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Seamless Topo-Bathymetric Surveys of Maiyegun Estate Waterfront Lagos State, Nigeria

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Abstract

Topo-bathymetric surveys are mostly desired in coastal area where water and land perpetually interact. This work explore the ground-based methods of topographic and bathymetric surveys in collecting data for the appropriate description of the Mayegun Estate water front and the adjoining land topography. To acquire depth data at pre-defined transects lines, hydrographic vessel and a trained diver were engaged. The topo-bathy DEM was produced at 1m and contour at 0.5m interval. The wave pattern was determined to be semi-diurnal. The fitted second order polynomial regression equation for wave amplitude against time yielded ($y = 2E\text{-}07x^2 - 0.0003x - 0.0276$ at $R^2 = 0.0064$) while that of depth versus sounded points gave ($y = 5E\text{-}09x^2 - 5E\text{-}06x - 7.1512$) at $R^2 = 0.0019$. The vertical and horizontal uncertainties were computed as 0.015m and 5m + (-0.47) at 95% confidence level based on (IHO) specification for order 1a. This principle can be adopted with caution as a viable alternative for topo-bathy surveys to minimize cost.

Keywords: Topo-bathymetric, Buoy, DEM, Depth, GNSS RTK, Tide

1.0 INTRODUCTION

Accurate mapping of coastal area remains a challenging task to the scientists, engineers, and water resources managers. Based on National Oceanic and Atmospheric Administration [1], it is important to understand the effects of a change in water level, the impacts of inundation, and various inter-related processes taken place around the dividing line in coastal area. This can be achieved by defining a seamless surface that represents the topography of the land and the bathymetry of the seafloor [1] or river bottom[2]. The coastal environment and its ecosystems are constantly changing (dynamic) in nature [3]. The methods of carrying out observations at the intersection point of land and water are either inter-dependent or entirely different in approach and instrumentation. Topo-bathymetric surveys are required to generate the dataset needed for topographic modelling and depth data fusion, for planning, design, and construction of engineering structures like dam, retention pond, bridge, shore protection, land reclamation etc. Mapping of coastal areas are mainly based on data acquired from passive or active sensors.

Although bathymetric mapping of coastal area from multispectral imagery known as satellite derived bathymetry (SDB) can be a highly efficient and cost-effective way of obtaining nearshore data [4]; [5] [6], yet its accuracy have been adjudged to be good and reliable only, for reconnaissance purposes[7];[8]. Other uses of SDB are in benthic habitat mapping [6]; [9]; [2]; [10], coastal monitoring and modeling [11]. Despite the fact that SDB is still able to provide meaningful outputs for various applications, including its ability to help fill the glaring hole in bathymetric coverage along shallow water coastlines where it has been deemed too dangerous for sea vessels to obtain sounding measurements [4], it has no recommendation for entire reliance in providing accurate data for engineering construction work such as shore protection. Therefore, the aim of this work is to provide alternative way of creating seamless topo-bathy digital elevation model, contour and triangulated irregular network for the study area. The objectives includes, the determination of the prevailing tidal pattern, the generation of topography of the adjoining land and the production of underwater DEM. The methods involve the integration of 3D topo and bathy information obtained from ground-based techniques. The information obtained is typically useful for near-shore construction of any kinds.

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2.0 THE STUDY AREA

The study area is Maiyegun Estate, located in zone

31N of the Universal Transverse Mercator (UTM) with Easting and Northing coordinates given as: ($3^0$28'00"E; $3^0$31'00"E and $6^0$26' 00"N; $3^0$24' 00"N). Figure 1 shows the map of the study area.

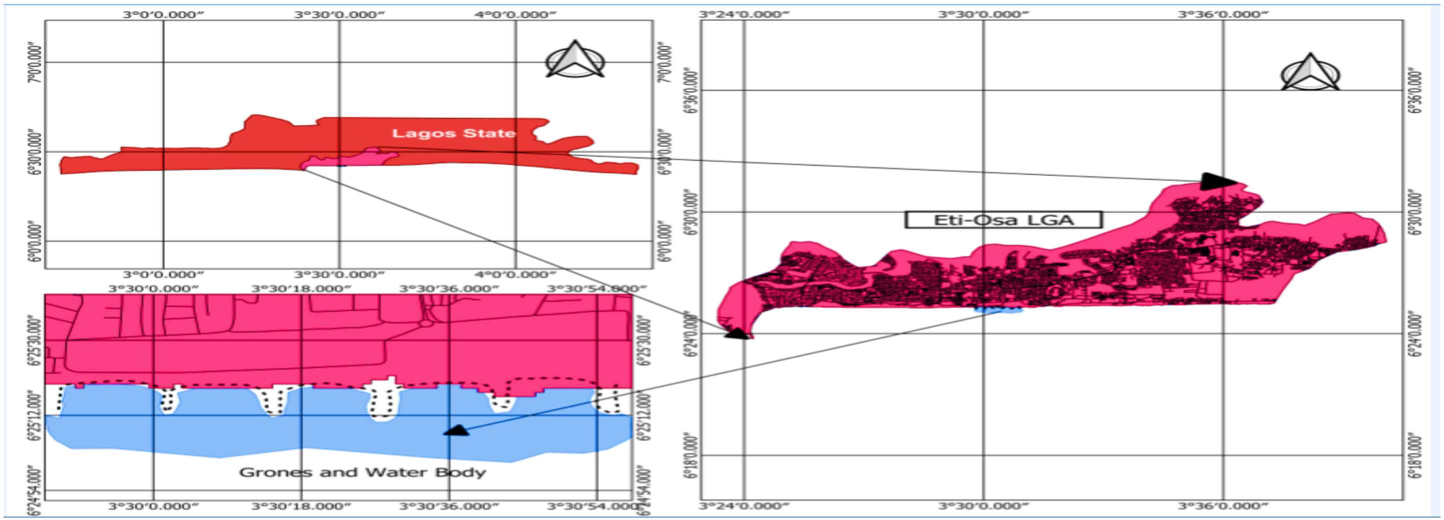

Figure 1: Map of Lagos State showing the position of the study area

Figure 2 represents Maiyegun water front shown in red at the right hand side and the tide gauge from where vertical reference was taken. The picture of the tide gauge station was superimposed on the Google Earth imagery to show the relative position of the study area to a standard Nigerian Navy dockyard established tide gauge.\

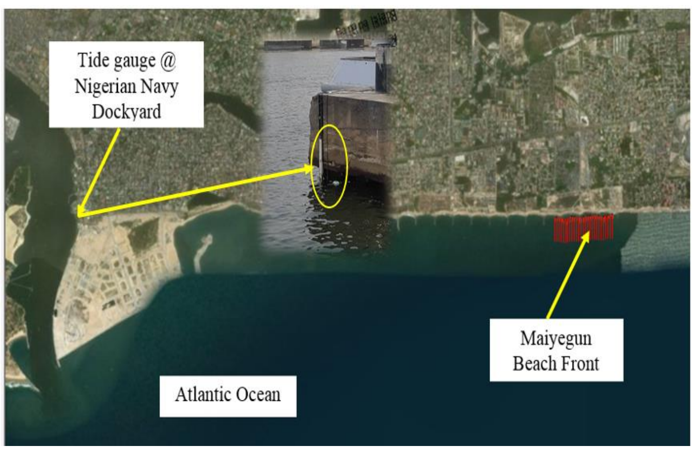

Figure 2: Navy tide gauge at the vicinity of the project location (source: Google Earth & picture taken from site)

From West to East, the survey extent covered Groyne-8 through Groyne-12 (bay-1 to bay-5) from longitude 3"29'48.16"E to 3"30'54.87E, which is a distance of approximately 2km. Furthermore, from North to South, the survey extended from the +2.0m Chart Datum contour to about 100m beyond the head of the groynes, with a distance of approximately 400m. Therefore, the survey area is approximately 0.8km^2. The survey allowed for contouring of the entire area at 0.5m depth intervals and the creation of sections at 50m intervals along the length of the beach.

3.0 METHODOLOGY

The methodology and procedure followed are briefly summarised in the diagram presented in Figure 3.

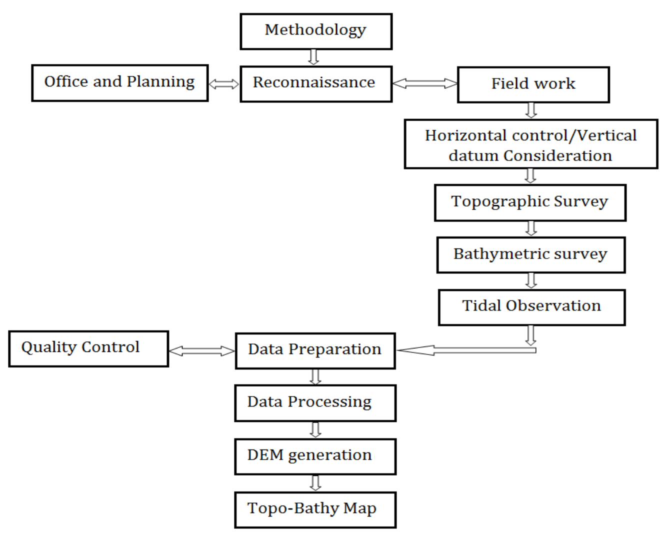

Figure 3: Flow diagram of the methodology

3.1 Topographic Survey Observation

Topographic survey commenced by setting the GNSS base receiver on benchmark ME2 which served as the vertical control station. The survey lines were pre-constructed in AutoCAD and downloaded to the RTK data logger/controller to enabled navigation and maintenance of the survey measurement on the required lines. The topographic points on the beach were picked via RTK-GNSS strictly at low tides, in order to cover as much extent into the sea as possible. A level of –1.5m were often achieved away from the shore into the sea. Plate 1, shows the GNSS base station and the rover at bench mark ME2

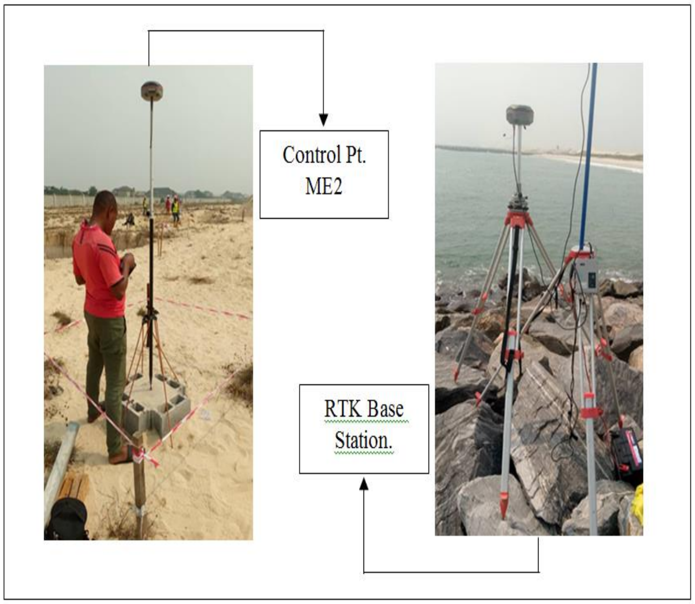

Plate 1: GNSS equipment setup on survey stations

3.2 Bathymetric Survey Operation

The procedure for bathymetric survey involved the use of hydrographic standard vessel of (length 7m x width 3m) having 0.3m draft, powered with 1 x 75 Hp Yamaha engines. The Echo-sounder's transducer was mounted on the Port side of the vessel and GNSS antenna was mounted above it to give zero offset from it. The Echo-sounder was interfaced with a navigation computer via comport. The movement of the vessel was guided by the navigation computer through the Hypack hydrographic survey software. The Echo-sounder was calibrated with a Bar-check Plate graduatedn at 1m interval.

The Toshiba Laptop received the corrected GNSS derived Latitude and Longitude from the KOLIDA K5-UFO GNSS rover. The antenna position is converted into the local datum coordinates. The coordinate reference system used for the project is MINNA datum. While for vertical reference station, Lagos datum of 1955 was used. The RTK antenna height was measured from the antenna reference point to the water level so as to provide continuous readings of water level while the echo-sounder measures from the water level to the seabed. This arrangement yields direct measurement of the seabed elevation with respect to the datum, this helps to (eliminating heave) and provided tide readings at 1sec stored in the software hard disk for post-processing onshore. A total of 36 predefined transect lines at 200m spacing were traversed following the Hypack Software onscreen guide. Figure 4, shows the vessel and the equipment arrangement.

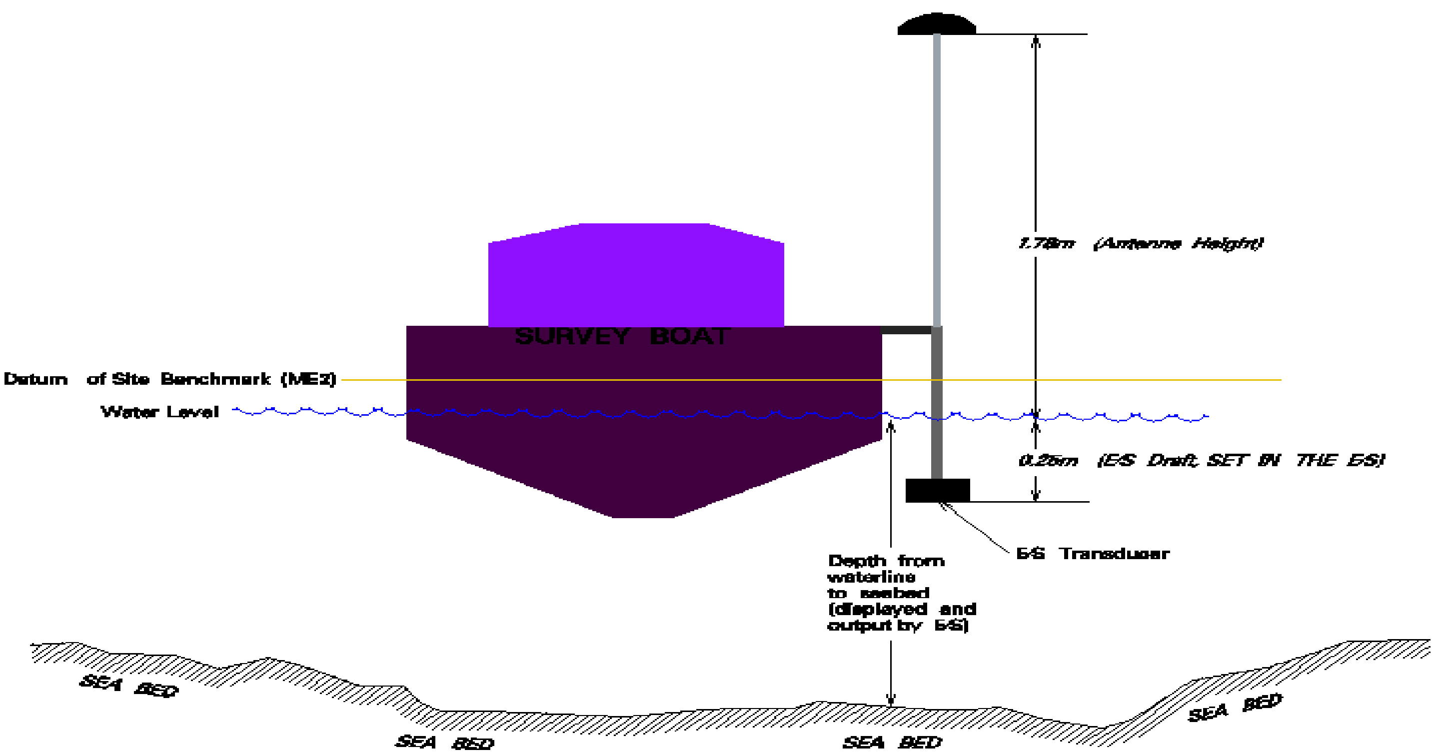

Figure 4: Bathymetry survey grade vessel with equipment

3.3 Tidal Observation Procedure

The site benchmark is ME2 having a 3D coordinate values in UTM Zone 31N as: (556624.604mE: 710184.814mN: 3.527m). Two other Benchmarks TID-1 and TID-2 were marked at the groyne and coordinated from (ME2) on the sand fill above flood level with values indicated as: TID-1 (556665.415mE: 709746.679mN: 3.094m) and TID-2 (556662.522mE: 709711.657mN: 3.338m). The RTK-GNSS rover mounted on buoy was used to calibrate the Tidemaster tide gauge water level readings to ME2 Benchmark at low ebb. Observations were performed for two (2) weeks from 22/11/2019 to 1/12/2019. The tidal height at the commencement of observations was 0.4m. As the days progressed toward the spring period, it increased to 1.5m on the finishing day. From the Tidal analysis, the MSL is 0.1m below the Zero of ME2. This means that the Level of ME2 above MSL is 3.527m+0.1m =3.627m. Lagos Chart Datum (LCD) = Zero of ME2 - 1.1m (that is, 1.5m-0.4m = 1.1m) or MSL – 1.0m (that is, 1.1m- 0.1m=1.1m). The result is as shown in Table 1.

Table 1: Calibration of Tidematser and RTK GNSS

Time	TideMaster WL	RTK-GNSS WL (1' ave. of 60 reading/sec)
15:30	1.472	-0.292
15:40	1.459	-0.311*
15:50	1.448	-0.372
16:00	1.430*	-0.378
16:10	1.443	-0.361*
16:20	1.441	-0.394
16:30	1.448	-0.357
16:40	1.452	-0.321*
16:50	1.450	-0.323
17:00	1.485*	-0.289
17:10	1.481*	-0.271
17:20	1.467	-0.247
Mean =	**1.456**	**-0.326**

*Asterisked values are outliers.

Mean without outliers = 1.451 and-0.313

Note: Correction to TideMaster WL = -0.326m - 1.456m = -1.782m, approximately -1.8m or (-0.313m - 1.451m) = -1.764m, which is approximately -1.8m also. Therefore, the raw gauge readings were corrected by -1.8m to bring their values to the height of ME2. The Nigerian Navy Dockyard Quay (Long: 003-24-21.78E, Lat: 006-25-20.81N) was used as independent check against the disturbing wave action.

3.4 Bathymetric and Topographic Quality Control

(i) Bathymetric Quality Control: The Echo-sounder was calibrated with a standard bar check plate and was adjudged to be measuring correctly before deployment for data acquisition.

(ii) Topographic Quality Control: The Topographic survey was carried out with Real-Time Kinematic GNSS equipment. Through which elevation was transferred from the Base Station ME2 to a new station TID-2 which was subsequently used for the entire Topographic and Bathymetric survey works. The coordinate transfer surveys were repeated twice on two consecutive days and yielded similar result with negligible error.

(iii) Vertical and Horizontal Uncertainties: The information useful for computing uncertainties in depth for vertical and horizontal is provided by [12] as follows.

$$\text{TVU} = \pm\sqrt{a^2 + (b \times d)^2} \quad (1)$$

Where:

a: -signifies the portion of uncertainty that is invariant with depth with value = 0.5m

b: - refers to a coefficient which represents that portion of the uncertainty that varies with the depth, with value = 0.013m

d: - is the maximum depth obtained = -9.4m

b x d: - represents the portion of uncertainty that varies with the depth = -0.1222

For this work, maximum depth of -9.4m was obtained and is less than 100m by the specification of order 1a. The uncertainty is derived as follows:

$\text{TVU} = \pm\sqrt{0.5^2 + (0.013 * 9.4)^2} = 0.515$ (0.015 at 95% confidence level).

Again, Total Horizontal Uncertainty (THU) is given by IHO as: 5m + 5% of depth

This implies that:

THU = 5m + 5/100 * -9.4m = 5m + (-0.47) at 95% confidence level.

4.0 RESULTS AND DISCUSSIONS

4.1 Reduced Depths

The reduced sounding depths for the bathymetric survey operation is as shown in Figure 5.

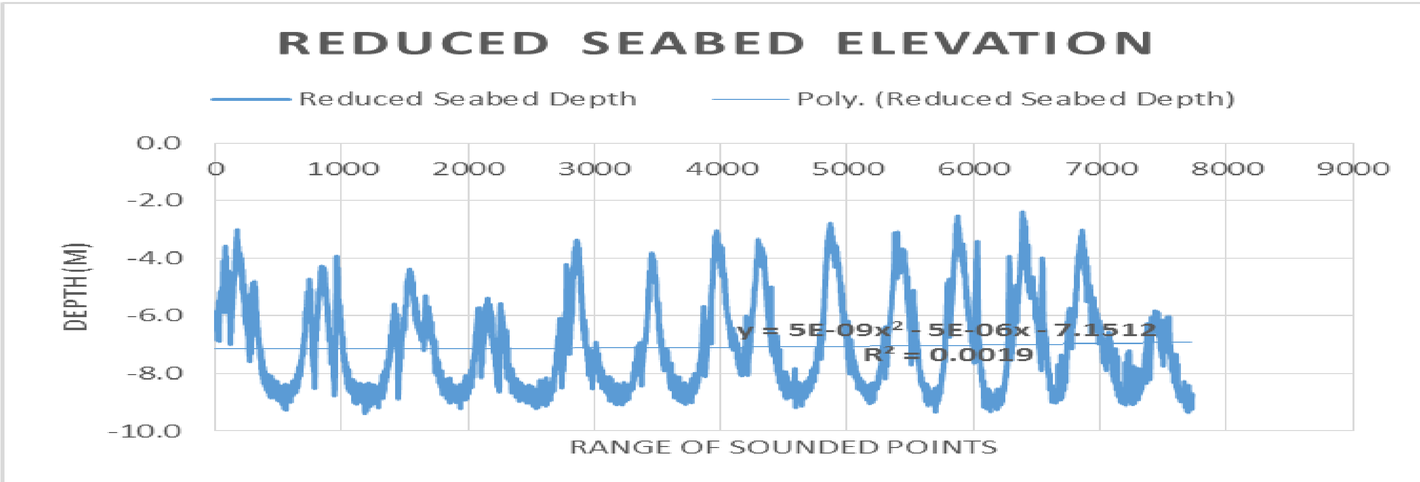

Figure 5: Plot of the reduced sounding depths

Figure 5 shows the reduced sounding depth chart over the entire study area. From the zero level of the tide gauge to depth range of about -2.4m it is obvious that the height of water column was enough to sustain the sounding vessel here. The vessel started to take measurement at depths above -2.4m to reach the highest depth of -9.4m seaward. The diver covers the acquisition of topographic depth data to -1.5mseaward by the GNSS RTK rover. In all a total of 7,742 points were fixed with their recorded depths. Data gap were interpolated for by IDW interpolation method. The pattern taken by the plotted chart of the recorded depths showed that the groynes contributed to the nature of the sea bed topography obtained at study area. A second order polynomial was used to fit the regression equation for obtaining the depth as a function of time: ($y = 5E\text{-}09x^2 - 5E\text{-}06x - 7.1512$ at $R^2 = 0.0019$).

4.2 Tidal Observation

The result of the tidal observation and the duration of measurement were plotted with the amplitude of the wave in the positive and negative from zero state of equilibrium. The plot is as displayed in Figure 6.

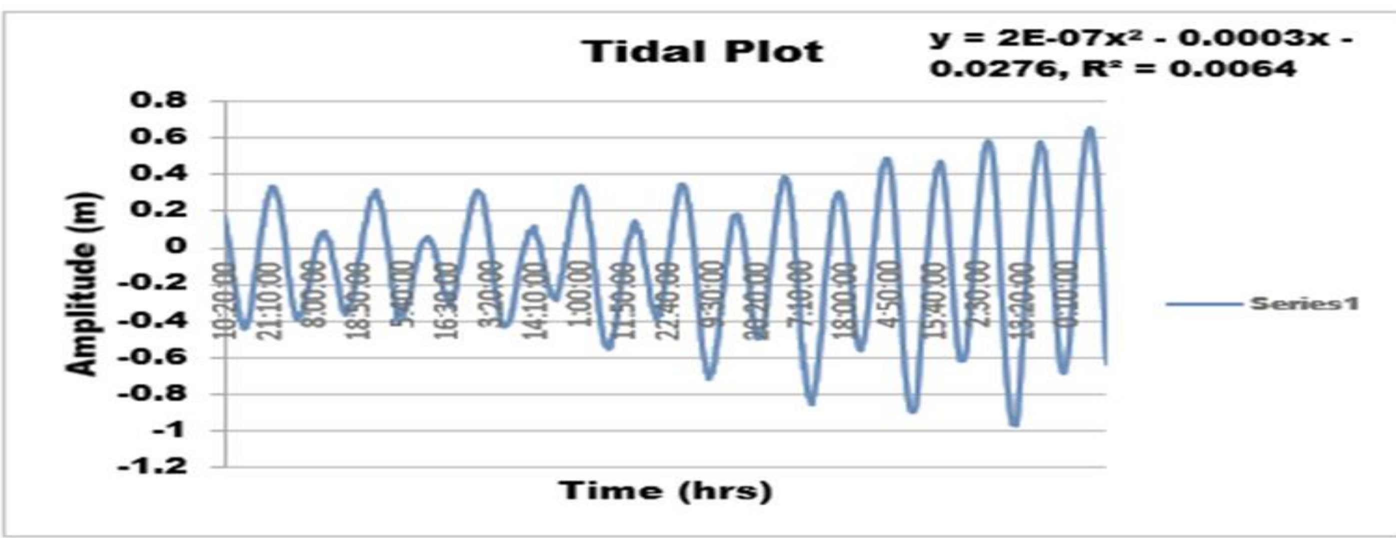

Figure 6: Tidal plot of height versus time

Figure 6, shows that observed tides at the study area are basically semi-diurnal in nature, with two high waters (H.W) and two low waters (L.W) every 24 hours. A total of 1,295 points were recorded having the maximum and minimum tide heights of 0.658m and -0.974m respectively. This confirmation is in conformity with [13]; [14]; [15], who described the tide along Nigerian coast as semi-diurnal. The second order fitted regression equation for wave amplitude against time yielded is given by: ($y = 2E\text{-}07x^2 - 0.0003x - 0.0276$) at $R^2 = 0.0064$.

4.3 Generation of TIN, DEM and Contour Surface Maps

The triangulated irregular network (TIN) and the digital elevation model (DEM) maps were created in ArcGIS 10.3 software. Data were added from the excel file formatted for this purpose. Figure 7 is the output of the analysis carried out. [9], reported a similar topo-bathy result differs only in that they used Lidar data in conjunction.

Figure 6, is the TIN produced for the study area. IDW interpolation method was used because it can close-up few open-ended areas observed from land-water overlap. The elevation of topo points are between 0.39m to 8.22m, while the bathy points are between -1.55m to -9.38m with respect to the site BM. The -1.55m to -9.38m are possible for the vessel to traverse but -0.39m and -1.55m was where diver was engaged.

The post-processed data were superimposed on the georeferenced Google Earth imagery of the study area. We ensured that the coordinates are in the same datum, otherwise it will not be possible to successfully derive the map.

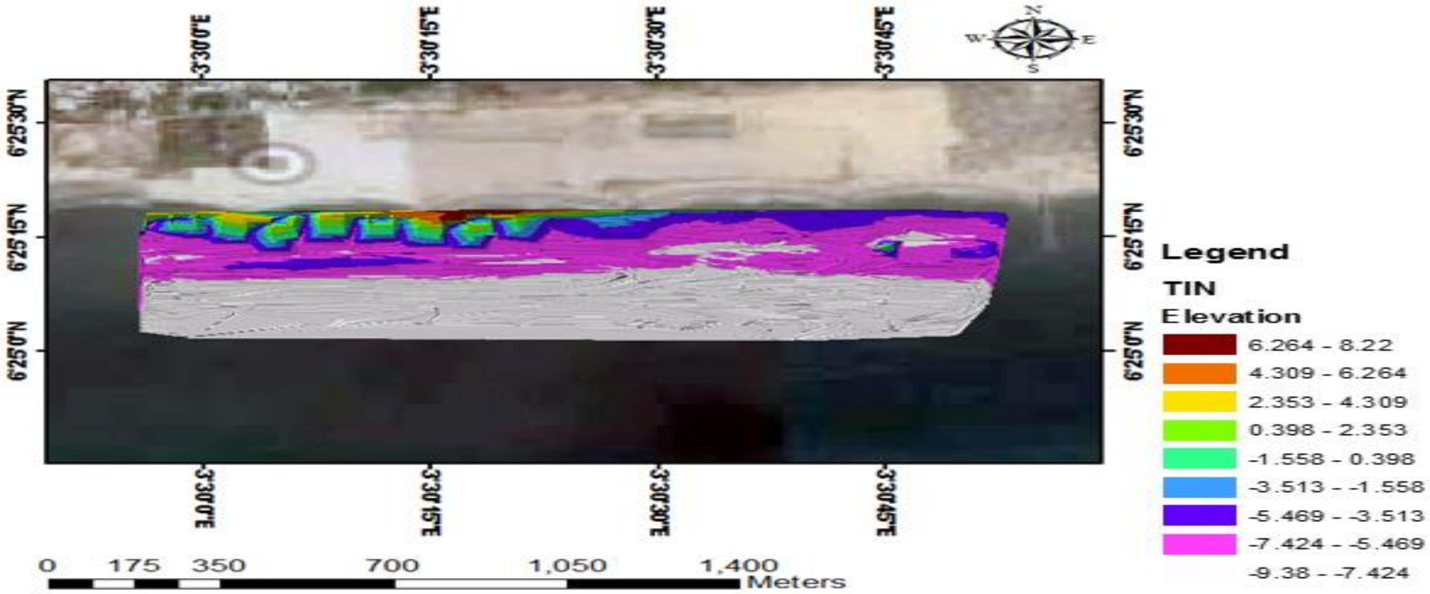

Figure 6: TIN of the study area

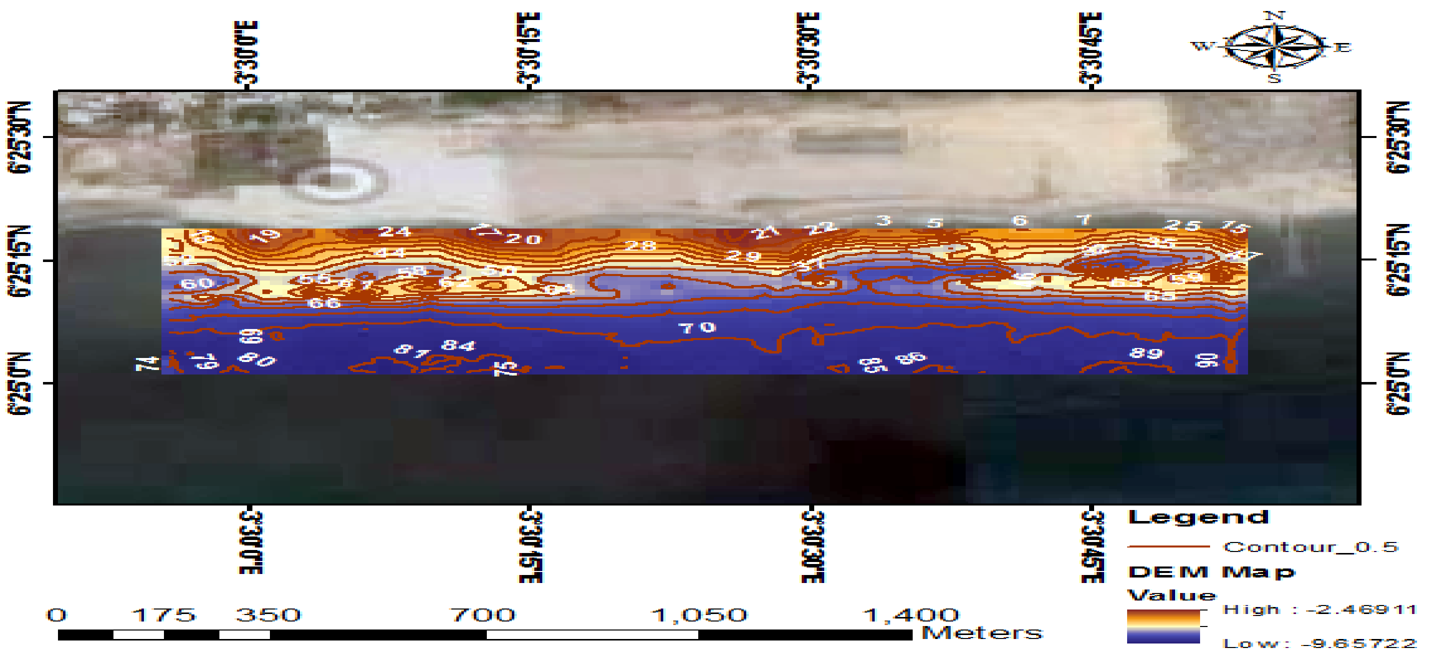

Figure 7: Topo-Bathy DEM and contour maps of the study area

The DEM in Figure 7 is a model of the terrain comprising of the two overlapping surfaces. The DEM was created by making use of the TIN created earlier as the input surface. The classification are -2.46m for high and -9.65m for low areas towards the Atlantic Ocean. The contour map is produced at 0.5m interval. In order for bathymetric data to be correctly and fully utilised, integration of bathymetric and topographic surveys vertical datum connections and their respective relationships must be clearly determined and described [12]. In the scientific literature, some methods have been employed to assimilate topographic and bathymetric data into a seamless surface model such as found in [6]; [17]; [18]; [19];[20].

5.0 CONCLUSION AND RECCOMENDATIONS

This work has demonstrated the efficacy of integrating data obtained from ground survey using GNSS and bathymetric survey using Midas Echo-sounder equipment in the production of seamless topo-bathy map of Maiyegun Estate water front at contour interval of 0.5m. Topographic elevations was 1.70m while bathymetric elevation was -0.50m respectively. The difference is 1.2m which is within the 1.5m depths covered by taken observations where the vessel could not gain enough depth. The beach head elevation ranges from +3m to 6m.

The following are recommended from the results of this work. Observation should be taken when wave action is relatively calm. Unmanned Surface Vehicle can be used at low tide to reduce the hazard or risk level of using a diver.

6.0 ACKNOWLEDGEMENT

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