources, life and cause environmental pollution. This research sought to provide analysis of navigational hazards on about 15Km of the study area using a positioning device and some acoustic sensors. It yielded the following findings. The upstream end of the research area had a depth range of 1.5m to 15.1m and its navigable channel with depth range of 3.2m to 15.1m while the Port Harcourt Wharf axes about 12Km farther downstream had a range of 0.1m to 18.7m and its navigable channel with depth range of 10.1m to 18.7m. The maximum depth being downstream was 18.7m. The upstream area was noticed to have the presence of all wrecks (visible and submerged) in the study area. The percentage space occupied by the wrecks (partly submerged and completely submerged) in relation to the entire research space was less than one percent. Although the magnetometer detected several isolated ferrous presence, the side scan sonar representation of the riverbed suggest the ferrous presence are all buried debris. These findings upstream suggests the need for maintenance of the section.

Keywords: *bathymetry, hydrography, navigation, seabed profile, wreck*

Cite This Article: D. M. J. Fubara, Lawrence Hart, and Golden Ibinabo Otasanya, "Navigational Hazard Analysis of Part of Bonny River, Rivers State Nigeria." *Journal of Geosciences and Geomatics*, vol. 8, no. 1 (2020): 25-34. doi: 10.12691/jgg-8-1-4.

1. Introduction

There has always being the need to convey, in large quantities, goods and supplies from source location to customers or end users. The marine transport system arguably happens to be the main avenue of transporting this in huge quantity. The entire expense of waterbody is always not navigable as unseen debris could be lurking beneath water surface [7], hence the need to have knowledge of parts in the wide expense of water that will aid safe navigation.

The term navigation stems from Latin *(navigationem)* and was coined from Latin words *navis* meaning "ship", and *agere* meaning "to drive" (Wikipedia accessed: 20191025). The term was thus solely for marine travel, however, it is now used in air, land, marine, and space travels. Navigation is attentively and consciously controlling, ordering and monitoring the movement of a vessel, craft, barge or any object from a point to another over a predetermined route.

Hazard is a behaviour, object or situation that has the latency of causing damage, ill health, or injury to persons, to property or to the environment (Oxford Dictionary).

Bonny River, the subject of discuss has along its banks important towns and organisations as the loading and turning basin of the Nigeria Liquefied Natural Gas (NLNG) Limited, the bay of Federal Light and Ocean Terminals (FLT & FOT), Port-Harcourt Wharf, Saipem Contracting Limited and Aveon Offshore Limited quayside amongst other companies. This makes Bonny River one of the most important shipping route into Rivers State, Nigeria. As a requirement of the International Hydrographic Organisation (IHO), study to ensure it is safe for navigation [9] is required. The river forms part of the delta section of the River Niger. As shown in the tidal prediction tables the river is a semi diurnal tidal river, (two alternating crests (High Water (HW)) and troughs (Low Water (LW)) within 24 hours cycle [11]). The river is characterized with bends and turns, a typical character of a river at its final phase [1], and has on most of its banks mangrove vegetation cover. The river is heavily used for servicing the oil and gas mining industry located offshore the coast of Nigeria. Also on this river is one of the Nigerian Naval Docks.

With regular activities such as fishing and transportation of people and goods along the river comes mishaps. There is need to monitor the changes that may occur as a result of these activities or mishaps that can impede safe navigation and passage of ships and loaded barges of varying sizes. This brings about the need for an activity that will periodically analyse hazards such as shallow sections, vegetation out-growth, protrusions and debris on the seabed or water surface and with these findings create charts that will enhance safe navigation through the river.

1.1. Aim of the Study

The aim of this research was to analysis the navigational hazards associated along part of Bonny River.

Consequently the objectives of this research are:

1. To produce a bathymetric terrain profile and smooth sheets of the study area using the obtained bathymetry information of the channel of approximately 15Km (Starting from Aveon Offshore LTD Quayside).
2. To determine the position of detected debris from the deployed sensors.
3. To analyse feature characteristic such as dimension, nature (ferrous or non-ferrous), and if identified (ferrous) debris are exposed or buried beneath the riverbed as obtained with the aid of the Sonar Imaging (from the Side Scan Sonar) and Magnetometry with respect to the position stamp from the navigation software and incorporate in smooth sheets in Objective 1.

1.2. Study Area

The Study area location lies within the Geographic location: Latitude 04̊25’48” to 04˚47’34” North and Longitude 06̊56’23” to 07˚13’59” East in Rivers State, Nigeria.

The researched segment of the river course is shown in Figure 3. The research segment has a length of approximately 15Km and it starts from the quayside of Aveon Offshore Limited (Upstream end of Bonny River) in Rumuolumeni, Port Harcourt, Rivers State, Nigeria.

Figure 1. Rivers State as Located in Nigeria (Source: [6])

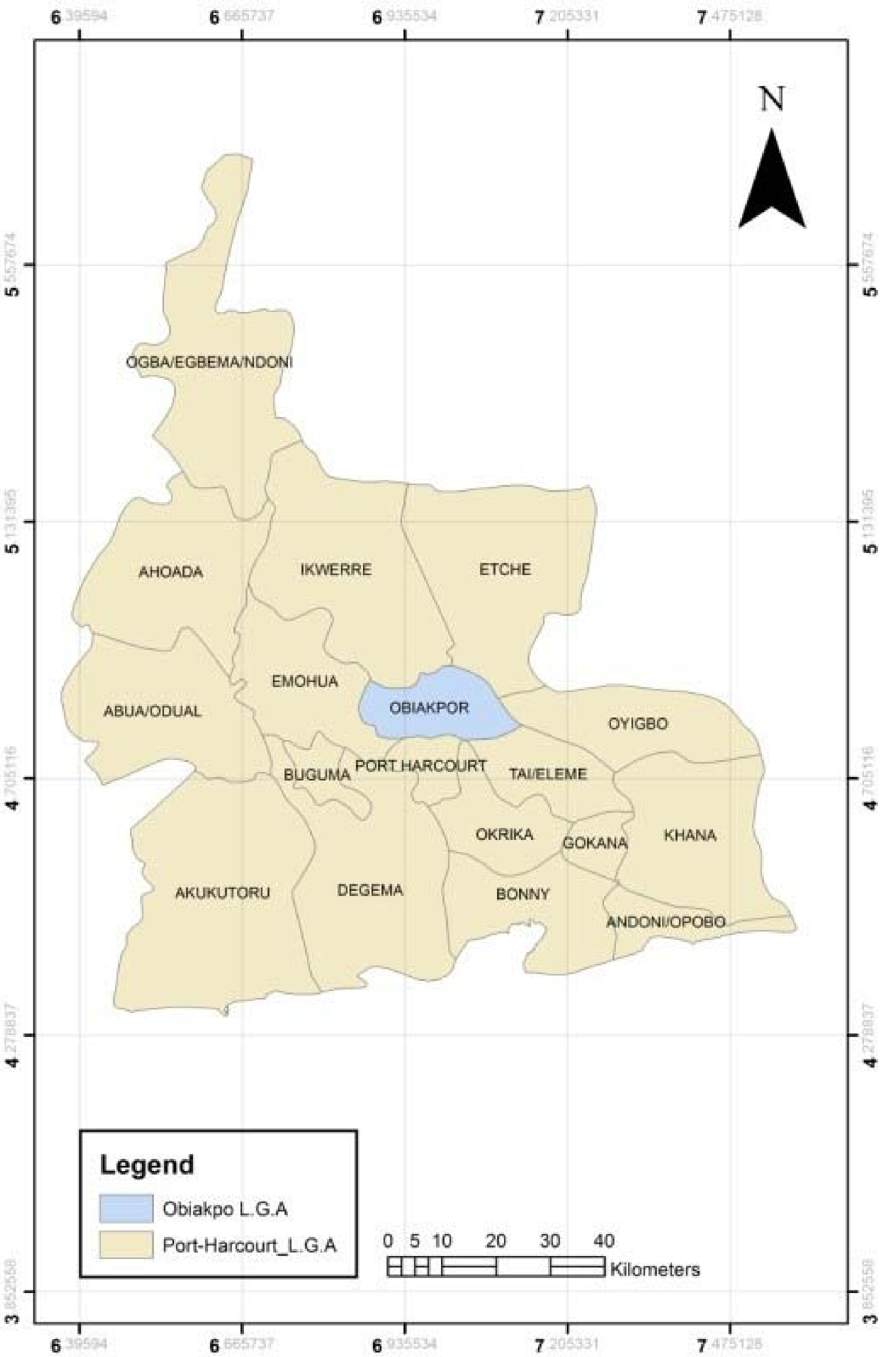

Figure 2. Rivers State (Source: [6])

The course of the researched segment of the river is along the geographical coordinates in Table 1.

Table 1. Geographical Coordinates of Research Route along Bonny River

S/N	Location	Latitude (North)	Longitude (East)
1	Start (AVEON)	04° 47’ 27.42”	006° 56’ 30.66”
2	Point A	04° 46’ 22.08”	006° 56’ 59.16”
3	Point B	04° 46’ 30.00”	006° 57’ 24.60”
4	Saipem Environ	04° 46’ 13.74”	006° 57’ 53.88”
5	Point C	04° 45’ 20.82”	006° 57’ 45.24”
6	Point D	04° 45’ 24.06”	006° 58’ 30.48”
7	PH Wharf Environ	04° 46’ 26.22	007° 00’ 26.94”
8	End location	04° 45’ 42.60”	007° 00’ 13.86”

Source: Author’s field work.

Figure 3. Imagery Showing Study Area (Source: Adapted Landsat Imagery 2019)

1.3. Materials & Method

The methods adopted for data acquisition include Global Navigation Satellite System (GNSS) for surface positioning, acoustic system of seabed interrogation, and marine magnetic variation monitoring.

The system (the GNSS) uses the trilateration method to determine positions on the earth surface. This system, which the DGPS (Differential Global Positioning System) is a part of, monitors: satellite clock error, orbit perturbation, the microwave trip through the different layers of the atmosphere and other factors that have effect on the microwave signal from the satellite. These errors, except the satellite clock error, are variables errors [10].

The acoustic system of seabed interrogation is a method which uses the propagation of pulse (sound) in water. The method uses the knowledge of the speed of sound in water. The two-way travel time (to the seabed and back to the source (transducer)) is recorded and with the knowledge of speed of sound in water, the depth or firm surface can be deduced [11].

The equipment and hardware used for the study include: DGPS receiver (C-Nav 3050) for surface positioning, Meridian Gyro compass for bearing determination, Odom Echotrac CVM (Topside and Transducer) for bathymetry determination, Motion Sensor (TSS Motion Sensor), Tide Gauge (Valeport TideMaster) for tide determination, Side Scan Sonar (EdgeTech 4125) for acoustic riverbed imaging, Magnetometer (Geometric G882 Cesium Magnetometer) for environ magnetic variation monitoring and a Passport-19 boat (MV Emiso) as the survey vessel.

The software include: EIVA NaviPac, MagLog lite for the magnetometer, Seanet Pro for the Side Scan Sonar (SSS), Notepad, Microsoft Excel/Word, TideCalc, SonarWiz, Micro Station, then Surfer (surface modelling software) and AutoCAD

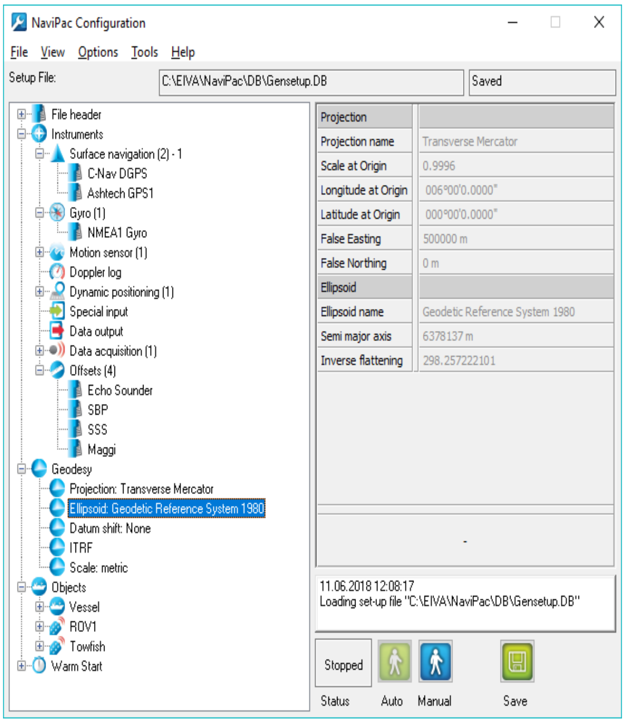

Figure 4. EIVA NaviPac Configuration & Launch Page (Source: BSNL (Batoil Services Nigeria Limited) 2018)

The EIVA NaviPac Integrated Navigation Software was used to aid data acquisition. This software with its configuration page display in Figure 4 is designed to accept raw data such as data from the DGPS receiver and bearing from the gyro. It displays a visual representation of the real time orientation and position of the dynamic object on its helmsman display. Once the appropriate inputted layback and offset (see Table 2) of the primary objects (sensors deployed during the study such as: SSS, and magnetometer tow-fishes, Echo-sounder transducer) is made, the software computes their corresponding positions. The software can serve as digital storage device for all position data, the logged bathymetry and, with a special dongle, various sensors' data. It can also be used to transmit position data to other equipment.

Table 2. Sensor Offsets on MV EMISO

Objects	Athwart X (m)	Along Y (m)
CRP (Mid-Stern)	0.00	0.00
Motion Sensor	0.00	4.00
Echo Sounder	0.95	5.00
Parametric Sub-Bottom Profiler	-0.95	5.00
DGPS Antenna	-0.90	3.50
Side Scan Sonar (Cable-Out)	0.95	-7.2 (-8.00)
Magnetometer (Cable-Out)	-0.95	-14.3 (-15.00)

Source: Author's Field work.

Vessel CRP (Common Reference Point) and Offsets

The mid-stern position of the vessel was defined as the Common Reference Point (CRP) from which all offsets were defined. The vessel (dynamic object) must be describe in shape and size numerically (the CRP being the origin (0,0) of the shape in a Cartesian graph system) with a notepad file with .shp to specify it is a shape file to help the navigation software recognise the object.

Using these objects in the navigation system, position details are generated using their corresponding **layback** (for towed sensors) and outputted to appropriate sensor topsides through the serial adapter.

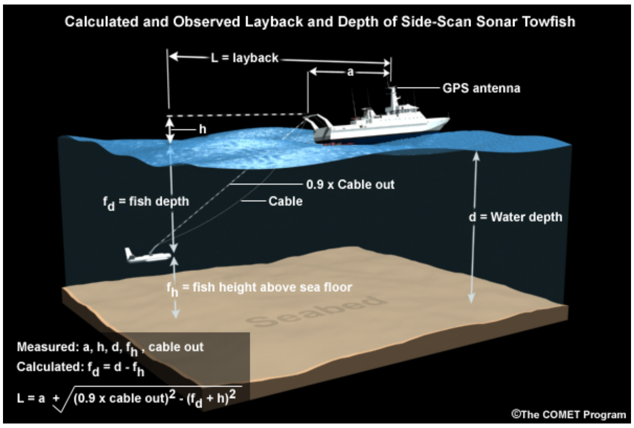

Figure 5. Tow-fish Layback Calculation (Source: [12])

Layback (a function of the vessel CRP (Common Reference Point) and located on the Along Axis (y)) can be computed using a modified form of the Pythagoras Theorem (as seen in Figure 5) for towed sensors by adopting the formulae:

$$a^2 + b^2 = c^2 \tag{1}$$

Thus,

$$a = \sqrt{(c^2 - b^2)} \quad (2)$$

So

$$True\ (y) = \sqrt{((0.9 \times \text{Cable} - \text{Out})^2 - (\text{f}_\text{d} + \text{h})^2)} \quad (3)$$

Where,
$True\ (y)$ = The Along Axis input to Navigation Computer
$\text{Cable} - \text{Out}$ = Along Axis Value as seen in Table 2 above
f_d = The Flying Height of the Tow-Fish, and
h = The Height of the Vessel Deck or Rail above the Sea Surface

The tow-fishes are tied to drag effects while the other acoustic sensors (side-mounted) tied to the gyro to aid position determination on the navigation software.

During the setting-up phase, instrument offset position referenced to the CRP is made. With the various deployed instrument offsets (listed in Table 2), the corresponding positions are computed by EIVA (NaviPac) software from the DGPS receiver combined with the bearing using the traditional Eastings and Northings computation formula:

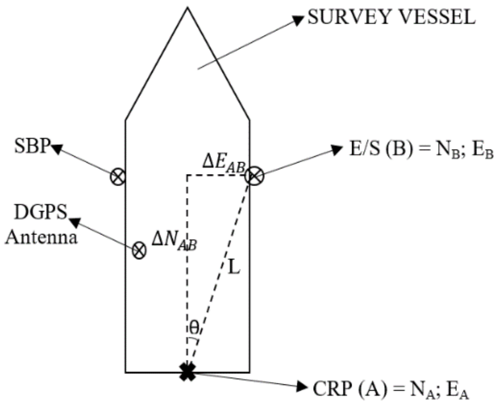

Figure 6. Offset Coordinate Generation from CRP

Note in Figure 6 that;

$$Latitude, \Delta N_{AB} = L \cos \theta \quad (4)$$

$$Departure, \Delta E_{AB} = L \sin \theta \quad (5)$$

While;

$$N_B = N_A + \Delta N_{AB} \quad (6)$$

$$E_B = E_A + \Delta E_{AB} \quad (7)$$

Where;
N_A = Northing coordinate at CRP (A),
E_A = Easting coordinate at CRP (A)
N_B = Northing coordinate at E/S (B),
E_B = Easting coordinate at E/S (B)
ΔN_{AB} = Change in Northing between A and B
ΔE_{AB} = Change in Easting between A and B.

As the boat sails, the navigation software with the aid of the DGPS and gyro compass data in reference to the CRP (flexibility of the software allows for the CRP and DGPS Antenna to be different), continually generate offset positions of the required reference points using Eq. (4) and Eq. (5).

The towed sensors however uses instead of the gyro aided positioning, the computed ***layback*** (see Figure 5 and a simulated drag effect as modelled by the software to continually generate their positions.

2. Results & Discussion

The data analysis and results obtained were produced from a combination of SonarWiz, TideCalc, Notepad, Microsoft Excel/Word, Micro Station, then Surfer (surface modelling software) and AutoCAD Software were used for processing, analysing and result presentation. Survey navigation data was downloaded from back-up disks created from the on-line survey computers (navigation computer) and then assembled into working batches and acquisition sub-directories.

2.1. Bathymetry Information

On reduction of the bathymetric data (removal of tidal effect from obtained bathymetry), a range with value of 0.1m to 18.7m was detected in the research area. The deepest being at the Port Harcourt Wharf axis and the shallowest at about 1.5Km after the Port Harcourt Wharf.

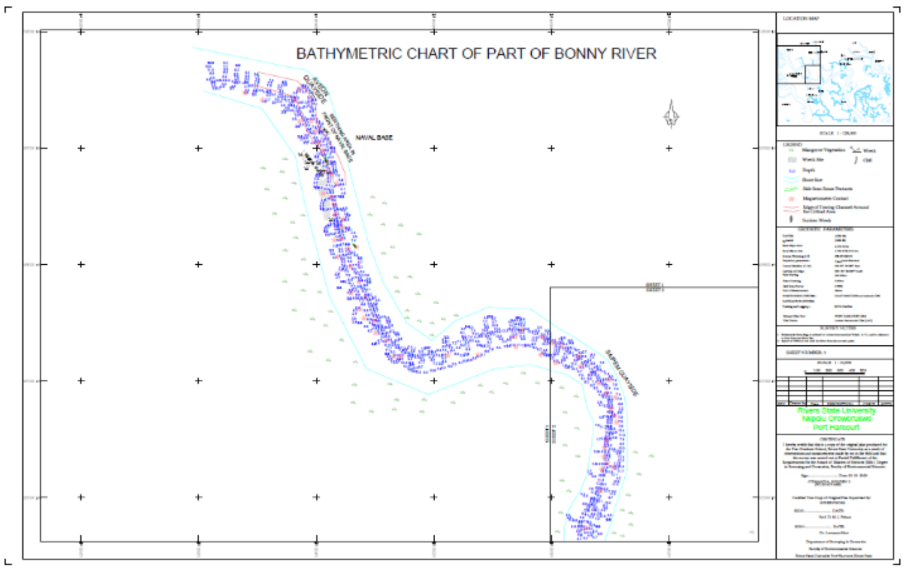

Figure 7. Bathymetric Chart of Part of Bonny River- Sheet 1

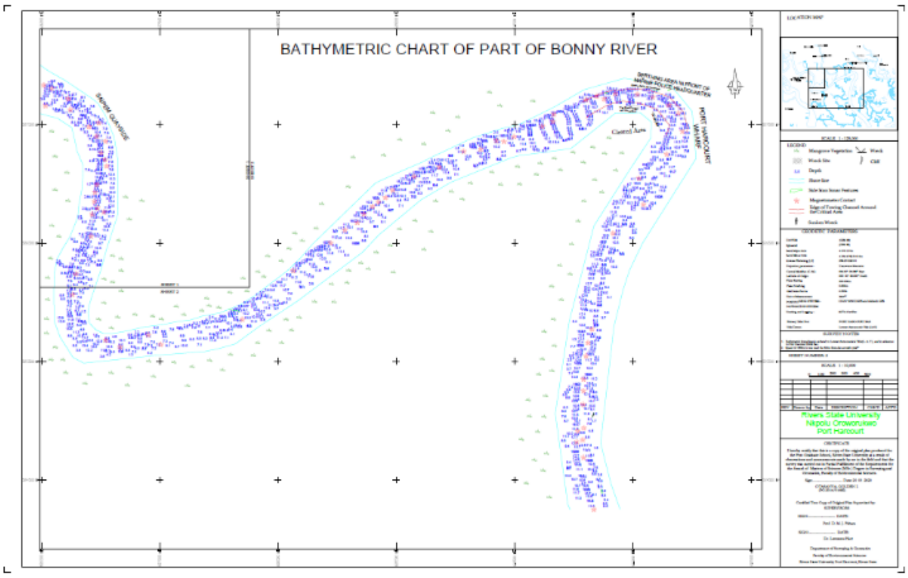

Figure 8. Bathymetric Chart of Part of Bonny River- Sheet 2

The research site as seen in Figure 7 & Figure 8 has a total area of approximately 6,252,795m^2, and a perimeter of 35,330m.

2.2. Sonar Imagery Processing

Factors required to determine the height (z Component) of a debris protruding higher than the natural seabed as illustrated in Figure 9.

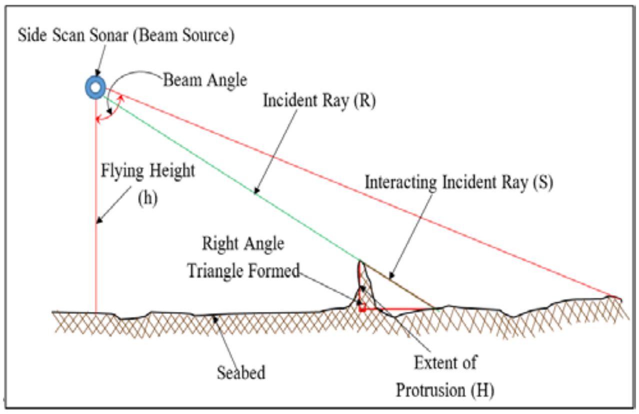

Figure 9. Geometry that aids Generation of z Component from 2-D Sonar Imagery

From Figure 9, the shadow cast of the debris, the interacting incident ray and the extent of the protrusion of the debris constitutes a right-angled triangle. This right-angled triangle forms a Similar Triangle with the sensor flying height, incident ray and an arbitrary seabed.

Thus in Figure 9,

$$H = \frac{S \times h}{S + R}, \tag{8}$$

Embedded in the SonarWiz software are these triangle theorems that use the existing information stamp from the each ping (SSS beam) and its characteristics with the user input (shadow cast length) to compute the height of each identified debris.

2.2.1. Debris Details

The study of the side scan imagery using SonarWiz provided findings which were highlighted in Table 5, Table 6 and part of Table 7 in Section 2.4.

Partly submerged debris (see Figure 10) made navigation during the research difficult and made analysis patchy as was the case with the first image seen in Figure 10.

Figure 10. Sunken Wrecks in the Naval Yard Environ (Source: BSNL 2018)

2.3. Magnetic Contact Processing

Flag are created manually and help identify ferrous present in a water environment. The flags are generated in real-time (while acquiring data on field), however for quality assurance and control, each survey file is played back with the Geometric MagLog software and fresh set of flag, having different identity numbers are generated and these compared to the real-time flags. Position of Ferrous Debris

The individual magnetic interference was spread-out over the research area. Some of these interference were consistent with some debris notice on the side scan sonar imagery. The position of ferrous debris within the research area are on the spread as seen on Table 4.

Table 3. Coordinates of Some Magnetic Spike

S/N	Easting (mE)	Northing (mN)
1	603894.12	529979.56
2	604043.20	529912.79
3	604323.84	529910.60
4	604356.72	530000.36
5	604358.92	529733.26
6	604457.58	529733.26
7	604525.76	529546.26
8	604554.27	529480.58
9	604598.12	529378.78
10	604562.31	529299.29

The magnetic contact registered within the research area was without a pattern, but was spread all through the research area.

2.4. Discussion

Figure 7 and Figure 8 which are the result from the bathymetric data acquisition, satisfied Objective 1, and infers that the upstream end of the research area had a depth range of 1.5m to 15.1m and its observed navigable corridor of at least 115m width with depth range of 3.2m to 15.1m while the Port Harcourt Wharf axes which is downstream had a range of minimum value of 0.1m to a maximum value of 18.7m and its observed navigable corridor with width between approximately 125m to 150m with depth range of 7.6m to 18.7m. Farther downstream the observed navigable corridor of about 75m wide also had a depth ranging from 6.1m to 14.6m. This indicates that the downstream and the Port Harcourt Wharf environ had its observed channel width at 75m to 100m and depth of 6.1m to 18.7m. The wharf observed channel area having a minimum width of 100m and depth range of 7.6m to 18.7m. The maximum depth at the Lagos Port is 24.0m [5] as compared to that of Port Harcourt will still have a good vessel hull clearance for berthing or sailing vessels for some vessels.

Column 2 (Aveon Quayside) in Table 4 implies that a vessel with keel of 3.2m is not safe to navigate this waters. So also, although Column 3 (Saipem Quayside) had a minimum channel depth of 5.3m, Column 4 with depth of 5.1m will restrict the safety of vessel with hull beyond 5m approaching the Saipem Quayside environs. This also affects the Port Harcourt Wharf axes as the downstream area of the research site has a minimum depth of 6.1m in the observed channel compared to 7.6m registered at the Port Harcourt Wharf environ. Table 5 below shows bathymetric on and around identified sonar images and dimensional details of the objects identified by the SSS (Side Scan Sonar).

The bathymetry analysis state indicates the need for maintenance dredging in the research area with more attention at the Aveon Quayside axes of the research area.

The north-western part of Figure 11 reveals a section with its colour code indicates an area with shallow depth. The left side of the profile also buttress the state of the north-western part of the research segment.

Aside the charts seen in Figure 7 and Figure 8, Figure 11 is also an analyses of the reduced bathymetry of the studied area. Figure 11 further showed the elevation profile of the entire stretch of the research area.

The processed sonar findings indicated well over 90% undisturbed seabed as the absence of seabed scar or drags were noticed through the research area. Scars and drags are as a result of ship deploying their anchor for midstream berthing.

Sonar interaction on processing and analysing showed features of interest that can hamper safe navigation exists (two completely submerged and others partly submerged) upstream at the Aveon axes of the research site. Downstream, almost 1.5Km after the Port Harcourt Wharf the sonar imagery showed an underwater cliff-like formation (a sudden steep depression) which can hamper safe navigation or berthing of ship.

Table 4. Analysis of Depth and Wreck Distribution in Research Site

S/N	Section of River	Water Depth Range (m)	Channel Depth Range (m)	Channel Width (m)	No of Wrecks (Buried)
1	Aveon Quayside	1.5-15.1	3.2-15.1	140	10 (2)
2	Saipem Quayside	1.2-14.4	5.3-14.4	140	Nil
3	After Bend	0.4-15.7	5.1-15.7	150	Nil
4	Port Harcourt Wharf	2.0-18.7	7.6-18.7	130-160	Nil
5	Downstream	0.1-14.6	6.1-14.6	210	Nil

Table 5. Nature and Dimension of SSS Imagery with Water depth Information

S/N	Coordinate		Feature Description	Dimension (m) Length×Width×Height (L×W×H)	Average Water Depth (m)	Depth over Debris (m)
	Northing (m)	Eastings (m)				
1	529420.28	604563.89	Ferrous Debris	63.73×17.13×4.10	9.53	6.10
2	528649.87	604839.13	Ferrous Debris	49.85×12.73×3.04	7.35	Nil
3	525939.51	608082.05	Ridge	89.14×3.80×1.65	9.80	9.80
4	525048.70	611164.13	Depression	36.15×1.26×4.46	9.37	4.20
5	527760.28	611274.58	Debris	49.62×Nil× Nil	11.57	10.40
6	527781.61	611716.06	Pile Formation	22.34×9.03×5.26	13.00	13.00
7	527791.84	611796.20	Debris	18.34×3.32× Nil	11.80	Nil
8	524401.90	611234.38	Debris	32.22×13.54×1.12	5.85	5.60

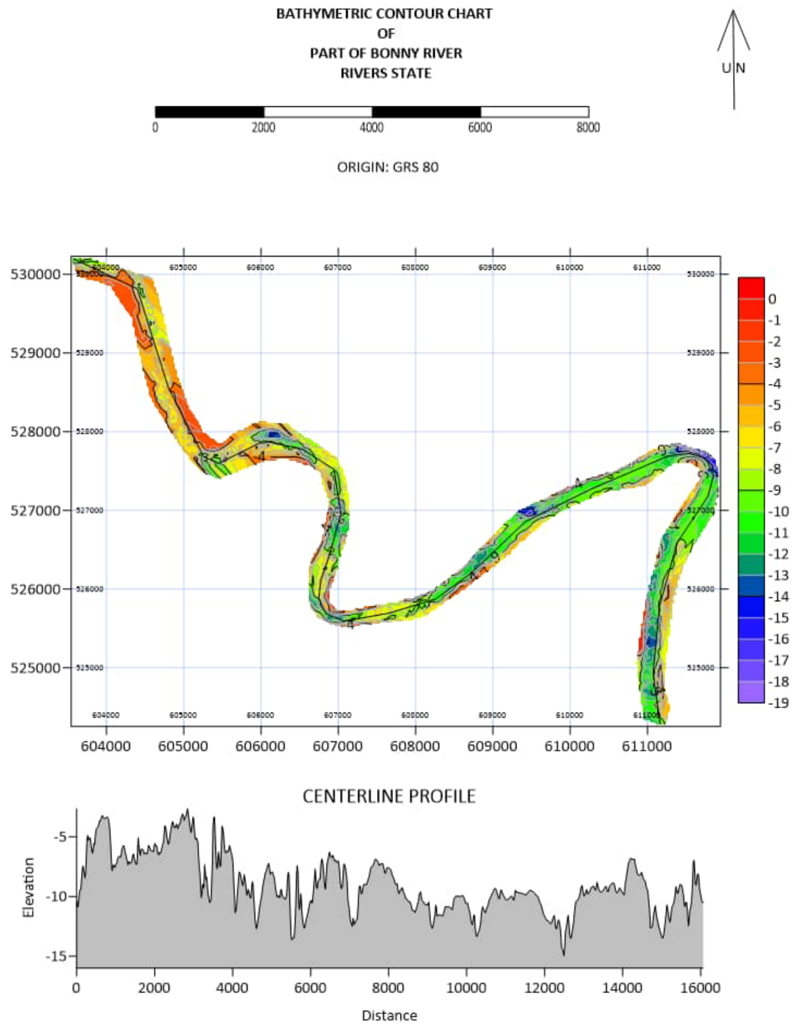

Figure 11. Bathymetric Contour Chart and Profile of Bonny River

Table 6. Coordinates of Sonar Contacts in Research Site

S/N	Northings (m)	Eastings (m)	Length (m)	Width (m)	Height (m)	Observed Feature
1	529420.28	604563.89	63.73	17.13	4.10	Debris
2	528649.87	604839.13	49.85	12.73	3.04	Debris
3	525939.51	608082.05	89.14	3.80	1.65	Ridge
4	525048.70	611164.13	36.15	1.26	4.46	Depression
5	527760.28	611274.58	40.64	0.62	1.51	Formation 1
6	527781.61	611716.06	Nil	Nil	Nil	Formation 2
7	527791.84	611796.20	18.34	3.32	Nil	Debris
8	524401.90	611234.38	32.33	13.54	1.12	Debris

Table 7. Wrecks Analysed

S/N	Northings (m)	Eastings (m)	Length (m)	Width (m)	Height (m)	Debris Status	Ferrous Fix off Debris (m)
1	529420.28	604563.89	63.73	17.13	4.10	Submerged	0.00
2	528649.87	604839.13	49.85	12.73	3.04	Submerged	0.00
3	529447.67	604363.47	60.00	15.00	Nil	Part Submerged	Nil
4	529327.62	604412.39	65.00	Nil	Nil	Part Submerged	Nil
5	529290.41	604596.98	55.00	15.00	Nil	Part Submerged	Nil
6	529375.76	604513.14	30.00	Nil	Nil	Part Submerged	Nil
7	529413.84	604436.23	Nil	Nil	Nil	Part Submerged	Nil
8	529309.70	604550.57	Nil	Nil	Nil	Part Submerged	Nil
9	529382.26	604422.62	Nil	Nil	Nil	Part Submerged	Nil
10	528892.97	604622.33	Nil	20.00	Nil	Part Submerged	Nil

Table 6 was extracted from SonarWiz software and it shows spatial and other attribute of the riverbed features sported during the data acquisition of the research. This showed eight features.

As tabulated in Table 7 which satisfies the Objective 3, there are at least 8 partly submerged and at least 2 debris (wrecks) detected by the acoustic sensor. The 8 partly submerged wrecks occupy an approximate area and perimeter of 51,428m^2 and 1.50Km respectively at the upstream area while the 2 debris occupy an approximate area and perimeter of 1,298m^2 and 0.167Km and 654m^2 and 0.127Km each. The research site has an area of 6,252,795m^2 while the summation of the area of debris (wrecks) and wreck dump had an area of 53,381m^2. This indicates that all wreck in the research site constitute 0.85% (less than 1%) of the research area. This imply that the study area is not free of hazards.

There also appeared to be presence of ferrous debris scattered along the research site. The pattern of its distribution with no particular consistency in formation suggested the absence of an infrastructure as a pipeline crossing the research area.

The nature of the seabed as revealed by the side scan sonar and the combination of the magnetometer contact suggested the several ferrous contacts detected by the sensor are buried beneath the riverbed.

3. Conclusion and Recommendation

3.1. Conclusion

The Aveon/Saipem axes (the upstream end) of the research area had a depth range of 1.5m to 15.1m and its navigable channel with depth range of 3.2m to 15.1m while the Port Harcourt Wharf axes which is farther downstream had a range of minimum value of 0.1m to a maximum value of 18.7m and its navigable channel with depth range of 7.6m to 18.7m.

Sonar interaction was made all through the research area, however on processing and analysing, the features of interest that can hamper safe navigation mainly were found (two completely submerged and others partly submerged) upstream at the Aveon axes of the research site. Notwithstanding, almost 1.5Km after the Port Harcourt Wharf (downstream) the sonar imagery showed an underwater cliff-like formation (a sudden steep depression) which can hamper safe navigation or berthing of ship.

There appeared to be presence of ferrous debris scattered along the research site with no particular consistency in formation that could be likened to an infrastructure as a pipeline crossing the research area.

3.2. Recommendation

The bathymetric findings could be referred to as a maiden epoch for further research to aid the production of a sediment transportation model to further understand and have a maintenance schedule plan for the research area.

Furthermore, the bathymetric findings of this research also shows the critical need for a maintenance dredging exercise. If this is considered, the authorities can decide to put other port in the country to considerable use like the Lagos Port which has a maximum depth of 24.0m [5].

There is also the need for the installation of fairway buoys along this axes of the channel of Bonny River.

The tidal findings showed a difference between the Aveon Quayside and the Port Harcourt Bar to be 0.7m (Only a 24 Hour observation). Further study of the upstream section of the research area can be further made to understand the tidal dynamics of the section of the research site to aid tidal predictions of this segment.

Further studies of the wreck dump to ascertain whether or not salvaging the wrecks at the upstream section of the research area should be executed to enhance and further improve the navigability at the upstream end of the research area which had a range of 3.2m to 15.1m as compared to Port Harcourt Wharf axes which was found to have a maximum depth of 18.7m or the Lagos Port with a maximum depth of 24.0m [5].

Further studies of the research site to evaluate the magnitude of the numerous ferrous debris so as to aid a successful maintenance activity that is needed on the river section.

Navigational hazards in this research focused on the river depth and topography in addition to the presence of wrecks and some debris that could have the potential of impeding safe navigation. An aspect that could obstruct inter-visibility at bend (meander), shrub outgrowth, was not considered in this research. As this can also constitute navigational hazard, a research to include this form of hazard can be carried out in a subsequent research.

Acknowledgements

I give God profound gratitude as He took me through the pain of losing a parent to the joy of having my new-born son during the course of this educational journey

I sincerely thank the Managing Director and the management team of Batoil Services Nigeria Limited (BSNL) for their support and permission to use the data for this research.

I am also sincerely grateful to my supervisors Emeritus Professor D. M. J. Fubara, and Dr. Lawrence Hart for their immense contribution in shaping my thought in conceiving and giving birth to this research.

I also appreciate the immense input of lecturers from the Department of Surveying and Geomatics in Rivers State University especially Surv. G. T. Pepple and Surv. S. N. Eke.

To my beautiful and lovely wife, Lezor OTASANYA, and our sons, Rayhan and new-born Othniel, I am grateful you took this journey with me having unflinching support for my progress.

To my family, friends and colleagues who shored me up with prayers and support I am eternally grateful.

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