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Delineation of Topography with respect to Mean Sea Level using the Geoid Method for B-Dere and Ejama-Ebubu in Rivers State, Nigeria

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ABSTRACT: Accurate leveling is critical to every hydrogeological investigation. Areas of study in need of data point leveling include flooding, design of drainage infrastructure, mapping of drainage basins, solute/contaminant transport, groundwater recharge and discharge zones. The objective of this paper is therefore to employ the use of geoid method in the correction of Global Positioning System (GPS) derived elevation values to delineate the natural topography vis-à-vis the mean sea level at B-dere and Ejama-Ebubu in Rivers State Nigeria. The data revealed that B-dere study site located about 19 km southeast of Ejama-Ebubu was found to be below sea level as all five sampling points returned elevation values varying between -6.4 m-msl and -3.5 m-msl. Four sampling points located northwest of Ejama-Ebubu study site out of the thirteen positions occupied also yielded elevation values differing between -4.2 m-msl and -1.1 m-msl. These areas are topographic troughs and subject to flooding - a realization impossible to reach using the GPS elevation reading directly since results are always positive.

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Years ago in an international meet hosted in Benin City, Nigeria, the problem of geodetic survey with respect to hydrogeological investigations was brought to the fore (Oteze and Ogude, 1988). The researchers were of the opinion that geodetic surveying was more of 'academic interest in hydrogeological investigation'. In their words: 'Inaccuracies which greatly affect the quality of hydrogeological investigations currently undertaken arise mainly from the heighting techniques being used and from failure to determine accurately the planimetric positions of these points being heighted.' Thirty-five years down the line, there has not been much unification of thought or improvement on this most critical aspect of site investigation – topographic field survey and vertical geodetic referencing (VGR). There is a correlation between groundwater and surface water distributions that plays a critical role in every local ecological unit (Kalbus et al, 2006). One of such association is in the attribute of hydraulic connectivity – a feature that brings about localized hydrological units, hence drainage basins. The delineation of these local watersheds is the focal point of hydrological/hydrogeological studies. Several infinitesimal topographic and hydraulic divides contribute to the provincial drainage patterns. Accurate heighting/leveling is therefore critical to every hydrogeological, engineering assessment towards infrastructure proposals. Fields of study in need of data point leveling include flooding, design of drainage infrastructure, mapping of drainage basins, solute/contaminant transport, groundwater recharge

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and discharge zones. The aforementioned components, essential for a successful urban planning, are dependent on accurate heights from a common datum. Reliable inference to geological structures and phenomena (discontinuity, roll-over structure, groundwater mounding) underlying a site can only be affirmed on the basis of accurate datum referencing - a direct outcome of leveling in ground surface survey. Analytical groundwork design had depended on leveling data provided by professional surveyors for depth measurement below ground level (bgl). This approach had been applied in studies to correlate lithological units, define static groundwater levels, flow directions or paths, and even contaminant plumes. Aside the issues of using inaccurate localized benchmarks, hydrogeological studies do not have the freedom of generous funding to accommodate the hiring of a separate professional surveyor. So most earth science researchers had assumed a flat plane denoted as a horizontal line/surface on or over the earth under which every subsurface layering or structural profile is adjusted. Quite a few have continued the use of estimated elevation values obtained from topographical maps or visual estimates in studies of critical dimension. The coming on of space technology, had introduced the use of the handheld global positioning system (GPS) devices in survey during studies. Elevation values obtained therein had been applied directly to try to solve height challenges. The issues, therefore, informing this study arose from the practice of localized benchmarking (BM), application of a flat surface tied to a temporary bench mark (TBM), use of elevation values from topographic maps and the direct application of GPS elevation readings in hydrogeological and geotechnical investigations. The concern for elevation correction had always come up during pre-remediation investigations towards an onshore oil spill site in the Niger Delta region of Nigeria. Practitioners are expected to come up with a leveling idea for VGR. Even when surveyors conduct leveling exercise using a local bench mark, the authenticity of the TBMs used or the process of application could not be verified. In most survey theodolites (electronic or optical) the altitude (z), is usually determined through series of adjustment relative to aerial reference point called - benchmark (BM). The leveling involves adjusting all occupied locations in the area studied to a plane surface under which gravitational attraction becomes normal at all points (Filomeno, 2000). Usually, surveyors consider the horizontal line and the level line in the optical instrument as one and the same thing due to the relatively short distances that they cover. The objective of this paper is therefore to employ the use of geoid method in the correction of Global Positioning System (GPS) derived elevation values to delineate the natural topography vis-à-vis the mean sea level at B-dere and Ejama-Ebubu in Rivers State, Nigeria.

MATERIALS AND METHODS

At longer distances, the horizontal line is tangential to the level line due to the curvature of the earth and measurements would be subject to arithmetic adjustments relative to an arbitrary height and reduced level.(Figs.1 and 2). Remarkably, both in the field of geology and survey the mean sea level satisfy the need of a datum (Freeze and Cherry, 1979; Filomeno, 2000 and Fetter, 2001). By implication all elevation readings should be referenced to the mean sea level (msl). For the purpose of this research, two major survey techniques will be here expounded – the conventional and modern methods.

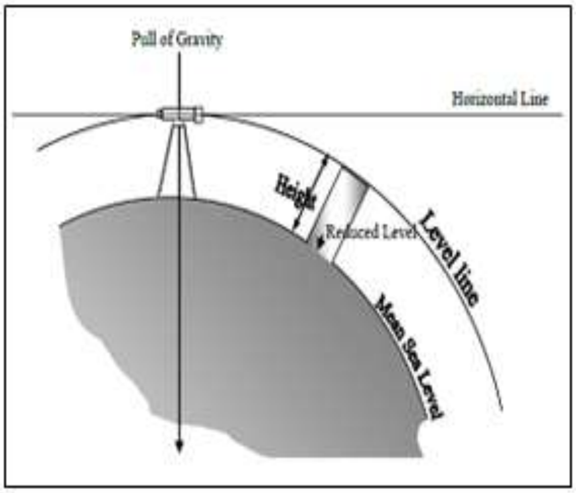


Fig 1: Illustration of Basic expressions in leveling (Filomeno, 2000)

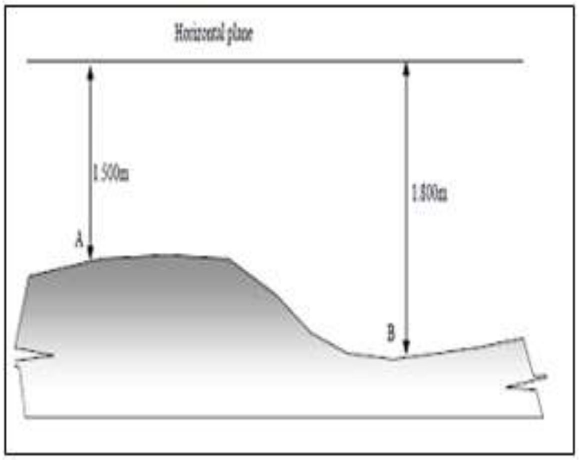


Fig 2: Illustration of leveling in surveying (Filomeno, 2000)

The traditional method of leveling latches on the open sea by establishing ordnance bench marks (OBM) relative to the mean sea level (ordnance datum). These are expanded into national grids of fixed displacement and made available for stakeholders (USACE, 2010). Site investigators could then key onto the nearest OBM to determine a site master bench mark (MBM) on which temporary bench marks (TBMs) and subsequent leveling can be evaluated (Filomeno, 2000). This is certainly not the leveling practice in Nigeria and even so, it cannot meet the need of hydrogeological investigation. The modern method refers to the satellite-based GPS ellipsoidal reference systems. After Hurricane Katrina in 2005, a study conducted 'found a number of project elevation and reference datum issues'. The elevation of engineering infrastructures built for flood protection and water control in the affected areas were referenced to uncertain or land-based geodetic vertical datum instead of hydraulic/water level referenced datum. The engineers misunderstood the proper application of satellite-based (ellipsoidal) and water level datum to engineering and construction projects. Similarly, there is a general opinion about the inaccuracy of the elevation obtained by the GPS device among users leading to complete discounting of the elevation parameter in the device. Terrain surveying can be improved by demonstrating the relationship between hydraulic/tidal and geodetic datum in geodetic referencing by applying the universally acceptable WGS 84 NAD 83 EGM 96 reference geoid (USACE, 2010).

The Principle of the Geoid: Geographic coordinates depicted on the GPS receiver screen consist of latitude, longitude, elevation and these define the position of a point on the surface of the Earth with respect to some "reference ellipsoid." The reference ellipsoid is the datum surface that is GPS-derived from the World Geodetic System of 1984 (WGS84) reference system (UNAVCO, 2019). The ellipsoid surface cuts through all level surfaces since it is independent of the Earth's gravitational force (Fig. 3). So the elevation that the GPS receiver record is based on the GPS ellipsoid surface and it is always positive. The GPS elevation reading must be converted to reference the mean sea level (msl). The geoid is the equipotential surface of the Earth's gravity field that best approximates the mean sea level when it is at rest (Michael, 2011). The equipotential surfaces are irregular surfaces whose gravity potential energy remain constant at every point (Fig. 3). The geoid can be lower or higher than the ellipsoidal surface (Fig. 4). When the geoid is higher than the ellipsoid the geoid height (the difference between the geoid and ellipsoid) will be deducted from the ellipsoidal height to correct it to the true elevation; whereas the reverse will be true if the geoid is lower than the ellipsoid (Fig. 4). The numerical ellipsoidal height "h" determined by GPS can therefore be converted to the orthometric/true height "H" by using the arithmetic relationship:

$$H = h - N \quad (1)$$

Where, h = Ellipsoid Height, H = Orthometric (True) Height (above msl) and N = Geoid Height

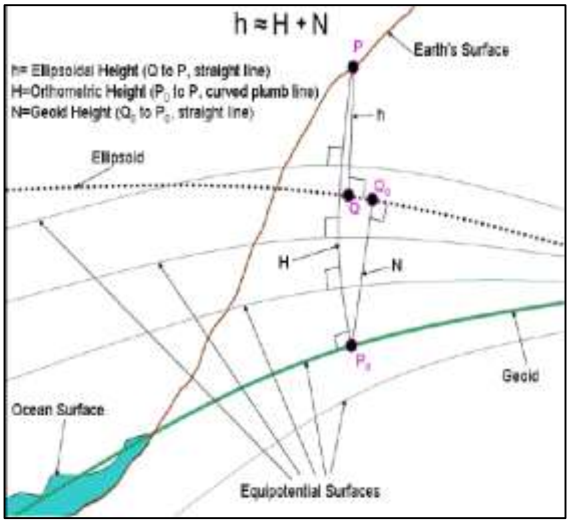


Fig 3: Relationship between the Ellipsoid, Geoid and Orthometric (True) heights (USACE, 2010)

It is necessary to note that the actual sea level (geoid) cannot be static as the sea level everywhere is subject to tidal influence. On the average, sea levels vary on hourly basis, coinciding with the o'clock; that is why dwellers on the coastline can reasonably predict high and low tide occurrences. Time-based distribution of data on o'clock basis means the sea level is expected to be at the same undulation in that duration (i.e., 9a.m. – 10a.m. etc.).

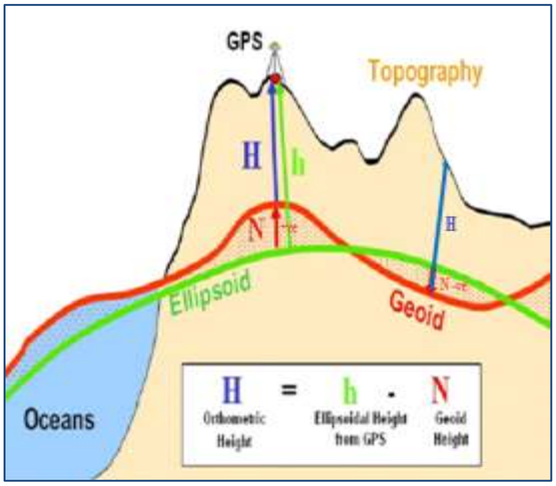


Fig 4: Schematic Representation of a GPS Elevation Correction (UNAVCO, 2019 Adapted)

Developed Earth‟s gravitational models (EGMs) incorporated into the Geoid Height Calculator software is useful in calculating the geoid height at any given 'xyz' coordinate obtained from GPS using the WGS84 and North American Datum of 1983 (NAD83) reference system (UNAVCO, 2019). The Geoid Height Calculator online software accomplishes the task of correcting GPS field elevation readings to mean sea levels by: (a) presenting the geoid in the occupied location as a color-coded bar scale, (b) pinpointing the occupied station as a 'black dot' in the world map and (c) evaluating the true elevation from the field data comprising the 'x, y' coordinates in degrees and the accompanying GPS altitude reading in meters.

Niger Delta Settings (Topography, Geology and Hydrogeology): Niger Delta region comprises nine southern states of Nigeria namely Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and Rivers states (Fig. 5). The continental area of rainforest type vegetation receives between 1400 – 3000 mm of rainfall annually (Abija and Nwankwoala, 2018). The region exhibit moist evergreen and semi-evergreen as well as mangrove and swamp types of forest. The regional landscape is low-lying (0 to 100 m-msl) with minor undulations. The region comprises three basin designations (Akindele and Adebo, 2004) namely the: Benin – Owena River basin involving Edo and Ondo states characterized by dendritic drainage pattern, Delta river basin which cuts across Delta, Bayelsa and River states and Calabar basin (east of the Niger).

Fig 5: Physical Map of the Niger Delta States of Nigeria (after ESRI, 2021)

The Sedimentary basin of Southern Nigeria is generally outlined as a scene of cyclic sedimentation (Nwajide, 2013) - a function of the rate of deposition (Rd) and subsidence (Rs). The Tertiary stratigraphy comprises three chronostratigraphic units - Akata, Agbada and Benin Formations in ascending order. The sedimentary succession is an overall coarsening upward sequence of more than 12000m thick (Short and Stauble, 1967).

The topmost Benin Formation outcrops at surface in many states of the Niger Delta: at Elele – 1 wild-cat well (N5º 4' 12"/E6º 50' 4") it was logged from 0 mbgl to 1402 mbgl (Short and Stauble, 1967, Nwajide, 2013). The Formation is mainly sand units, generally unconsolidated, with pebble beds in places as well as clay and sandy clay bodies occurring in lenses. The sequence is of Oligocene to the Recent.

The Agbada Formation, underlying the Benin Formation, is mainly subsurface in occurrence as observed in Agbada-1, Akata-1, Bomu-1 and Pennington-1 wells (Nwajide 2013). The Formation is mostly an alternation of sands, sandstones and siltstones with shale intercalations. The sediments are of upper deltaic plain origin and of Eocene to Recent age. Akata Formation is the lowermost unit and has been described as a uniform marine shale development comprising dark, grey, shale. There are impregnations of plant remains in the shale and some mica especially in the upper part of the Formation (Azeez, 1989). The type locality was chosen in Akata – 1 well (coordinate 4º41'50.5"N and 7º46'58.6"E), at depth below 2155 mbgl (Short and Stauble, 1967). The widely accepted age range of the Formation is from Eocene to Recent. Groundwater recharge is by rain fall. Aquifer systems in the Niger Delta are generally phreatic and unconfined with shallow water table - 0 to 10 mbgl (Offodile, 2002). Productive aquifers in Abia State were mapped to correlate with the alluvial deposits and the Coastal Plain Sands lithology of fine, medium and coarse grained often pebbly sands with some intercalations of clays (Abija and Nwankwoala, 2018).

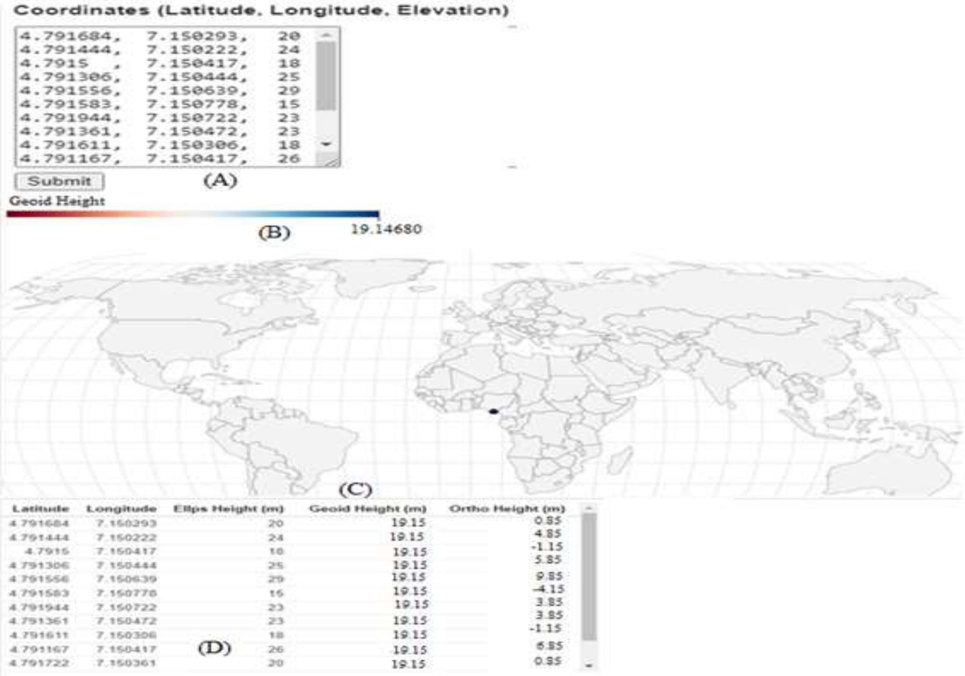
RESULTS AND DISCUSSION

Case Study 1: The site at Ejama-Ebubu in Eleme Local Government Area of Rivers State covered an area bounded by latitudes 4°47'28.2" to 4°47'31" and longitudes 7°9'0.8" to 7°9'3.5". The instrument used was the handheld GPS WGS 84 model. Thirteen (13) sampling stations (SSs) were leveled within 1343hrs and 1400hrs. Measurements were made on collar tops with the GPS device oriented northwards. Placing the GPS on collar top (top of casing cap) ensures a more flattened surface for device to achieve stable readings. The longitude and latitude readings were recorded in degrees and the GPS ellipsoidal elevation in meters as required by the geoid height calculator software (Table 1). It is important to keep in mind that any change in the placement of values under latitude and longitude columns on the web page would alter the location on the geoid height calculated and the resulting map.

Table 1: Field Survey Data from a WGS 84 GPS Model Device

Sampling Station ID	Latitude (degree)	Longitude (degree)	GPS Elevation (m)
BH1	4.791684	7.150293	20
BH2	4.791444	7.150222	24
BH3	4.7915	7.150417	18
BH4	4.791306	7.150444	25
BH5	4.791556	7.150639	29
BH6	4.791583	7.150778	15
BH7	4.791944	7.150722	23
BH8	4.791361	7.150472	23
BH9	4.791611	7.150306	18
BH10	4.791167	7.150417	26
BH11	4.791722	7.150361	20
BH12	4.791611	7.150361	15
BH13	4.791667	7.150556	16

The results of the elevation correction conducted infer that the geoid height was 19.15 approximately (Fig. 6B) and all stations occupied were in the south-south region of Nigeria (Fig. 6C) which perfectly fit the site location. That the geoid height is higher in five (5) stations than the ellipsoidal height suggested that the resulting negative othometric (true) heights were below mean sea level by a few meters (Fig. 6D). Thus the true elevation at the site ranged from a minimum of -4.15 m-msl at BH12 to a maximum of 9.85 m-msl at BH5 (Table 2). A plot of the surface elevation map of the site was used to compare the reliability of the direct use of the geoid for elevation correction (Fig. 7). Four sampling stations west of the AA' section line (BHs 3, 9, 12 and 13) sit in an area below the sea level (defined by the 0.0 contour line). This topographic analysis perfectly reflected the characteristic of that portion of the site as a region prone to flooding. The section revealed that what appeared like a flat land actually had minor undulations – descending from 6.9 m-msl at BH-10 location to 3.9 m-msl at BH-07. Interestingly, within about a two and half (2(1/2)) hour period, the geoid height remained the same. However, the ellipsoidal height varied widely sometimes by as little as 0.5% to as much as 15%, suggesting that the corrected elevations would yield results that could be at odds if the timing is ignored. For instance, if GPS elevations were taken at some SSs between 1100hrs to 1200hrs and the elevation of the remaining SSs delayed till the interval time of 1200hrs to 1300hrs, the resulting corrected elevation would be unreliable. Likewise, with the geoid height constant, it may seem like an academic exercise correcting the ellipsoidal height to true elevation referenced to the geoid. But the true architecture of the northeast quadrant of the site as a land location below sea level was revealed when the GPS elevation was corrected to the geoid; same stations occupied would return negative values as true elevation irrespective of the time reading was made. Representing section AA' in mbgl from a rather hypothetical straight line on or above the ground surface would eliminate the undulation just analyzed.



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4.791684,   7.150293,   20
4.791444,   7.150222,   24
4.7915  ,   7.150417,   18
4.791306,   7.150444,   25
4.791556,   7.150639,   29
4.791583,   7.150778,   15
4.791944,   7.150722,   23
4.791361,   7.150472,   23
4.791611,   7.150306,   18
4.791167,   7.150417,   26
```

Latitude	Longitude	Ellps Height (m)	Geoid Height (m)	Ortho Height (m)
4.791684	7.150293	20	19.15	0.85
4.791444	7.150222	24	19.15	4.85
4.7915	7.150417	18	19.15	-1.15
4.791306	7.150444	25	19.15	5.85
4.791556	7.150639	29	19.15	9.85
4.791583	7.150778	15	19.15	-4.15
4.791944	7.150722	23	19.15	3.85
4.791361	7.150472	23	19.15	3.85
4.791611	7.150306	18	19.15	-1.15
4.791167	7.150417	26	19.15	6.85
4.791722	7.150361	20	19.15	0.85

Fig 6: Screen-shot of Ejama-Ebubu Geoid Height Analysis Template

Table 2: Elevation Correction of Sampling Points in Ejama-Ebubu Site

BH ID	Lat. (°)	*Northing (m)	Long. (°)	*Easting (m)	GPS E (m)	GH (m-msl)	EC (m-msl)
1.	4.791684	529914.12	7.150293	294853.09	20	19.15	0.85
2.	4.791444	529887.6	7.150222	294845.14	24	19.15	4.85
3.	4.7915	529893.74	7.150417	294866.79	18	19.15	-1.15
4.	4.791306	529872.27	7.150444	294869.73	25	19.15	5.85
5.	4.791556	529899.86	7.150639	294891.44	29	19.15	9.85
6.	4.791583	529902.81	7.150778	294906.87	15	19.15	-4.15
7.	4.791944	529942.75	7.150722	294900.76	23	19.15	3.85
8.	4.791361	529878.35	7.150472	294872.85	23	19.15	3.85
9.	4.791611	529906.05	7.150306	294854.51	18	19.15	-1.15
10.	4.791167	529856.91	7.150417	294866.69	26	19.15	6.85
11.	4.791722	529918.3	7.150361	294860.65	20	19.15	0.85
12.	4.791611	529906.03	7.150361	294860.61	15	19.15	-4.15
13.	4.791667	529912.16	7.150556	294882.26	16	19.15	-3.15

**Coordinates converted to Universal Transverse Mercator (UTM) system to facilitate plotting of grid and map dimensions.*

Table 3: Field Survey Readings Using the Handheld GPS WGS 84 Model

MW-ID	Latitude-deg.	Northing-m	Longitude-deg.	Easting-m	Elevation-m	Time (Hrs)
BH01	4.67661	517152.01	7.27661	308835.5	12.9	1222
BH02	4.67558	517038.25	7.27697	308875.29	15.4	1204
BH03	4.67547	517026.19	7.27617	308785.88	16	1227
BH04	4.67464	516933.94	7.2765	308822.73	13.6	1232
BH05	4.67381	516841.71	7.27675	308850.15	15.8	1236

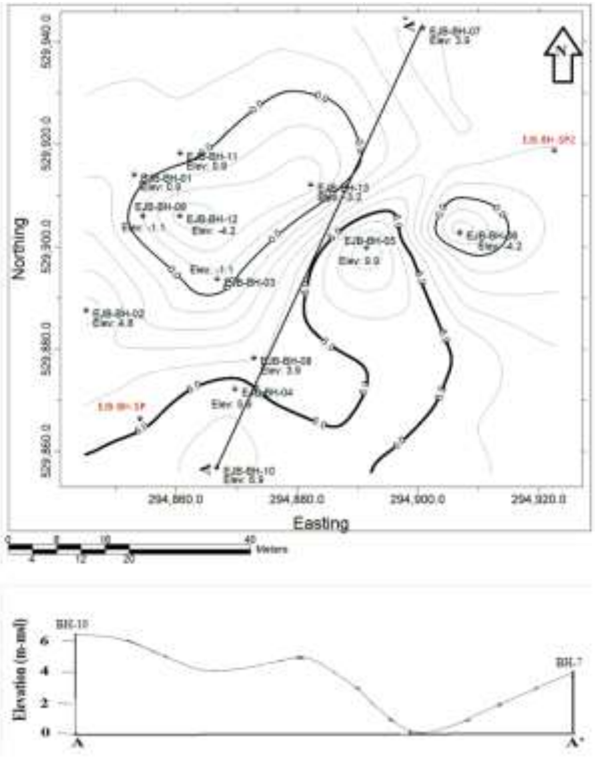
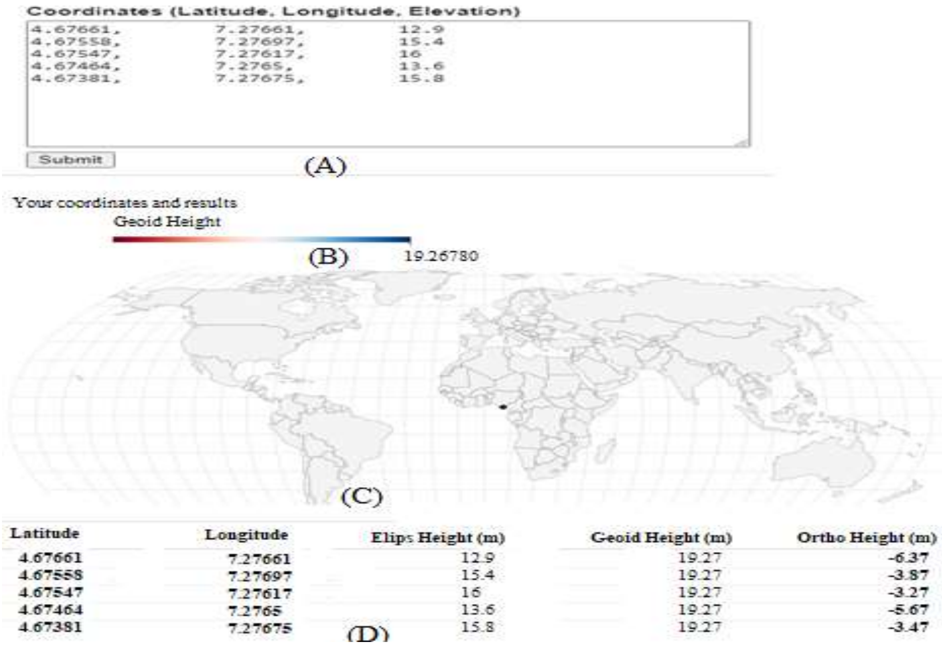


Fig 7: Localized Topographic Map of Studied Site with a Complementing Longitudinal (AA') Section

Case Study 2: B-Dere site in Gokana Local Government Area of Rivers State was located about 19 km southeast of Ejama–Ebubu by the shortest possible route. B-dere site was bounded by latitudes 4.67381° to 4.67661° and longitudes 7.27617° to 7.27697° (Table 3). Coordinate conversion to UTM was to ease the plotting of map. The results of the elevation correction with the geoid height calculator software are here illustrated as a screen-shot page (Figure 8).

The evaluated elevation values were applied to produce 2-D models: surface topography and the SSE - NNW section maps (Fig. 9). By comparison, the direct use of GPS elevation reading (Ellipsoidal height) and the use of the GPS elevation corrected to the geoid (the true elevation) could be likened to the distance in a map and the actual distance on ground. Subsequently when used to generate maps both elevation values would produce similar map outline (Figs. 9 and 10). However, the true elevation map would represent the area in its natural state. Regarding B-dere site, the GPS ellipsoid value showed the site as a normal continental landscape with elevation values ranging from approximately 13 m-msl to 16 m-msl (Fig. 10). But the true elevation (GPS corrected to the geoid) presented the landscape as being below sea level with elevation values varying between -6.4 m-msl and -3.5 m-msl (Fig. 9). This seemingly little difference in the geomorphology of the site has geological, hydrogeological and engineering impacts.



Coordinates (Latitude, Longitude, Elevation)

```
4.67661,        7.27661,        12.9
4.67558,        7.27697,        15.4
4.67547,        7.27617,        16
4.67464,        7.2765,         13.6
4.67381,        7.27675,        15.8
```

Your coordinates and results

Geoid Height

19.26780

Latitude	Longitude	Elips Height (m)	Geoid Height (m)	Ortho Height (m)
4.67661	7.27661	12.9	19.27	-6.37
4.67558	7.27697	15.4	19.27	-3.87
4.67547	7.27617	16	19.27	-3.27
4.67464	7.2765	13.6	19.27	-5.67
4.67381	7.27675	15.8	19.27	-3.47

Fig 8: B-dere Analysis Template Screen-shot from Geoid Height Calculator Program

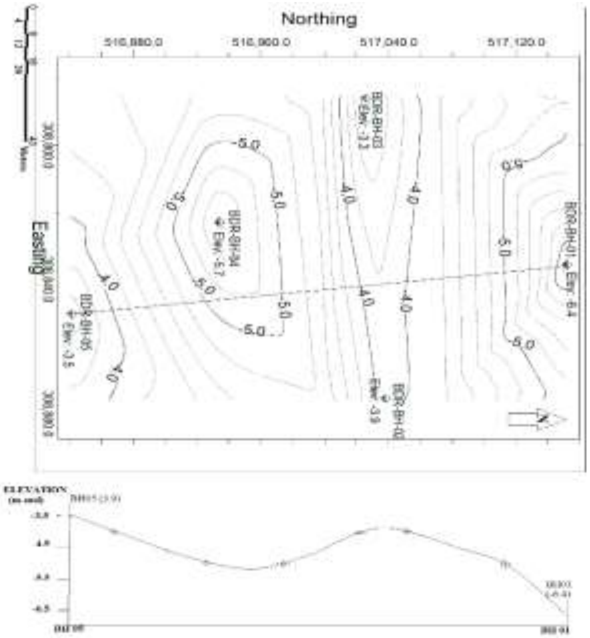


Fig 9: Surface Topography Map of Bdere Site with a Complementing SSE-NNW Section

Conclusion: The use of the geoid method to correct for GPS derived elevation values within the investigated sites at B-dere and Ejama-Ebubu in Rivers State Nigeria, resulted in delineating their natural topography with respect to the mean sea level. In line with best practice, it was possible to infer not just ridges and troughs but terrains that are below sea level. Therefore, the use of the geoid to evaluate true elevation would improve the determination of flooding surfaces, lithology correlation, static water levels, groundwater flow models and unearthing the hydrogeological phenomenon yet unknown in Niger Delta and elsewhere

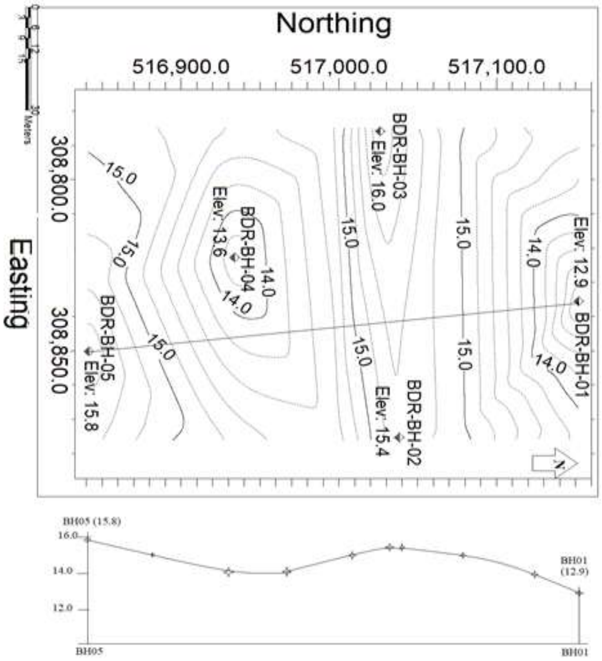


Fig 10: Topographic Map of Bdere Site with a Complementing SSE-NNW Section

The elevation correction using the geoid method would be helpful in the engineering design of sustainable infrastructures in the Niger Delta states.

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