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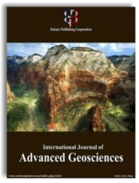

Determination of orthometric elevations using gnss-derived height with the egm2008 geoid height model

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Abstract

The Global navigation satellite systems (GNSS) has imparted positively on civilian positioning & surveying in the horizontal component in Nigeria for the past two decades. The GNSS receivers' data are longitude, latitude & elevation. However, the vertical distance measurement have not been fully exploited by geodetic and land surveyors. The GNSS derived heights are ellipsoidal elevation. To convert the GNSS elevation to orthometric heights, a geoidal elevation models is needed. The Earth Gravitational Model, 2008 (EGM2008) is a global geoidal models that can be used to obtain GNSS orthometric heights by defining the relationship with the ellipsoid. This work determines GNSS-derived orthometric heights with ellipsoid-geoidal relationship using GPS ellipsoidal heights and EGM2008 geoidal model GIS data. The EGM2008 GIS data was downloaded and interpolated with GPS data to obtain geoidal heights using ArcGIS 10.1. GNSS-derived heights determined with geoid-ellipsoid relationship formula. The result shows minimum elevation of -2.37599m and maximum elevation of 53.8566m.The derived orthometric heights use to create a model in raster format. The orthometric elevation models created useful in all vertical surveying work, construction work and urban planning. The GNSS orthometric heights models need to be compare with spirit levelling and the local geoidal model determined for improve accuracy.

Keywords: *EGM2008; Geodetic Heights; GNSS; Orthometric Heights; Vertical Benchmark.*

1. Introduction

Accurate determination of benchmark heights with respect to the geoid surface from GPS derived heights has dominated geodesist's areas of research currently (Kemboi et al, 2016). Orthometric elevations are used for engineering construction project & land surveying with referenced geoid surface. The Earth Gravitational Model, 2008 (EGM2008) is one of the current global geoidal model and available in Geographic information systems (GIS) raster format.

The NAVigation System with Time and Ranging (NAVSTAR) Global Positioning System (GPS) one of the Global navigation satellite systems (GNSS) have impacted on traditional horizontal surveying in Nigeria and the world at large. Nigeria has adopted its use for control surveying; also the US National Geodetic Survey (NGS) has adopted GPS technology surveying techniques.

GPS defines any point on the earth surface by longitude, latitude, and elevations (ellipsoidal height).Vertical surveying control in Nigeria remains undeveloped as in the US. Orthometric elevation is conventionally determined by the use of spirit levelling and defined by the vertical distance above the geoids as measured along plumeline.GPS elevations are obtain directly from the geocentre position vector from GPS measurement (sickle,2008). The geoid is an equipotential surface as define by gravity (Ghilani and wolf, 2008). The GPS elevation is measured in relation to the WGS84 ellipsoid and is called geodetic height or ellipsoidal heights (Uzodinma 2015).

GPS elevation can be converted to orthometric heights using geoidal models (Uzodinma 2015). Earth Gravitational Model EGM2008 is a useful model for the above conversion. EGM2008 gravitational model uses spherical harmonic degree and order 2159 (NGA 2013). The WGS 84 constants used to define the reference ellipsoid with EGM2008 are (NGA, 2013);

- semi-major, a = 6378137.00 m
- flattening, f = 1/298.257223563
- Earth's mass and the Gravitational Constant, GM = 3.986004418 x 1014 m^3s^{-2}
- Earth's angular velocity, ω = 7292115 x 10-11 radians / sec.

Orthometric elevations information is useful in tidal measurement, construction projections, urban planning etc. This work use a created raster geoidal model (EGM2008) of 2.5 x 2.5-minute resolution and GPS controls spread all over Rivers state to determined the orthometric heights model of the study area using geoid-ellipsoidal relationship and GIS tools.

2. Study area

The Rivers state lies at latitudes 4.396420°N and 5.982150°N and longitudes 6.552790°E and 7.658370°E. rivers state is in the southern part of Nigeria with an area of approximately 278.080276 sq.km base on Spatial query using ArcGIS tool and view from the Rivers state administrative map shows it is bounded in north boundaries with

The population of Rivers State is 5,198,716 (census, 2006). It is today the centre of Oil activities in Rivers State in Nigeria.

Eludoyin et al, (2011) describe Rivers state as a monsoon tropical climate that hot is as a result of its position on equator. A major characteristic of a tropical monsoon climate is rainfall which usually between April & October with range between 2000 - 2500 mm it record high humidity with higher inland temperature yearly (Eludoyin et al, 2011). Rivers state upland vegetation is mostly palms (raffia), mangrove thick forest with rain light forest (Eludoyin et al, 2011).

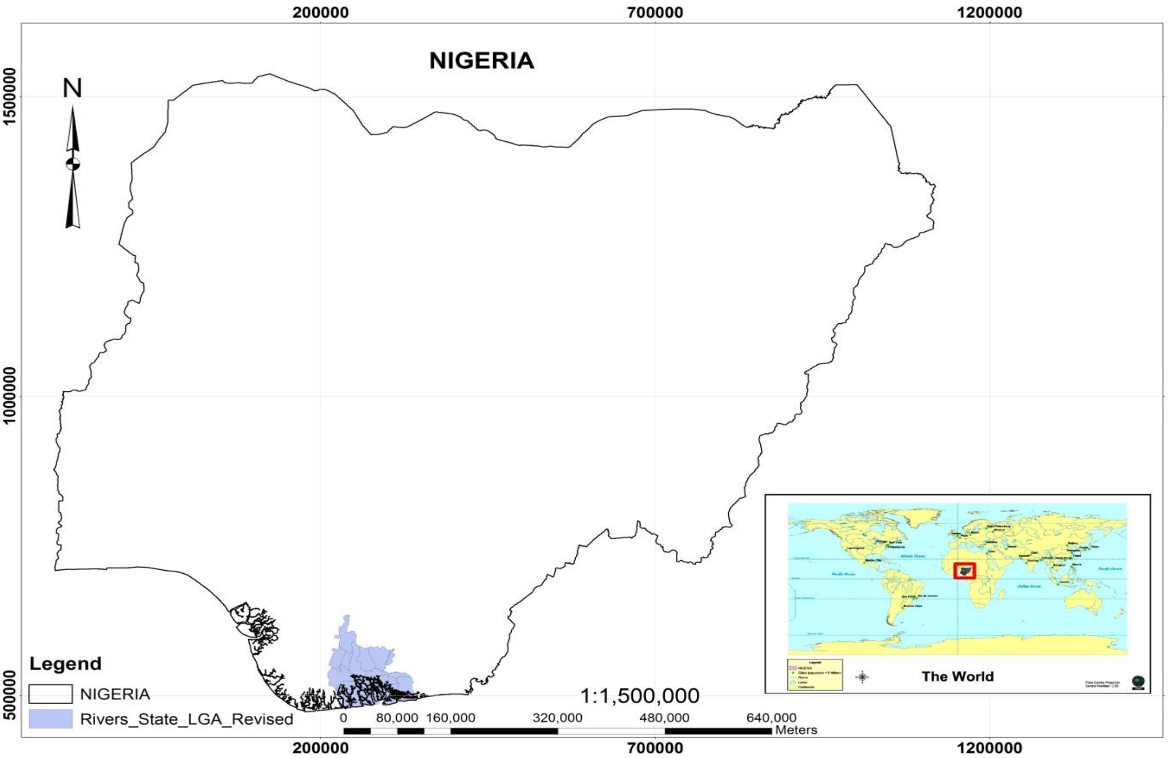

Fig. 1: Map Showing the Nigeria as Situation Map of Rivers State.

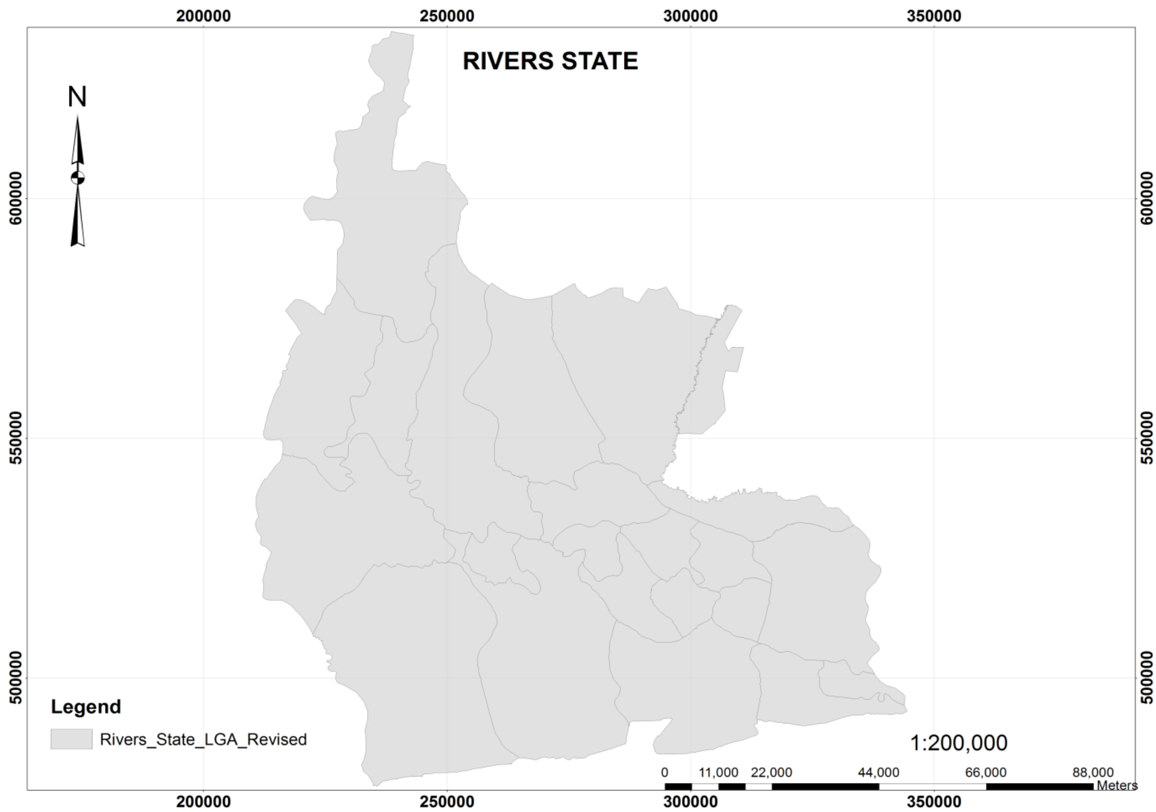

Fig. 2: Map Showing the Study Area Rivers State.

3. Methodology

"Geoid is an equipotential gravitational surface located approximately at mean sea level, which is everywhere perpendicular to the direction of gravity"(Ghilani and wolf, 2008).

"Ellipsoid is a mathematical surface obtained by revolving an ellipse about the earth's polar axis" (Ghilani and wolf, 2008)

Orthometric height as defined earlier is the height above the geoid.

"Deflection of the vertical is the angle between the direction of a plume line with the ellipsoidal normal through the same point" (Sickle, 2008).

"Mean sea level is the average location of the interface between ocean and atmosphere, over a period of time that all the ramdom and periodic variations of short duration average to zero" (Sickle, 2008)

3.1. Height relationships

The surveyor can only determine the orthometric elevation of a point of a GPS measurement by knowing the extent of the separation between the ellipsoid and geoid. In transforming Gps elevation (ellipsoidal heights) h, into orthometric elevations H, is given as (sickle, 2008);

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

Where, N is the geoid-ellipsoidal separation (Geoidal undulation or Geoidal Height).

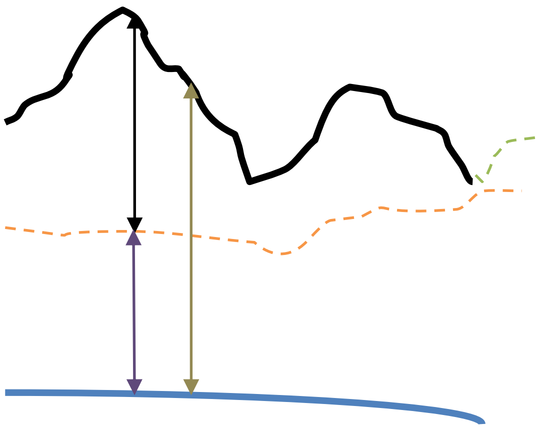

Fig. 3: Relatiotionships betweens Difference Surface.

3.2. Determination of orthometric heights with GPS-derived elevation with EGM2008

The field observation methods for GPS point positioning make equation (1) to now become;

$$H = h_{GNSS} - N_{EGM2008} \quad (2)$$

Where;
$N_{EGM2008}$ = Geoidal Height
h_{GNSS} = Geoidal Height, and
H = orthometric heights

But in relative GPS positioning, the observation baseline of the components can be calcutated accurately with geodetic difference in height (Δh) of the two GPS control points (Idwijay, 2003). From equation point one and two can be rewrite as;

$$H_1 = h_1 - N_1 \quad (3)$$

$$H_2 = h_2 - N_2 \quad (4)$$

And this no becomes;

$$H_2 - H_1 = \Delta H = h_2 - h_1 (\Delta h) + N_2 - N_1 (\Delta N) \quad (5)$$

Or

$$\Delta H = \Delta h - \Delta N \quad (6)$$

Rewriting (6) in form of (2) as;

$$\Delta H = \Delta h_{GNSS} - \Delta N_{EGM2008} \quad (7)$$

In practise, due to varying undulation geoid (ΔN), a change for geodetic height (Δh) will not be equal to a change in the orthometric height (ΔH). This implies that Δh and ΔN determination must be accurate and this work assume that they are correct as possible.

3.3. Data collection and methods

The Earth Gravitational Model (EGM2008) was downloaded from http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/egm08_gis.html. The GPS elevation data and administrative boundary data used in this work was collected from the office of the Surveyor-General of Rivers State, Nigeria (OSGRS).
The EGM2008 used as geoidal undulation in this work was masked to the administrative boundary of Rivers State using ArcGIS 10.1. The GPS coordinates was interpolated with EGM2008 dataset in ArcGIS 10.1 to extract geoidal base heights. Determination of orthometric heights was carried out using Microsoft excels. Lastly, the orthometric heights were modelled in form of a raster dataset (digital elevation model, DEM) in ArcGIS 10.1. This method is summarised in figure 4.

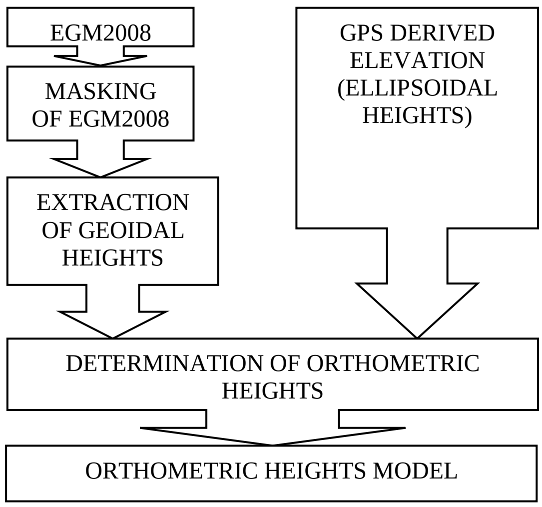

Fig. 4: Flowchart of Methodology for Orthometric Heights Determination with GNSS.

4. Results and discussion

Results deduce from equation (1) to determine orthometric heigths at 50 GPS control stations shows minimum elevation of -2.37599m and maximum elevation of 53.8566m. Orthometric heights were calculated using Earth Gravitational Model, 2008 as geoidal undulation and GPS benchmark as GNSS. The overall results are as shown in table 1 below.

Table 1: Results of Orthometric Heights Determination with GNSS(50 GPS Control)

Pillars	GPS Height (m) h_{GNSS}	Geoidal heights (m) $N_{EGM2008}$	Orthometric Heights (m) $H = h_{GNSS} - N_{EGM2008}$
XSV671	28.453	19.00600052	9.446999481
XSV672	19.368	19.03300095	0.334999054
XSV674	24.733	19.00600052	5.726999481
XSV673	19.934	18.97200012	0.961999878
XSV662	27.603	18.9090004	8.693999603
XSV665	30.005	18.6590004	11.3459996
XSV661	40.696	19.0510006	21.6449994
XSV691	20.965	18.82099915	2.144000855
XSV664	29.046	18.54299927	10.50300073
XSV663	27.644	18.79899979	8.845000214
XSV696	18.556	18.95400047	-0.398000473
XSV693	20.708	18.94499969	1.763000305
XSV695	19.965	19.00099945	0.964000549
XSV694	19.936	18.94499969	0.991000305
XSV684	24.864	18.36100006	6.502999939
XSV683	24.524	18.36400032	6.15999968
XSV692	21.894	18.57900047	3.314999527
XSV682	22.361	18.36400032	3.99699968
XSV685	27.953	18.23699951	9.716000488
XSV666	54.69	18.62000084	36.06999916
XSV681	44.357	18.53300095	25.82399905
XSV686	29.398	18.18899918	11.20900082
XSV687	28.228	18.19000053	10.03799947
XSV688	31.49	18.28300095	13.20699905
XSV667	51.313	18.77700043	32.53599957
XSV690	32.762	18.47200012	14.28999988
XSV668	61.7	19.07500076	42.62499924
XSV670	67.83	19.20199966	48.62800034
XSV669	73.093	19.21999931	53.87300069
XSV701	39.271	19.20599937	20.06500063
XSV708	24.274	19.16900063	5.104999374
XSV675	29.055	19.09799957	9.957000427
XSV706	36.069	19.23999977	16.82900023
XSV707	33.449	19.24500084	14.20399916
XSV704	36.335	19.36700058	16.96799942
XSV703	36.572	19.45299912	17.11900089
XSV705	32.763	19.32099915	13.44200085
XSV710	18.61	19.33200073	-0.722000732
XSV709	19.924	19.3010006	0.622999405
XSV676	18.217	19.20400047	-0.987000473
XSV677	19.944	19.20100021	0.742999786
XSV678	18.259	19.23399925	-0.974999252
XSV680	16.896	19.27300072	-2.377000717
XSV699	17.66	19.06299973	-1.402999725
XSV679	21.211	18.94499969	2.266000305
XSV700	17.82	19.37700081	-1.557000809
XSV698	20.027	19.30500031	0.721999695
XSV697	19.69	18.9489994	0.741000595
RSUST	21.654	18.97200012	2.681999878
ZVS300	32.308	18.97999954	13.32800046

The orthometric heights models in a digital elevation model (DEM) as shown in Figure 6.

The GPS controls distribution density over the study area in figure 5.

The results were obtained from a mathematical model calculation by combining gravimetric information (data) with distributed network of GNSS control points. Differential correction needed as requirement for surveying & engineering work accuracy. That is, difference between base station and the rover must be determined as accurate as possible. Guideline of publication NOS NGS-58 should be observed for GNSS field measurement. Geodetic levelling needed in other to compare with GNSS data.

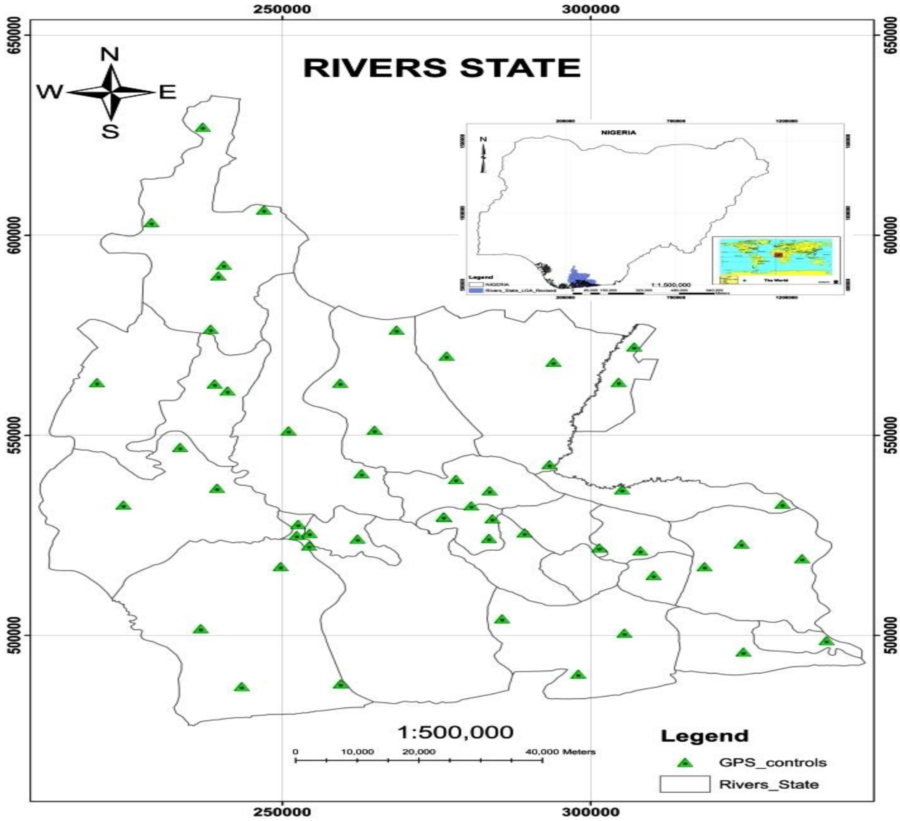

Fig. 5: GPS Controls Distribution Density over the Study Area.

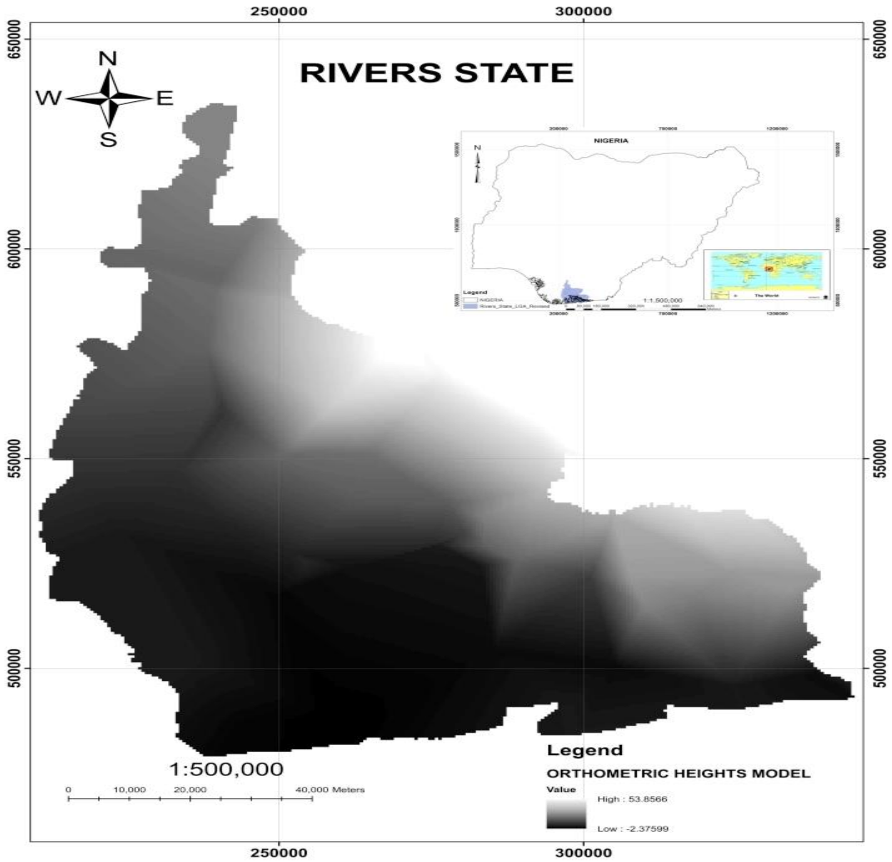

Fig 6: The Orthometric Heights Models.

5. Conclusion and outlook

The result obtain shows that orthometric heights at any point on the earth surface can be estimated using mathematical model. GNSS observations on benchmark and a geoidal heights model such as EGM2008 needed to achieve results. High control density needed for small area to achieve needed accuracy. Ellipsoidal differences in height between benchmark should be determined in Differential GPS to achieved accuracy for surveying and engineering applications.

Future work within the study area includes; validation of EGM 2008 accuracy, differential levelling to compare with GNSS derived heights and determination of a geoidal model.

Acknowledgement

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