Investigation of Sediment Accumulation in Ojo Creek Channel using Geostatistical Techniques

O. A. Jimoh[1]*, I. A. Hamid-Mosaku[1], O. F. Oguntade[1], K. A. Raheem[2], A. Balogun[3]
[1]Department of Surveying and Geoinformatics, University of Lagos, Lagos, Nigeria
[2]Department of Civil Engineering, University of Port-Harcourt, Rivers State, Nigeria
[3]Geospatial Analysis and Modelling Research (GAMR) Group, Department of Civil and Environmental Engineering, Universiti Teknologi Petronas (UTP), Perak, Malaysia
*Corresponding author email: abeeblekan@gmail.com

Abstract
River channels are characterized with natural processes, anthropogenic activities, geomorphology, and climate change, resulting in sediment accumulation. This consideration, however, has geomorphic impacts on riverbed, bank erosion, channel widening, sediment deposition, floodplain scour and destruction of near structures; thereby, significantly impacting on safe navigation and aquatic habitat. This paper investigates sediment accumulation in Ojo creek channel over a period of 9 years using geospatial techniques. Acquired hydrographic, bathymetry, and geospatial information of the study area were structured into spatial database for further integration with spatial analysis using geostatistical methods of Kriging/Co-kriging interpolation method in ArcGIS environment. Relative comparisons of volume of the water over the years were done for accretion and erosion. The net loss and gain in material over the years were revealed to be 1,601,251.949m3 and 1,017,252,326.841m3 respectively. Therefore, the volume of sediment calculated to be approximately 1,015,651,074.892m3. Furthermore, prediction and error analysis conducted was used to quantify the effect of sediment deposits and volume of water in the river channel. Thus, this study provides a framework for quantifying sessions of the channel that requires dredging and the amount of sand dredged for channel maintenance leading to safe navigation and good water supply.

Keywords: River channels, geostatistical techniques, spatial database, sediment deposit, geomorphology.

1.0 INTRODUCTION

River channel dynamics are induced by natural processes, water discharge, sediment loads, anthropogenic activities, geomorphology (landforms and classifications) andclimate change (Langat *et al.,* 2018; Saleh *et al.,* 2013). Moreover, Pan et al. (2015) observes the complex nature of river bank morphological changes, erosion and accretion processes in river channels controlled by the interplay of natural factors (such as: stream flow, bank lithology, elevation of landscape, and channel geometric characteristics) and anthropogenic activities. Consequently, flooding events can generate dramatic and sudden river channel changes. In addition, anthropogenic activities and natural impacts can have great effects on river banks and coastline shapes. Joyce *et al.* (2018) classified these factors into fluid-flow related, soil-related and geometrical factors. These factors either affect the river channel directly or indirectly while the most important variables identified by Abidin et al. (2017) are bed and bank resistance to flowing water, flow velocity and discharge, longitudinal slope, sediment load, geology, and anthropogenic activities.

A stream channel can be considered to be relatively stable when its water flow and sediment flux are in balance over time. If there is a change in either of these two factors, then the channel will adjust its slope, depth, width, meander pattern, bed composition and vegetation density accordingly. The extent and rate of these adjustments are dependent on the extent and rate of change in the water flow and sediment load (Water-Notes, 2000; Chil, 2006). All rivers carry sediments, due to surface erosion from watersheds or bank erosion along the river course. The mobile material that makes up a stream's bed, banks and floodplain has been carried and deposited there by the stream and can be moved again given the right conditions. Thus, understanding the dynamic equilibrium between sediment supplies from upstream and a river's sediment capability is paramount to the success of river engineering design and management (Water-Notes, 2000; Chil, 2006). Surface erosion, sediment transport, scour and deposition have been the subject of study by engineers, hydrographers, geologist and various scientists for centuries, due to their importance to socio-economic development. Most ancient civilization existed along rivers in order to use its water supply for irrigation, navigation and commercial activities (Nwilo and Badejo, 2004; Chil, 2006). The average annual inflow of sediments into a river channel together with the total sediment volume accumulated in the channel and the distribution of the sediments within such river channel are important attributes of any channel (Abidin *et al.*, 2017; Oladosu *et al.*, 2019). Engineers built levees along rivers for flood control purposes, while reservoirs ensure water supply and flood control. Canals are built for water supply and navigation. Sustainable use of these hydraulic structures depends on proper understanding of the erosion and sedimentation processes and how to apply them to hydraulic designs.

Once sediment has entered waterways it is difficult and expensive to remove, requiring engineering solutions and heavy equipment (Palmieri *et al.*, 2001). Although sediment is a natural component of streams and rivers, it can be damaging when it is present in excess. Hence, measures must be put in place to reduce the effects (Morais *et al.,* 2016; Oladosu *et al.*, 2019). Preventative measures aimed at reducing further sediment transport are the best approach to reduce sediment accumulation. The revegetation of river banks will go a long way toward reducing sediment transport as healthy riparian vegetation is effective in reducing bank erosion. Riparian vegetation will also filter sediment being transported in surface water runoff. It is important to have riparian zones of adequate size for this purpose. The width of buffer strips for management of riparian areas for plant community diversity varies depending greatly on type of resource to be protected. To maximise diversity therefore, riparian buffers areas should extend from stream edge to upland, so the zones could be: from stream edge to upland along a complex environmental gradient (USACE, 1991; Hawes and Smith, 2005; Kasvi *et al.*, 2017). The width for vegetation diversity, according to Fischer and Fischenich (2000); Jontos (2004); Hawes and Smith (2005) is between 30 - 500 m, while Hawes and Smith (2005) hold the view that buffer width generally depends on soil type, slope, land use and other factors . On-farm retention of water through the use of dams and contour banks will also help to reduce the erosive power of water leaving catchments and thereby reduce the amount of sediment transported to and mobilised within stream systems (Water-Notes, 2000). Accurate representation of river bed topography, commonly referred to as bathymetry, also play a critical role in a variety of hydrologic and hydraulic applications including but not limited to flood modelling, sediment transport, quantifying nutrient exchanges, and aquatic habitat mapping *(Dey et al.*, 2019). Bathymetric surveys are important for many purposes, while integrated bathymetric survey provides river channel sedimentation details and much needed information such as channel depth, capacity and bottom topography with great accuracy to optimize channel operations (Palmieri *et al.*, 2001; Ojigi *et al.*, 2012; Chukwu & Badejo, 2015). According to Oladosu *et al.* (2019), bathymetry surveys in river channels are often required for the following reasons among others: (a) to establish channel maintenance practice for effective channel operation and safe navigation, (b) to calculate the sediment yield of the upstream hydrological basin, (c) to assist engineers in the design of reservoirs or dams in the region, (d) to predict the spatial distribution of sediment within the river channel and in particular close to hydraulic structures such as intakes, and (e) to evaluate methods of prevention or sediment removal to be adopted. Hence, bathymetry survey will also be helpful in reducing sediment accumulation and its effect in river channels. It will provide information on where to dredge and how much sand to be dredged in a water channel.

The construction and maintenance of Ojo creek channel was to support the domestic and industrial needs of the growing population in the area. Therefore, Ojo creek channel has been of immense benefit to the urban and rural communities of Ojo and Lagos at large. However, the sustainable provision of portable water for domestic, industrial and navigational use in this area has been under threat over the years due to several factors, including lack of spatial database (locations, depth, area, volume, etc.) and the threat by siltation and land use activities within the corridors of the channel (Jimoh, 2017). This study therefore aims at investigating the volume of sediment accumulation along the channel over a period of nine years with a view to providing relevant geographic information for stakeholders involved in channel management for safe navigation.

In term of sources abd types of sediment, catchment clearing and "river training schemes" result in the indirect mobilisation of sediment into stream systems. Sediment may also enter streams as result of other human activities such as the construction of dams and as a result of mining activity within a catchment (Downs & Piégay, 2019).

The construction of roads is known to be a major contributor of sediment to waterways (Musa *et al.*, 2010). In rivers and creeks, sediment exists in two forms, either as suspended or deposited material. Usually, it is the very fine sediment (silt and clay) that is suspended, and the coarse sands that are deposited. Under high flow sand may enter the suspended load and under low flow silts and clays may settle onto the stream bed. Sediment that is deposited may remain in place forming long plumes and channel bars or it may be transported downstream as part of slow moving bed load (Water-Notes, 2000). Apart from waste materials from residential and commercial areas in Ojo that are been dumped and transported to water ways and channels as sediments, dredging and construction activities are other sources of sediments in the study area (Jimoh, 2017).

2.0 MATERIALS AND METHODS

The materials and methods involved in this study as well as the analysis adopted in transforming the raw data obtained to required information are explained in this section.

2.1 Study Area

The study area (Figure 1) is located along Ojo creek from the Fishing village to Ibasha community, Ojo Local Government Area of Lagos State. The site falls within coordinates 3°15'14.768"E, 6°25'47.876N" and 3°17'48.423"E, 6°25'51.955"N. The Ojo creek together with Badagry creek improve the transport system of the area through ferry services and speed boats with the main jetty located at Ojo district off Olojo drive.

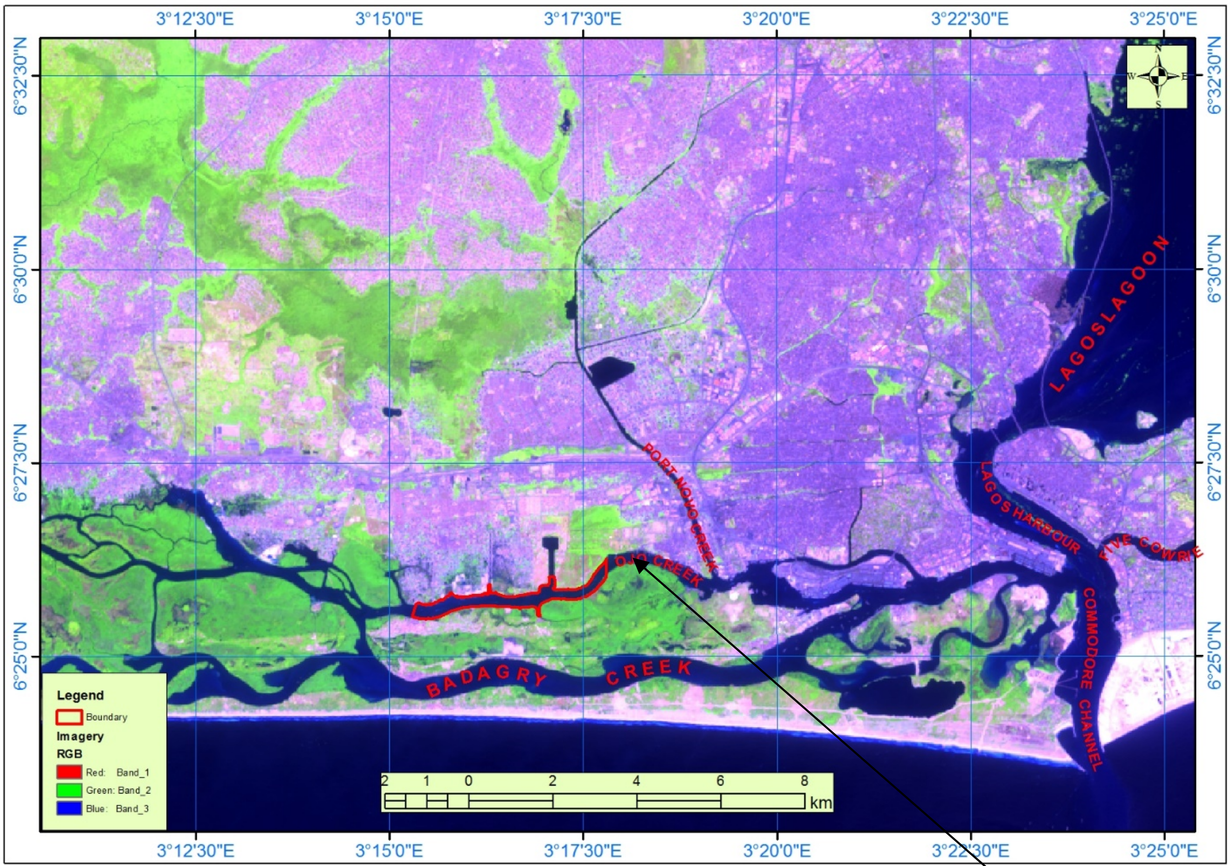

Figure 1: Location of the Study Area within Ojo Creek, Lagos

2.2 Reconnaissance

The reconnaissance (i.e. preliminary investigation) for the project was divided into two phases namely desk reconnaissance and field reconnaissance. Extensive literature search was done to put the project in the right course. Information on a set of second order control points located within the state were sourced although none was found around the project site. The reason for this is to tie the bathymetric survey to the shore controls and reference the bathymetric work to the desired datum. A good location was therefore identified for temporary bench mark TBM (top of the CHIPET Jetty embankment which formed the baseline at the project site). Furthermore, a 30metre- resolution Landsat Satellite Image of Lagos State which was used as basemap. This provisional base assisted in the delimitation of the coastline around the project area. Field visit was done to familiarize the study-team with the nature and extent of the project area by sailing through the creek. Handheld GPS and a service boat were used for the reconnaissance, and thus, the coordinates of the area were obtained. All equipment required for this work were identified and assembled in readiness for the commencement of this work. A digital Echosounder that is user-friendly and capable of integration with differential GPS was used for real-time data acquisition.

2.3 Instrumentation

The instruments used in this project for data acquisition, data processing and data manipulation are divided into two major classes, namely: software and hardware. The hardware requirement include the following; (i) Trimble Differential Global Positioning System (GPS), (ii) South SDE -28 Echosounders, (iii) Automatic Level, (iv) Small hydrographic vessel, (v) A Bar check and Bar rope (vi) Two Transducers (vii) 2KV Inverter and 200 AH Battery (viii) Safety Equipment and Tide Gauges (Levelling Staff). The hardware is complemented with the software which includes; (i) PowerNav Software for Sea Navigation, (ii) Hypack 2016 Hydrographic Software, (iii) GNSS/GPS Processing Software, (iv) Esri ArcView/ArcGIS 10.3 Software, and (v) AutoCAD 2017 Software

2.4 Instrument Check

Instrument test was respectively conducted to ascertain their optimal performance before using them for data acquisition.

2.4.1 Testing of Boat and Bar Check for the Echo sounder

A 5 m length by 2.5 m width, with a 25 horse power boat engine was used. A soft push from the jetty to gain a good enough depth to prevent the transducer from hitting the ground was sought. After which the engine was powered up and the speed of the boat tested by running a distance of 200 m at 20 km/h, the speed was increased to 30 km/h maintaining the same distance. Four transects were navigated from which the boat was observed and inferred capable of maintaining a straight line viable for the sounding exercise. In order to maintain quality and consistency in pinged depth, calibration of echo sounder is very pertinent because transmitted wave from the equipment through water column is usually affected by: speed of sound, spreading loss of sound in water, attenuation (absorption of sound in water), volume reverberation etc. For the South SDE 28 Echosounder, initial measurements were taken for both the leadline and Echosounder and comparison and assessments were made. The measurements from both the Echosounder and lead line were recorded on the field book. Ten measurements were made all together for both the lead line and South Echo sounder and a difference of -0.002 m was recorded. The calibration results are presented in Table 1. Average speed of 40km/h was used for the field work to ensure steady movement of the boat and full coverage of the channel.

Table 1: Calibration Data

S/N	Northing	Easting	Echosounder Depth (m)	Leadline Depth (m)
1.	710350.981	529256.253	1.91	1.93
2.	710302.739	529030.859	2.22	2.19
3.	710401.131	529425.760	1.33	1.34
4.	710394.540	529291.299	3.21	3.19
5.	710340.572	529233.521	1.18	1.20
6.	710219.461	528849.030	1.24	1.23
7.	710350.981	529256.248	1.91	1.93
8.	710417.260	529280.881	3.36	3.32
9.	710281.923	528985.410	1.95	1.97
10.	710292.329	529008.139	2.09	2.08
		Mean	**2.040**	**2.038**

2.5 Data Acquisition

The stages involved in data acquisition are described in this section.

2.5.1 Control Establishment

Before the advent of GPS technology and modern communication devices, hydrographic survey controls were established closed to the shoreline by radio positioning systems; today with the use of GPS, controls for hydrographic operations need not to be situated along the shore. The controls could be several kilometers from the site (Badejo, 2016). Verified reference first or second order stations or controls are used to transfer the X and Y coordinates to other controls so that all the controls and positions of sounding depths can have unified and homogeneous system in both longitude and latitude and UTM coordinates. These controls are transferred in phases along the project area. A temporary benchmark was established on top of the embankment beside CHIPET tank farm which falls within the project site. Other benchmarks were monumented on the property of the promenade Oil and Gas. The height of the embankment to the top of the instantaneous water on the day of observation, 13th of November 2017 (12.58PM) was 1.85 m. The benchmarks were transferred from a reference station (XST347) which is situated at the University of Lagos Distance Learning Roundabout and has verified 3D (X, Y, Z) coordinates. Trimble R8 Global Positioning Systems was used for coordination of the benchmarks by setting the base on XST 347 pillar while the rover unit was set on the benchmarks at the project site. The processed coordinates of benchmarks are shown in Table 2.

Table 2: Coordinates of Benchmarks

ID	Easting (Metre)	Northing (Metre)	Elevation (Metre)	Feature Code
BM01	528968.321	710652.376	1.637	PROM
BM02	528951.914	710651.175	1.190	EXT CONTROL
BM06	528969.659	710799.373	1.905	PROM
BM08	528975.425	710879.186	1.323	PROM
BM10	528983.179	710960.380	1.277	PROM
BM13	529051.701	710893.931	1.251	PROM
XST347 (Reference)	543241.676	719895.816	4.701	

2.5.2 Boundary Delineation

The water boundary was digitized from the satellite imagery that covers the study area using ArcGIS editor tool. The satellite imagery and the digitized map served as the base map for reconnaissance and proper survey. The established, monumented and coordinated shoreline controls were used to georeference the imagery. The Differential Global Positioning System (DGPS) coordinates (with centimetric accuracies) provide suitable control checks for corresponding points on the images. And the digitized map shows the geometry of the river channel.

2.5.3 Tidal Characteristics and Tidal Observations

Automatic level was used to run levelling operation from one of the controls (as benchmark) onto the water surface and level of water was monitored by staff gauge planted at the lowest river tide before and throughout the sounding period. Three days tidal observation at the tide gauge stations were analysed to get the tidal characteristics of the tide gauge stations. Predicted tides of Lagos Bar were used for this work. The predicted tides for Lagos Bar are based on the tides at East Mole. Since tidal observations from the East Mole were part of the data used in studying the tidal characteristics, the heights of the tide above chart datum at the project area were computed from the relationship between the tides at the East Mole and the tides at the project area. The predicted tidal information of Lagos Bar on the day of observation is presented in Table 3.

Table 3: Predicted Tide at the Lagos Bar for 13th November 2017

Time (hrs)	Height (m)	Remarks
02 20	0.9	
08 46	0.2	The Sounding operation was carried out between 1018hrs and 1613 hrs
14 40	0.7	The Lagos bar is 2.918m
20 39	0.2	

Source: (Nigerian Navy Tide Tables for the Year 2017)

Thereafter, tidal observation started before sounding at ten-minute interval and ended shortly after the sounding operation. It was done using the pole mounted tide gauge at the project site. The acquired tidal data was compared with the predicted tide at the Lagos Bar for the period of execution. And the final tidal correction as predicted in the Nigerian Navy Tide Tables for 2017 was adopted. This exercise formed the basis of reducing the sounded depth to chart datum. The observed tide at the project location is presented in the Table 4.

Table 4: Observed Tides at the project site for 13th November, 2017

S/N	Time	Height	S/No.	Time	Height
1	08:50	0.72	**25**	12:50	0.97
2	09:00	0.70	**26**	13:00	0.98
3	09:10	0.68	**27**	13:10	1.01
4	09:20	0.65	**28**	13:20	1.02
5	09:30	0.64	**29**	13:30	1.05
6	09:40	0.61	**30**	13:40	1.06
7	09:50	0.58	**31**	13:50	1.08
8	10:00	0.60	**32**	14:00	1.11
9	10:10	0.61	**33**	14:10	1.13
10	10:20	0.64	**34**	14:20	1.16
11	10:30	0.65	**35**	14:30	1.17
12	10:40	0.66	**36**	14:40	1.18
13	10:50	0.68	**37**	14:50	1.21
14	11:00	0.72	**38**	15:00	1.22
15	11:10	0.73	**39**	15:10	1.25
16	11:20	0.76	**40**	15:20	1.27
17	11:30	0.78	**41**	15:30	1.29
18	11:40	0.79	**42**	15:40	1.31
19	11:50	0.83	**43**	15:50	1.29
20	12:00	0.85	**44**	16:00	1.28
21	12:10	0.87	**45**	16:10	1.27
22	12:20	0.90	**46**	16:20	1.25
23	12:30	0.91	**47**	16:30	1.23
24	12:40	0.94	**48**	16:40	1.20

2.5.4 Bathymetry Survey

The Bathymetric survey was carried out using South SDE - 28 Echosounder, Trimble DGPS receiver and PowerNav Hydrographic Software. The DGPS receiver was used to fix the horizontal (X, Y) coordinates of sounding points while the echo sounder simultaneously records the corresponding depth (Z) values for the sounded points.

The raw data acquired by the South SDE-28 Echosounder was sorted by PowerNav software (a suite in the Echosounder). The sorted data were then further processed using Hypack 2016 software, AutoCAD 2017 Software and ArcGIS 10.3 Software. The bathymetric operational principle chart is shown in Figure 2.

The perimeter and the area of the water channel were determined from the digitized map by computation. The tide data was processed to compute sounding datum. The tidal correction and reduction was achieved using Eq. 1 (Badejo, 2015).

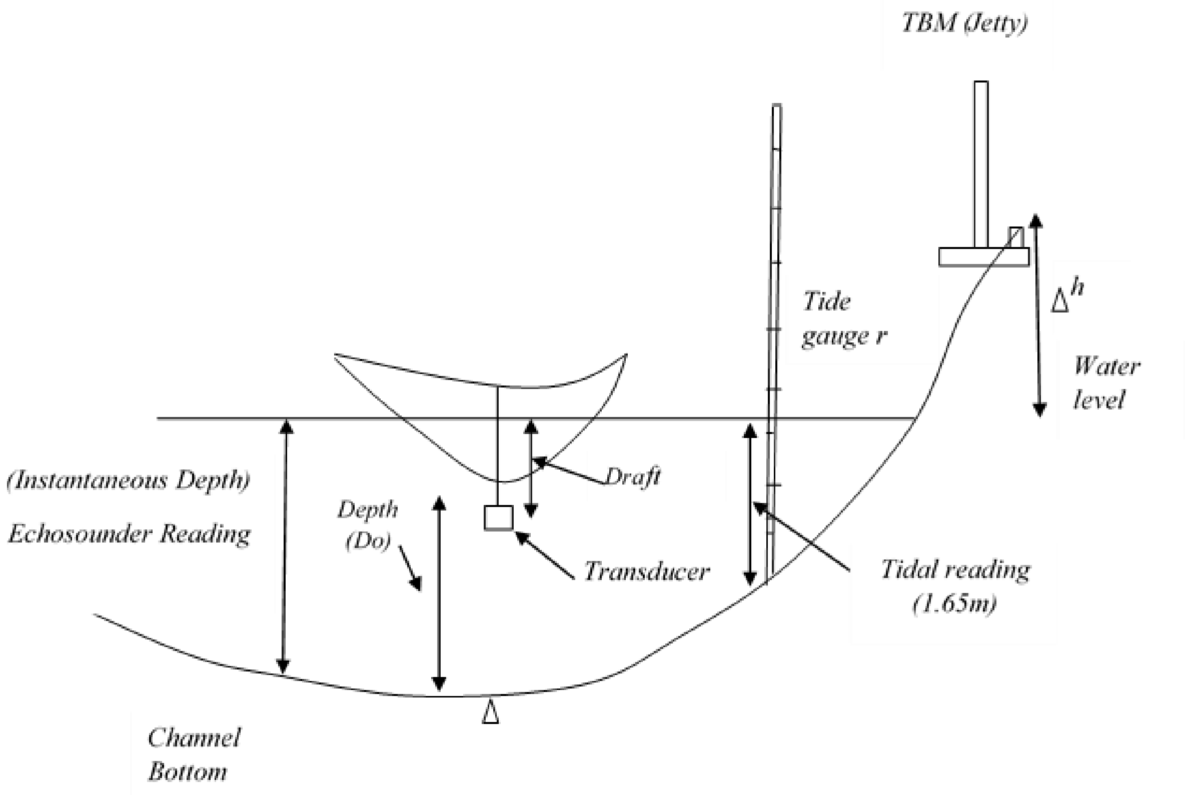

Figure 2: Chart showing the bathymetric operational principle

2.5.5 Data Reduction

The soundings obtained in the field must be reduced to standard reference plane, by subtracting from the height of the tide at the time they were taken. The predicted tidal values were used in reducing the sounding depth of this project. The predicted tidal values were obtained from the Nigerian Naval Tidal Prediction Table for the year 2017, where the predicted times and heights of high and low water were observed. Since the datum of prediction is the Chart Datum, there is no need to apply the chart datum value after the effects of tides have been announced for which is usually done when using observed tidal values. After interpolating, the tidal values are obtained for each time of sounding; the values obtained are simply subtracted from the sounded depth obtained from the field. This is the actual value of the seafloor obtained after the removal of the effect of tide and necessary correction and other phenomenon that constitute the raw data obtained from the sounding.

Mathematically,

$$True\ Depth\ (D_T) = D_O - T_C \quad (1)$$

where;

$D_O = Sounded\ depth$

$T_C \ = Tidal\ correction$

The actual depth was processed, and the values are stored in International Hydrographic Organization (IHO) format using Hypack software.

3.0 RESULTS AND DISCUSSION

The bathymetry chart of the channel was produced at standard scale of 1:5,000 as shown in Figure 3. Triangulated Irregular Network (TIN) was used to represent the seabed topography, and different shades of blue were used to show the depth variation. Areas depicted with deep blue are the deep areas of the channel and are suspected to be free of sediments or have been dredged, while the light blue represents shallow areas with possible sediment deposits. Isobaths map and 3D surface map of the bathymetry survey plotted using Surfer software are shown in Figures 4 and 5 respectively. The colour scale represents the depth variation at regular interval for visual impression. The pattern and volume of sediment trapped in relation to depths, that is, the tendency for sediment trapping occurred mainly in relation to particles sizes. Coarse particles settle down first to form delta while the fine particles preceded further down toward the seabed (Oladosu *et al*., 2019).

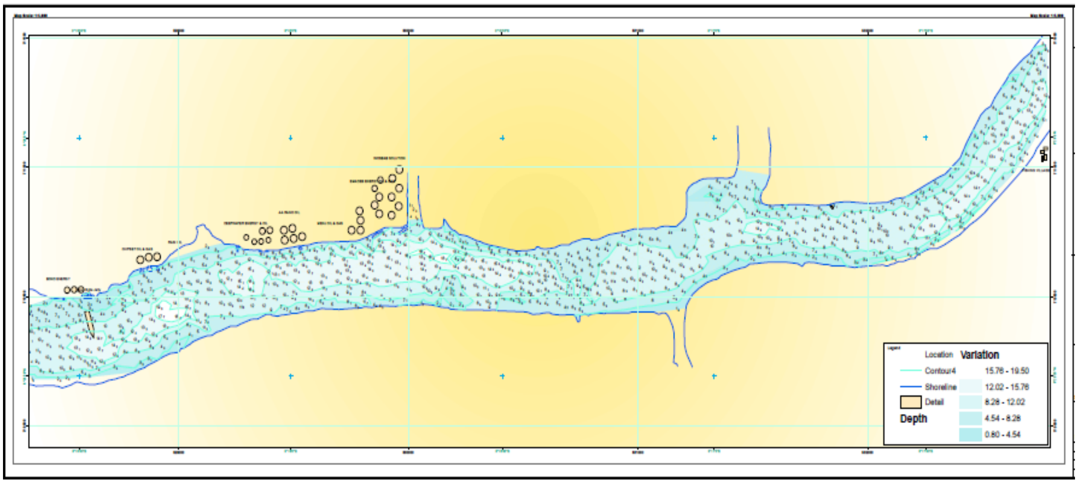

Figure 3: Bathymetry Chart of Ojo Creek channel

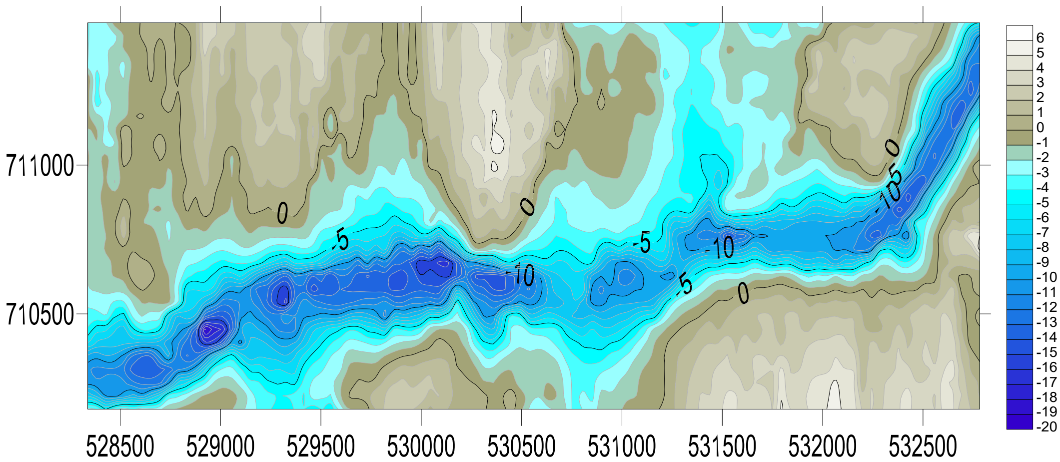

Figure 4: Isobaths Map of Ojo Creek channel

An isobath is a line on a map or chart that connects all points with the same depth values. The deep blue colour represents the centre of the channel and obvious on the 3D surface in Figure

5. The shoreline and its environs are also shown and represented with different shades of dust colour. It is evident on the colour scale that the values there are positives.

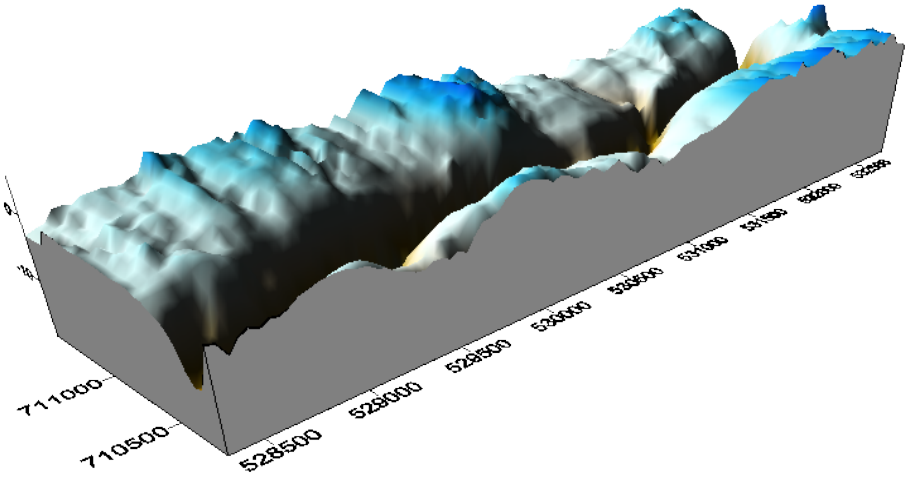

Figure 5: 3D Surface Map of Ojo Creek channel

3.1 Sediment Accumulation Volume

The volume of water present in the surveyed area was computed from the data obtained through field work using Surfer and ArcGIS and compared with the volume from existing data. From the 2008 bathymetry data, the volume of water in the study area obtained from (2008 Lagos State bathymetry survey) gave 4.47×10^{10} m^3, while in this study the computed volume of water calculated from the software grid file using kriging method (Table 5) gave 4.46×10^9 m^3**.** From the 2008 and 2017 results, a loss in volume of 1×10^9 m^3 for 9 years in the section of water channel was recorded. The reduction in volume is about 22% of the original volume. Rate of sedimentation is 0.11×10^9m^3 approximately (2.4%) annually.

Table 5: Surface Area and Volume Calculations

Description	Values
Maximum depth	19.50 m
Minimum Depth	0.88 m
Plane Height	0.00 (water surface)
Reference Plane:	Below Plane Height
2-D Surface Area	1,280,177,342.63 m^2
Volume	4,471,345,648.58 m^3
Computed Average Depth	8.89 m

3.2 Discussion on River Channel Dynamics and Sediment Impact

The impact of the quantity of sediment accumulation within the channel over the years is obvious. The channel is experiencing relatively strong environmental changes resulting from the complex interaction of natural and human induced processes that operates upon them. Due to the dynamic nature of all rivers, accurate and timely channel measurements are necessary *(*Langat *et al.*, 2018). By comparing measurements taken at different times, channel stability is determined. In order to properly study the spatio-temporal dynamics of the study area (Ojo creek), the 2017 survey data was compared with the existing 2008 Lagos State bathymetry survey data using cut and fill tool in ArcGIS 10.3 environment and the result is presented in Figure 6. The outcome of this study in terms of net loss and gain in materials were in support of previous studies (Langat *et al.*, 2018) wherein similar scenarios were obtained.

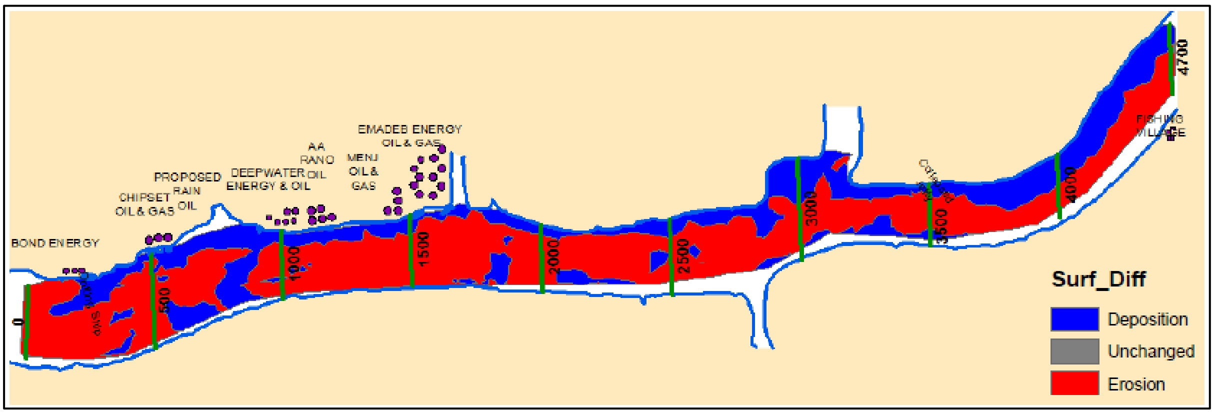

Figure 6: Ojo River channel dynamics (Accretion and Deposition)

The findings from the analysis as shown in Figure 6 are summarized below;

i. The net loss and gain in material over the years were revealed to be 1,601,251.949 m^3 and 1,017,252,326.841 m^3 respectively. Therefore, the volume of sediment or eroded materials was calculated to be approximately 1,015,651,074.892 m^3.

ii. The average depth of the study area as at November, 2017 was calculated to be 8.89 m while that of 2008 was calculated to be 8.60 m given rise to a difference of 0.29 m.

iii. There were erosion activities along the centre of the channel; this depicts the maintenance dredging activities that occurred along the centre of the channel over time in order to make the channel navigable. However, sediment accumulation occurred in some parts of the channel. There's need for recurrent survey and maintenance to ensure safe navigation.

iv. The massive deposition along the upper part of the channel is evident because dredging activities was restricted in the region to protect tank farms.

v. The deposition on the channel between 500 m and 1000 m is as a result of ongoing reclamation process for the then proposed Rain oil tank farm by Promenade Oil and Gas Limited.

4.0 CONCLUSION

The bathymetric survey of Ojo creek channel revealed a loss in water volume totalling about 1,015,651,074.892 m^3 as a result of sedimentation over a period of 9 years considered in this study. The depth within the project area is between 0.88 m to 19.50 m which shows that the channel is relatively deep with an average depth of about 8.89 m and it is navigable by vessels having draft not beyond 8 m. However, when compared with the survey done in 2008 some areas of accretion were detected due to sediment accumulation trapped along the creek channel. This poses threat to safe navigation if the sediment density is not properly managed for a long period. In view of the findings from this study and importance of the creek channel, the followings are recommended:

i. The government should monitor and regulate the dredging activities within Lagos Lagoon and creeks to prevent unauthorised dredging and sand mining.

ii. Routine bathymetric surveys should be carried out to provide information on the channel for sustainable maintenance and management.

iii. Data acquired and bathymetric chart produced should be used to create spatial database for future research, monitoring, maintenance and management of the creek channel.

iv. The government should set up monitoring agency to check indiscriminate disposal of waste into the creek.

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