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Analyses of Post Dredged Surveys of Elechi Creek for Channel Condition Monitoring

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Abstract
Siltation is a major recurring phenomenon at the entrance into the channel of Elechi Creek, which is one of the busiest transportation routes to where some oil and gas production facilities and other key marine infrastructure are located in Port Harcourt City, Rivers State, Nigeria. Access into the channel is usually very difficult particularly during ebb tide hours due to the shallow water depths that characterize the channel pathways, thus requiring periodic maintenance dredging to safeguard the required minimum navigational depths. Owing to the socio-economic importance of the creek, there is a need to maintain its navigability at all times in order to keep pace with the volume of traffic plying the route. Results from the analyses of preliminary and post-dredged bathymetric surveys carried out over a nine-year period between 2009 and 2017 showed that the channel, which was initially dredged to a threshold depth of 10.0 meters in 2009, had infilled to a new depth of 6.9 meters by the year 2017. Further analysis from the study also showed that approximately 91,000 m^3 of sediment volume had deposited back into the channel as of 2017 against the dredged volume of 162,000 m^3 in 2009, thus representing about 56% of the total sediment that was dredged in 2009. Overall, it was found that channel depth decreases exponentially as sediment accumulates over the years.

Keywords: *Siltation, Bathymetry, Chart datum, Maintenance dredging, Navigational depth*

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1. Introduction

Sedimentation is one of the major problems affecting the navigability of most rivers and creeks in the Niger Delta estuaries of Nigeria. Many coastal settlements in this region are inaccessible by water transportation due to the shallow depths that characterize the waterways, especially during ebb tide hours (Agunwamba et al., 2012). Local jetties, port and harbour facilities, oil and gas production platforms at these locations suffer from siltation of their berthing and maneuvering areas, thus requiring periodic maintenance dredging to safeguard the required minimum depths for navigation (Rosati and Kraus, 2009). The socio-economic activities of the people and companies operating in this environment are adversely affected and sometimes paralysed.

Dredging of channel approaches and harbour basins encourage the deposition of sediments in these channels because, when water currents pass over a dredged channel, the flow transport intensities are weakened and the ability to transport sediment decreases, which results in increased deposition of sediments in the newly dredged channel (Sanga and Dubi, 2004). Of particular interest in this study, is the access into the channel of Elechi creek which is located at the downstream of the Upper Bonny River estuary in Port Harcourt. This creek, which is approximately 3.0 km long and 150 m wide on average, is frequently silting up at the channel entrance due to the effect of tidal filling caused by sediment migration from the upstream of Bonny River. In October 2009, a 7.2-meter draft oil tanker laden with over 5000 metric tonnes of petroleum product was grounded at the channel entrance of this creek due to insufficient navigation depths, thereby resulting in the closure of the channel for 21 days to allow for dredging. Prior to dredging, the controlling water depth at the entrance was 4.6 meters below chart datum, and according to the Nigerian Port Authority pilotage regulations, the minimum under keel clearance for any cargo vessel is 0.5 meters (Bala-Usman, 2023), which means that the allowable maximum draft at low tide was 4.1

meters. Ships with greater draft were usually compelled to make use of tides (when water level reaches its peak) to enter and leave the channel. Apart from the limitation posed by the shallow depths at the creek entrance, there were also problems of numerous bends along the channel pathways which sometimes hindered navigation, resulting in delays to most of the larger vessels and consequently amounting to higher demurrage cost (Chilaka, 2023). At the completion of dredging works in November 2009, there was a great improvement in the navigability of the creek as the access and the main channel were dredged to a uniform depth of 10 meters. The dredged length of the channel was 500-meter over a 60-meter width corridor. This gave a dredged volume of about 162,000m^3 at a whopping cost of $216,000 which was about approximately ₦50,000,000 in Naira equivalent including the cost paid on demurrage in 2009. The dredged material was predominantly soft silty clay. This new channel improvement prompted the laying of light buoys to define the safe passage route along the channel and to provide guidance for vessels on safe corridor limits. The improved condition also made it possible for vessels of any size to navigate the channel without relying on tides at any time of the day.

2. Materials and methods

2.1 Study area

The study area was Elechi creek as shown in Fig. 1. It is located on the plain of Niger Delta basin in Port Harcourt City, Rivers State of Nigeria. The creek is one of the many tributaries of the Upper Bonny River estuary and it also has many other adjoining mangrove creeks situated near Eagle Island by the north eastern end of Rivers State University, Port Harcourt. The stretch of the creek is long and wide with meanders. The length is roughly 3.0 km with an average width of about 150 meters.

Fig. 1: Digitized map of the study area (Google Earth Imagery, 2017)

Geographically, the creek lies between latitude 4° 46' 03'' North of the equator and longitude 6° 59' 12'' East of the Greenwich meridian. The topography of the area is relatively flat and low-lying with an average elevation of about 3.0 meters above Low Low Water (LLW) mark. Though the terrain is a swampy environment, almost 60% of the wetland has been reclaimed to allow for the built-up structures that presently dotted the landscape as a result of the rapid growth in industrial activities taking place in the area. This industrial revolution has brought about considerable rise in human population and also an increase in commercial activities with majority of the inhabitants engaging in petty trading, timber logging and fishing as primary occupations.

The river system in the area is characterized by semi-diurnal tide regime. The daily tidal fluctuation is between 0.1 m at the minimum (low tide) and 2.4

m at the maximum (high tide). This variation occurs mostly at neap and spring tides respectively, giving an average daily range of between 1.8 and 2.1 meters rise in water level. The controlling water depths at Elechi creek ranged between 3.0 m and 7.0 m from the entrance while water current flows at an average of 0.27 m/s and 0.22 m/s at very low and high tide respectively (Masters Dredging Survey Report, 2015). The geological feature of the area is within the tidal flat zone and mangrove swamp belt of the Niger Delta characterized by coastal plain sand superficially overlain by mud peat and other clay-silt mixtures of quaternary. The soils in the area are in essence, composed of peat, organic clays, silty clays and sand. Peat constitutes the dominant soil which is locally known as '***chikoko***' with high compressibility and colour ranging from dark brownish to dark grayish and texture from soft to firm (SPDC, 2005).

2.2 Data acquisition

The field data acquired for this study were topographic, bathymetric and tide data. The need for topographic data was to interface by merging the terrain elevations with water depths measurements in order to create a seamless digital elevation model (DEM) of the study area. Ground controls were first established at site since none was in existence. This was achieved by boring four steel pipes filled with concrete mix on top of concrete jetty to serve as survey beacons and labelled with identification numbers of ME-1, ME-2, ME-3 and ME-4 respectively. The coordinates of each beacon were obtained with RTK GPS instrument observed in static differential mode, while their heights were obtained by levelling process using water level surface as reference datum. Spot levels were also taken on the adjoining land areas bordering the creek shorelines at 10m x 10m grid intervals for the purpose of producing elevations and contour map of the entire area. This was achieved with the use of Total station instrument. Table 1 shows the summary list of established coordinates from the survey which were later used as controls for the study.

Table 1: List of established reference controls with their coordinates.

Points	Easting (m)	Northing (m)	Elev. (m)	Remarks
ME-1	275797.125	527901.111	3.800	All points are located on top of the slab of the existing jetty with their heights referenced to the LLW. Horizontal coordinates are in UTM (Zone 32).
ME-2	275839.833	527871.714	3.791	
ME-3	275888.000	527841.555	3.747	
ME-4	275929.833	527810.857	3.705	

Bathymetric data were acquired in three phases. The first phase was the pre-dredge bathymetric survey for the proposed dredging. This involved sounding the entire 3.0 km stretch of Elechi creek and a section of Bonny River adjoining the creek. The second phase was the post-dredged survey**.** This was done immediately after dredging and the survey was limited to only the dredged section of the creek which measured 500 m by 60 m in area coverage and part of adjoining Bonny River. The third phase was the condition survey of the dredged channel for the purpose of monitoring the channel depths and also to determine the rate of siltation due to sediment deposition. This was done on yearly basis for a period of nine years (2009-2017)**.**

At each phase of the bathymetry, the following activities were performed:

i. Establishment of tide gauge pole for purpose of sounding (depth) reduction.
ii. Depths measurement by acoustic sounding method using single beam (SB) echo sounder.
iii. Position fixes of sounding points with GPS used in Real Time Kinematics (RTK) differential mode.
iv. Production of bathymetric charts of the channel drawn at a scale of 1/5000.

Tide poles were first established at the study area and referenced to the control point ME-1 located on top of slab of the existing jetty with the height value of 3.80 m above LLW. The need for tide is to record the time and height of water level at same instant. This requirement is necessary for the reduction of sounding data and also to determine the nature and characteristics of tide so as to know its effect on the sediment movement in the area. Tides were observed in each year of monitoring survey for a period of 24 hours and data recorded at hourly interval. Predicted tides from the Admiralty Tide Tables (ATT) covering these periods were also used to compliment the observed tides where actual tide observations could not be measured at site due to bad weather condition. Fig. 2 shows the field procedure on how tide pole was set up at the study area.

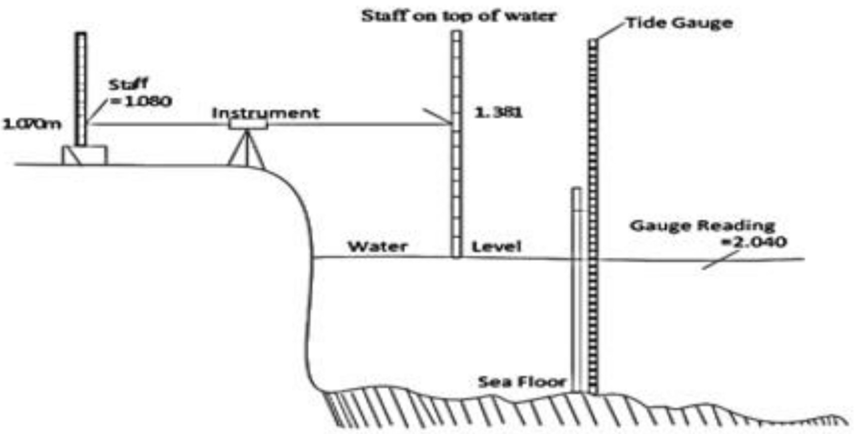


Fig. 2: Field procedure for establishment of Tide gauge Pole (Adapted from Ekpa and Eyakndue, 2017)

Measurement for bathymetry commenced with shoreline demarcation survey where baseline for the sounding operation was clearly set out along the creek bank. Thereafter, sounding lines were flagged out and uniformly spaced at 50 meters interval along the shoreline. Depths were measured and fixed at 10 meters interval across the width of creek along each sounding line. All measurements for depths, position fixes and tides were logged simultaneously in real time at every ship pass. Measured depths were later corrected for tides during data processing. Fig. 3 explains the working principles of a single beam echo sounder and Real Time Kinematics differential GPS respectively.

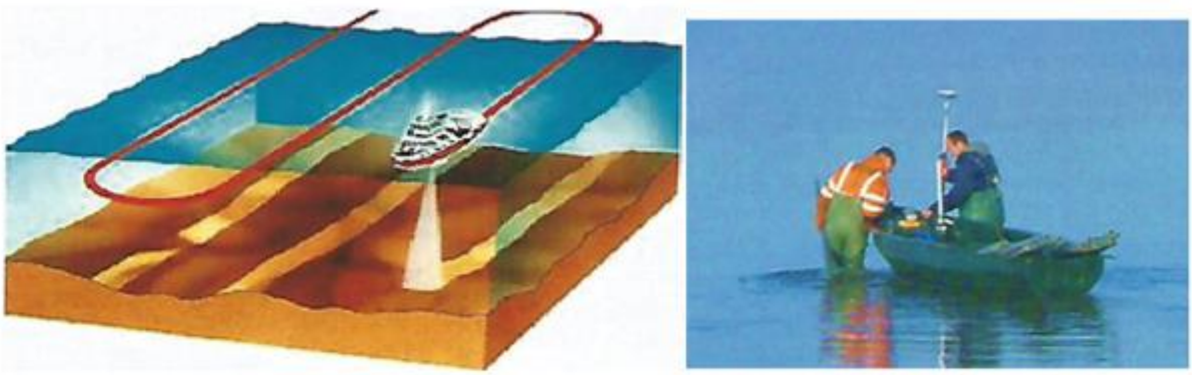


Fig. 3: Depth measurement with SB echo sounder and Position fixing with RTK GPS (Skilltrade, 2010)

2.3 Data processing

Data processing involved the following tasks: Production of Bathymetric Charts, Channel Surface Modelling and Channel Infill Volume computations. These tasks were achieved using relevant hardware and software packages which include: MSI CX62-7QL 16GB RAM, 512GB SSD Core, AUTOCAD CIVIL 3D, SURFER 13, ARCMAP 10.8 and MS Excel.

2.3.1 Production of bathymetric charts

All bathymetric and topographic data acquired in the field from different data loggers at different periods were downloaded and reformatted to MS excel sheet before being exported into AUTOCAD CIVIL 3D environment for chart drawings. All charts were produced at a scale of 1:5000. The contours shown on each chart were interpolated at 0.1 m height interval. Charts were produced for each year that condition survey was carried out using the dataset of pre and post dredged surveys of 2009 as the basis for monitoring any changes in channel depths when compared with the bathymetric survey of subsequent years between 2010 and 2017.

2.3.2 Channel surface modelling

The raw data collected from the field observations were exported into MS Excel format. This enabled data cleaning, transformation and formatting to be done to ensure that the data was in a format compatible with the modelling and visualization software. The data were saved in both excel spreadsheet format and comma separated value (csv) format.

To depict the morphology of the area, Triangular Irregular Network (TIN) was used to generate the 2D surface model. TINs are a form of vector-based digital geographic data and are constructed by triangulating a set of vertices (points). The vertices are connected with a series of edges to form a network of triangles. There are different methods of interpolation to form these triangles, such as Delaunay triangulation or distance ordering. ArcGIS software supports the Delaunay triangulation method. For this study, the csv datasets for each of the yearly observations were imported into the ArcMap 10.8 environment. The data were plotted in the X, Y, Z fields and exported as a shape file. The created shape file was then interpolated using the Natural Neighbour method of interpolation. This method ensured that the interpolation was contained strictly within the domain of study area and radius of the observed points. Appropriate colour convention was assigned to the resulting model to depict areas of high elevation in red and lower/deeper elevations/depths in blue. The surface was converted to a map containing the essential map elements.

The 3D surface models were generated using SURFER 13 software. The excel spreadsheet dataset was imported into the surfer environment and converted into a grid using the kriging interpolation method. This method of interpolation was used for the gridding to ensure that the resulting model covered a more extensive area. A grid report was created after the gridding and the 3D bathymetry surface of the channel was generated. The appropriate colour convention similar to the one used for the 2D model was utilized.

2.3.3 Channel infill volume

The volume of sediment that had accumulated in the dredged channel over time was quantified by partitioning the 500-m dredged length into six (6) sections at every 100 m interval. Depth values obtained from the pre and post dredged surveys between 2009 and 2017 were extracted for each section across the 60-m channel width corridor at 10 meters interval using the channel centreline as the origin of the cross section. The extracted values were further tabulated for purpose of calculating the area of the channel at each section point using trapezoidal rule method, while the volume in between sections were computed using the end area method. The mathematical expressions for area and volume calculations by these methods are given in Uren and Price (2010) as:

$$A_T = D\left[\frac{1}{2}(h_1 + h_N) + h_2 + h_3 + \cdots + h_{N-1}\right] \quad (1)$$

and

$$V_{EA} = L\left[\frac{1}{2}(A_1 + A_N) + A_2 + A_3 + \cdots + A_{N-1}\right] \quad (2)$$

where h_i $(i = 1\ to\ N)$ are the heights of sediment infill across channel, D is the distance interval in between them, A_i $(i = 1\ to\ N)$ are sectional areas across channel, L is the distance interval in between sectional areas taken along channel centreline and N is number of infill heights for area and number of sectional areas for volume respectively. Fig. 4 illustrates the method of volume calculation by end area method using five sections only.

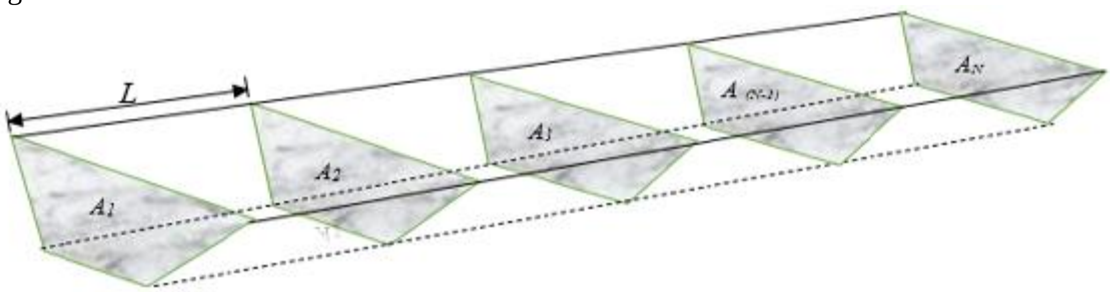


Fig. 4: Volume calculation using end area method

2.4 Data presentation

Data sets were presented in various forms. The superimposed pre and post dredged chart of Elechi creek as of 2009 was shown in Fig. 6. The Digital Elevation Models (DEMs) generated by Triangular Irregular Networks (TINs) showing the 2D morphology of the area as at 2009 and 2017 were presented in Fig. 7. The 3D bathymetry of the channel as at 2009 and 2017 were shown in Fig. 8. Volumetric analyses showing the quantities of sediment infilled into the channel due to deposition over the study periods was presented in Table 2 and Fig. 9, while graphical plots of depths variation with time were presented in Fig. 10.

3. Results and discussion

Tide at Elechi creek is semi-diurnal in nature. There are two tidal cycles per day with approximately six hours return period. The tidal curve showed a sinusoidal variation of water height with time, each with maximum and minimum levels representing the high and low water periods. The mean highest water level is 2.2 meters at flood tide hour and the mean lowest water level is 0.1 meter during ebb tide period. The mean tidal range is between 1.8 and 2.1 meters within the study period. Fig. 5 represents the nature of tide for the study area.

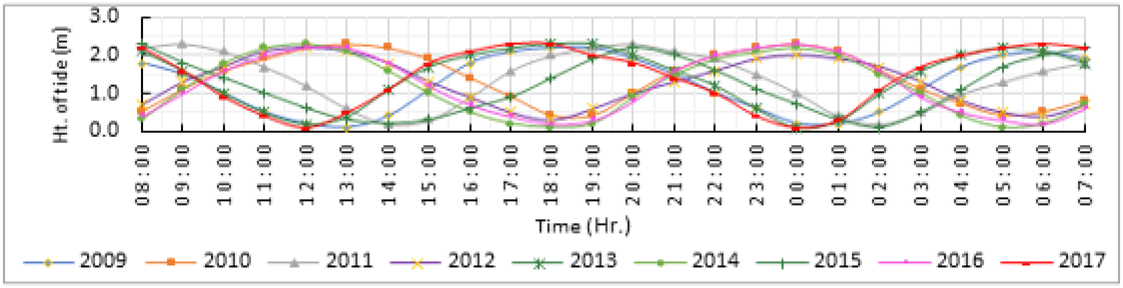


Fig. 5: Semi-diurnal tide nature of the study area from 2009 to 2017

From available data, topographic analysis of the area showed that average terrain elevation was about 3.0 meters above chart datum, which is an indication of a relatively flat and low-lying terrain, except for areas adjoining the creek shoreline eastward where elevations are generally below 2.0 meters. Similarly, results from the bathymetric investigation also revealed that the average depths prior to dredging in 2009 was between 2.0 meters and 4.0 meters at the channel entrance, while depths along the channel corridor were generally less than 5.0 meters thereby making navigation very difficult for vessels with high water draft particularly at low tide hours. However, as at 2017 the channel depth which was dredged to 10.0 meters in 2009 had gradually reduced to about 7.0 meters depth due to sedimentation effect caused tidal filling thus translating to about 3.0 meters height of infill from channel bed.

Volumetric analyses of sediment quantities deposited into the channel between 2009 and 2017 was determined using the end area method. Results from the computations showed that approximately 91,000 m^3 of sediment material had infilled the channel by 2017 against the dredged volume of 162,000 m^3 in 2009 representing about 56% of the dredged material. The summary results of the computed volumes and heights of channel infill between 2009 and 2017 are shown in Table 2 and Fig. 9 respectively.

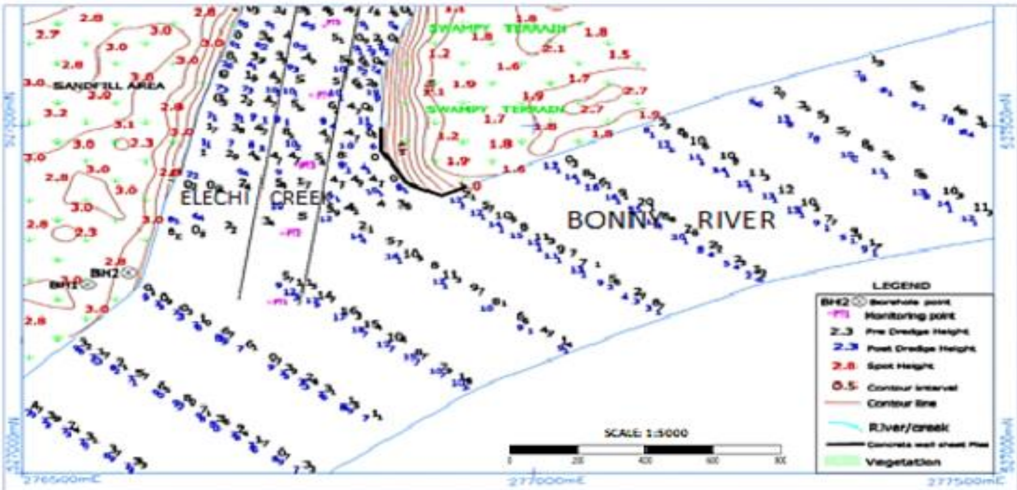


Fig. 6: Pre and post dredged bathymetric chart of Elechi creek as at 2009

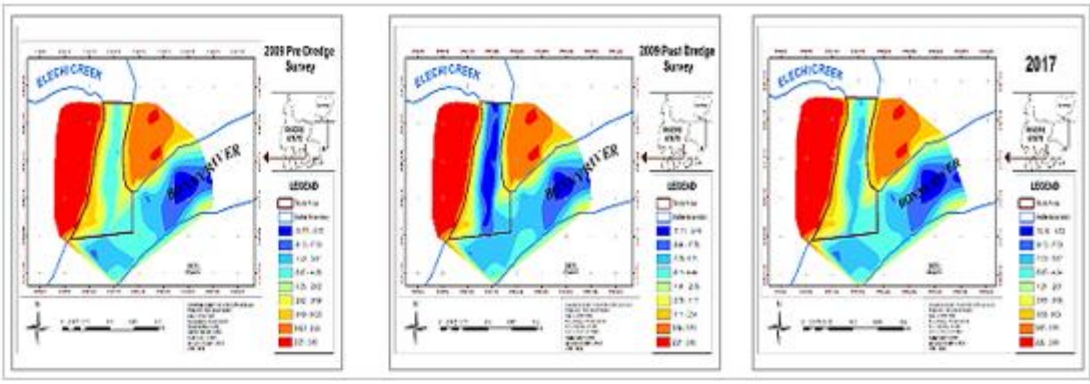


Fig. 7: 2D surface morphology of Elechi channel as at 2009 and 2017

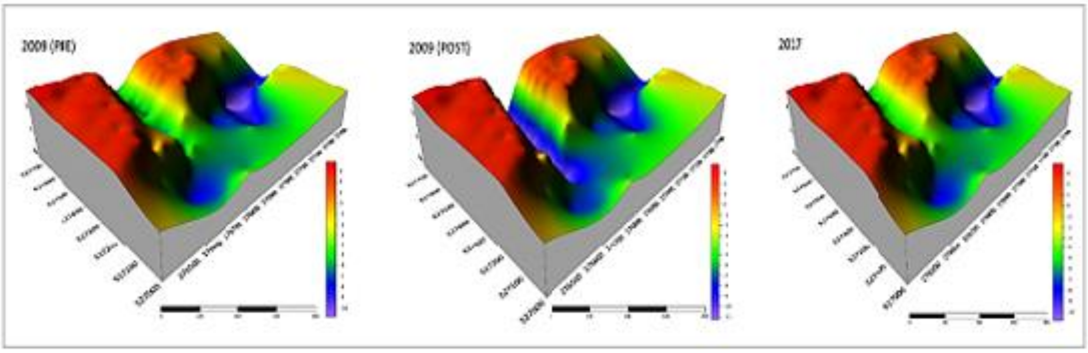
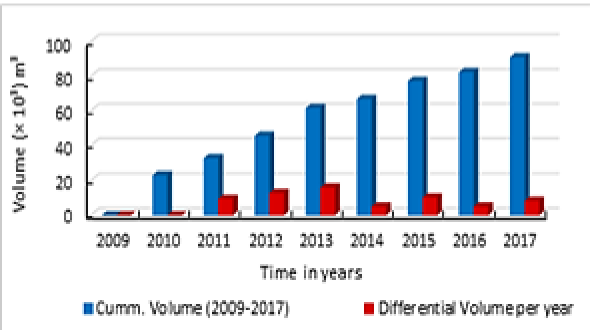


Fig. 8: 3D bathymetry surface of Elechi channel as at 2009 and 2017

Table 2: Extract from Volume computation datasheet

Section b/w monitoring points	Volume (×10 m^3) in between sections as at:									Net Diff.
	2009	2010	2011	2012	2013	2014	2015	2016	2017	
0 — 100 m	0.0	4.8	6.2	9.2	12.3	13.4	15.6	16.6	18.2	**13.4**
100 — 200 m	0.0	4.5	6.5	9.2	12.3	13.3	15.5	16.2	18.2	**13.7**
200 — 300 m	0.0	4.5	6.7	9.2	12.4	13.4	15.5	16.5	18.2	**13.7**
300 — 400 m	0.0	4.8	6.7	9.2	12.4	13.5	15.4	16.7	18.2	**13.4**
400 — 500 m	0.0	4.7	6.7	9.0	12.5	13.5	15.5	16.7	18.3	**13.6**
Cumm. Vol. (×10 m^3)	**0.0**	**23.3**	**32.8**	**45.8**	**61.9**	**67.1**	**77.5**	**82.7**	**91.1**	**67.8**
Diff. Vol. (×10 m^3)/Yr.	0.0	0.0	9.5	13.0	16.1	5.2	10.4	5.2	8.4	



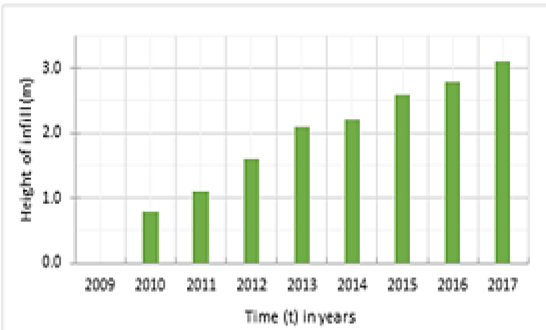


Fig. 9: Volume and height of channel infill from 2009 to 2017

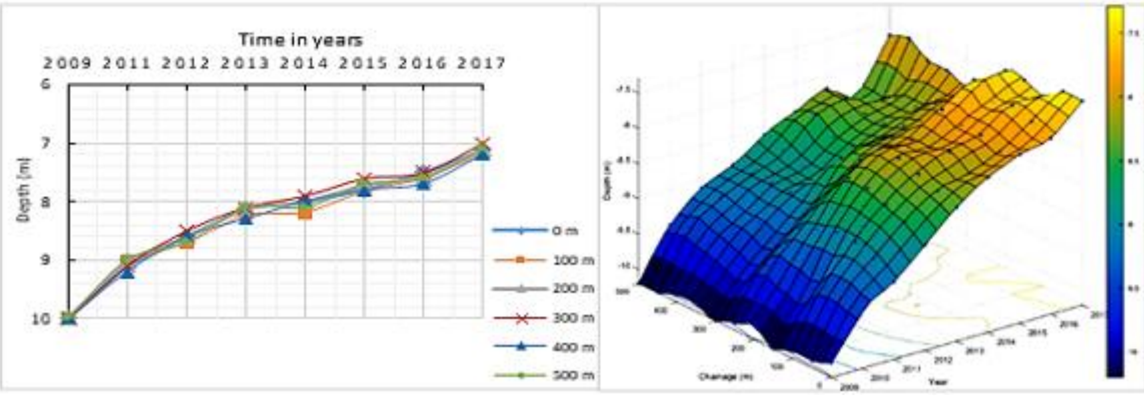


Fig. 10: Graphs of depths variation with time in 2D and 3D plots at monitoring points

4. Conclusion

This paper examined the survey processes involved in monitoring sedimentation rate in a dredged channel where deposition of fine sediments by tidal currents is the prevailing factor. The channel of Elechi creek was used as a case study. The study approach was based on an assessment of geospatial data obtained from field surveys carried out between the years 2009 and 2017. The results from analyses of pre and post dredged bathymetric data showed a clear transition in the channel bed profiles as they evolve over time. It was also evident from the study that as at 2017, the channel depth has become shallower than the dredged depth of 2009 as the depths continue to decrease gradually over the monitoring periods. The decrease rate is exponential and this suggests that with time, the channel may infill back to its natural depth if no maintenance dredging takes place before then, and this may pose further danger to safe navigation.

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