Validation of EGM2008-Based Orthometric Heights in a Micro Environment in Nigeria

Uzodinma, V.N., Oguntuase J.O, Onah E., Chike C., and Ehigiator R (Nigeria)

ABSTRACT

The Earth Geopotential Model of 2008 (EGM2008) is the latest effort by NIMA (National Imagery and Mapping Agency, USA) at generating an accurate global geoid height model which will facilitate accurate conversion of geocentric ellipsoidal heights to their corresponding orthometric equivalent. This paper evaluates the accuracy of the EGM2008 model in a 23 hectare micro-environment located within the compound of the University of Nigeria, Enugu Campus. The validation was done by comparing EGM2008-based orthometric height differences with height differences determined from spirit levelling. GNSS and spirit levelling measurements were taken on twenty-one validation points. Results obtained indicate an accuracy of ± 1.019m (std. dev) for EGM2008 within our study area.

Key words: EGM2008, Orthometric heights, micro-environment, GNSS, Spirit-levelling

Validation of EGM2008-Based Orthometric Heights in a Micro Environment in Nigeria

Uzodinma, V.N., Oguntuase J.O, Onah E., Chike C., and Ehigiator R (Nigeria)

1. INTRODUCTION

Topographic data acquisition is an important aspect of mapping projects which requires accurate ground data sampling of elevations at resolutions adequate for its intended use. Traditionally, ground survey methods for the production of elevation models include spirit levelling, tacheometry, and trigonometric surveys (using total stations) (Kavanagh, B.F, 2006). Though these methods yield accurate orthometric heights of points, are very tedious and require a lot of time when large expanse of land is to be surveyed. However, with the advent of GPS technology which is much faster and more convenient method of deriving ellipsoidal heights, research attention has shifted to the precise determination of local, regional or global geoid models which are required for accurate geometric conversion of ellipsoidal heights to orthometric heights (Featherstone et al, 1998).

The Earth Geopotential Model of 2008 (EGM2008) is the latest effort by NIMA (National Imagery and Mapping Agency, USA) at generating an accurate global geoid height model which will facilitate accurate conversion of geocentric ellipsoidal heights to their orthometric equivalent. This model has been acclaimed to be a high- resolution global model of the earth's gravity field suitable for global topographical applications (Martensson, 2002).
This paper verifies the suitability of the EGM2008 model for accurate topographic mapping in a micro environment by evaluating its accuracy in a 23 hectare micro-environment located within the compound of the University of Nigeria, Enugu Campus.

2. DESIGN OF STUDY

Twenty-one ground control points (GCPs) were selected as validation stations from a number of controls spread across University of Nigeria, Enugu Campus (UNEC). The controls used as the validation stations are listed in Table 1 and shown in Fig.1.
In this project, the GPS space technique (and Total Station instrument for stations under tree canopy) was used to obtain the ellipsoidal heights (h) of points within the study area, while Earth Geopotential Model 2008 (EGM 2008) was used to determine the geoidal height (N) at those points. The spirit levelling method was used to determine the elevation differences between the validation points. The validation was done by comparing EGM2008-based orthometric height differences with their spirit levelling equivalent. Also, the resolution of the EGM2008 model in a micro environment was studied by comparing EGM2008 geoid height values with a geoid model (UNEC model) built from spirit level heights.

2.1 Description of Study Area

The study area for this project is located within the University of Nigeria, Enugu Campus (UNEC) and the area is located between Latitudes 6°25'21.524"N and 6°25'47.667"N and Longitudes 7°30'07.956"E and 7°30'42.204"E in the WGS84 (ITRF2008) reference system. The area covered was about 23.56 Hectares. Figure 1 shows the satellite image of the project area and the validation points.

The topography of the study area is characterised with gentle slopes (Fig 2) and our validation stations were carefully selected along slopes of interest to enable analysis of varying elevations (Fig 3).

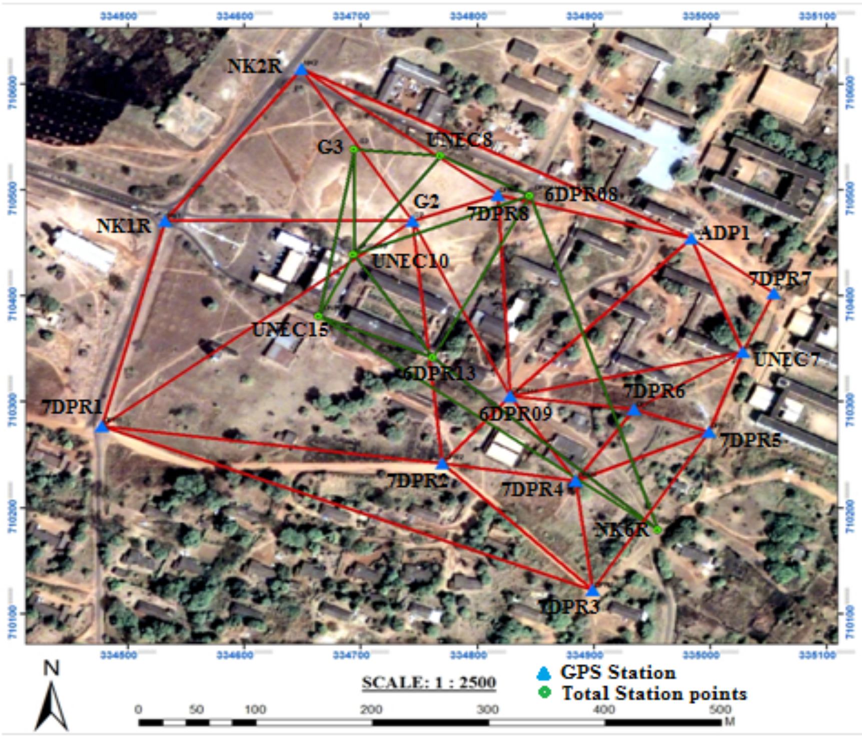

Fig. 1: Google image of Study Area showing the positions of Validation points

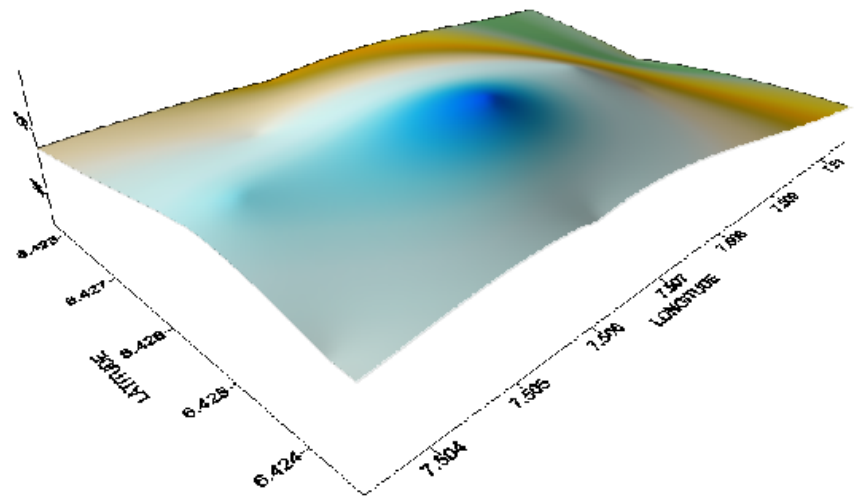

Fig 2: Topography of the study area

2.2 Field Methods

2.2.1 Planning

Planning was done in the office before proceeding to the field. This involved the use of UNEC topographical map on scale 1:2000 showing existing control points. The base map enabled us to select the most suitable validation points as well as the levelling routes to be used. Fourteen of the validation points were suitable for GPS observation (stations marked by blue triangular shape in Fig 1) while seven fell under tree canopies and were observed with a Total Station instrument (stations marked by green circular shape in Fig 1). Six levelling loops were selected for the validation points (Fig 3).

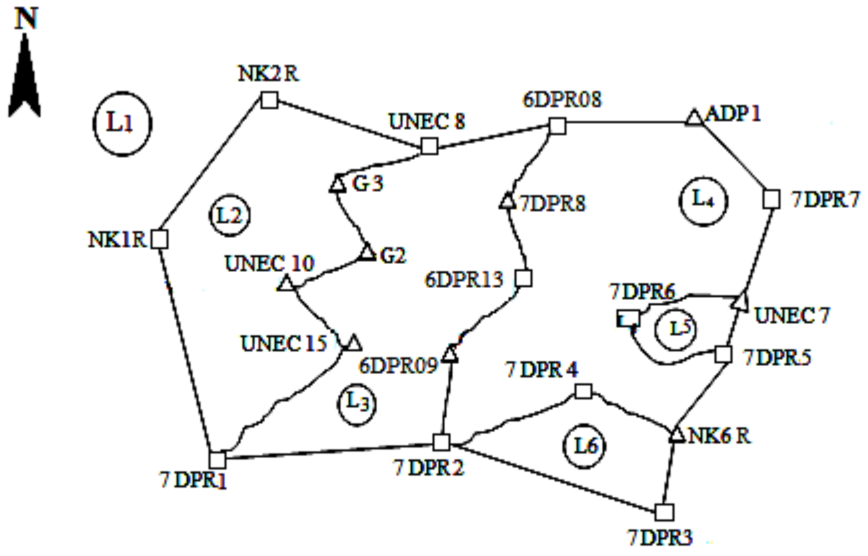

Fig 3: Sketch of the levelling loops over the validation points

2.2.2 Reconnaissance

During the field reconnaissance the chosen 21 validation points were identified on the ground. The 6 levelling loops were also identified (See Fig. 3).

Table 1: The 21 stations in the six Levelling loops

S/N	Loop	Stations
1	1	NK1R, NK2R, UNEC8, 6DPR08, ADP1, 7DPR7, UNEC7, 7DPR5, NK6R, 7DPR3, 7DPR2, 7DPR1
2	2	NK1R, NK2R, UNEC8, G3, G2, UNEC10, UNEC15, 7DPR1
3	3	UNEC8, 6DPR08, 7DPR8, 6DPR13, 6DPR09, 7DPR2, 7DPR1, UNEC15, UNEC10, G2, G3
4	4	6DPR08, ADP1, 7DPR7, UNEC7, 7DPR6, 7DPR5, NK6R, 7DPR4, 7DPR2, 6DPR09, 6DPR13, 7DPR8
5	5	UNEC7, 7DPR5, 7DPR6
6	6	NK6R, 7DPR3, 7DPR2, 7DPR4

2.3 GPS Measurements and Data Processing

GPS observations were carried out on 14 station monuments. The dual frequency Leica GPS 1200+ instrument was used in the static mode to make observations on all the observed points. Observations were made at an epoch rate of 30 seconds for a period of one hour [session] per station. The following precautions were taken to minimise errors:

- The antenna height was made to be higher than the observer;
- No observation was taken to less than four satellites;
- The observation session of one hour was consistently maintained and;
- All GPS observations were restrained from areas under canopy.

The captured raw observation data were converted to RINEX data format and sent to the CSRS-PPP (Canadian Spatial Reference System - Precise Point Positioning) processing service for on-line processing.

2.4 Total Station Observations

Total station observations were carried out at the seven stations where it was impossible to use GPS method because of tree canopy cover. These include UNEC 8, UNEC10, UNEC15, G3, 6DPR3, 7DPR09, and NK6R. Leica [TS 06] total station instrument was used to observe the above stated points. For observations to be carried out with a total station, a minimum of two known inter-visible points are required. The instrument was set up on G2 and oriented with station 7DPR8. The WGS84 coordinates of both stations were keyed into the instrument.
The observed data were downloaded from the total station to the computer and processed in the same (WGS84 datum) as the GPS data since the input data at the initial points are the GPS data.

2.5 Heights by Spirit Levelling Method

Spirit levelling observations were carried out with SOUTH™ automatic levelling instrument and a levelling staff. The observations were taken in loops as shown in Figure 3. Back sights, foresights and intermediate sights were observed and recorded accordingly. Change points were established at points where the rays grazed or were too close to the ground.
The height of instrument method was used in computing the reduced level of all points. The EGM2008-derived orthometric height of NK1R was used as a reference datum to reduce the heights of other points in the area.

2.6 The EGM2008 Model and Method of Geoid Heights Extraction

EGM 2008 (Earth Geopotential Model of 2008) is a global geoidal undulation model which can be used to transform GPS-derived ellipsoidal heights to orthometric heights. It was computed and released in April 2008 by the United States National Geospatial Agency (USNGA). It is a high- resolution global model of the earth's gravity field beyond spherical harmonic degree 2000. Its spherical harmonic coefficients are complete to degree 2190 and order 2159 (NIMA, 2008).
The EGM2008 geoid heights (N^{EGM08}) were obtained from the GeoidEval™ on-line utility (Anon, 2013). The curvilinear coordinates (Latitude and Longitude) of each of the observed points were input and their corresponding geoidal heights were automatically displayed on the screen.

2.7 Computation of Orthometric Heights from Ellipsoidal Heights

The ellipsoidal heights obtained from GPS observations were transformed to orthometric heights by applying the geoidal undulations obtained from EGM 2008 geoid height model using the mathematical model given in (Heiskanem and Moritz, 1967):

$$H = h - N \qquad ..... (1)$$

Where:
H= Orthometric height,
H =Ellipsoidal height,
N= Geoidal Undulation

3.0 RESULTS AND DISCUSSIONS

3.1 Results

Table 2: WGS84 Coordinates Derived from Direct GPS Observations

S/N	STATION	LATITUDE	LONGITUDE	ELLP. HT (h)m
1	NK1R	6º 25’ 31.4131’’	7º 30’ 13.7201’’	236.840
2	ADP1	6º 25’ 30.9289’’	7º 30’ 28.4213’’	233.806
3	7DPR1	6º 25’ 25.1091’’	7º 30’ 11.9586’’	232.392
4	7DPR2	6º 25’ 23.9910’’	7º 30’ 21.4918’’	232.949
5	7DPR3	6º 25’ 20.0947’’	7º 30’ 25.6919’’	232.969
6	7DPR4	6º 25’ 23.4644’’	7º 30’ 25.2085’’	241.394
7	7DPR5	6º 25’ 24.9802’’	7º 30’ 28.9179’’	234.142
8	7DPR6	6º 25’ 25.6600’’	7º 30’ 26.8457’’	239.234
9	7DPR7	6º 25’ 29.2431’’	7º 30’ 30.7276’’	229.070
10	7DPR8	6º 25’ 32.2354’’	7º 30’ 23.0028’’	235.694
11	6DPR13	6º 25’ 26.0598’’	7º 30’ 23.3667’’	240.812
12	G2	6º 25’ 31.4449’’	7º 30’ 20.6259’’	241.293
13	NK2R	6º 25’ 36.1069’’	7º 30’ 17.5152’’	231.468
14	UNEC7	6º 25’ 27.4256’’	7º 30’ 29.8685’’	231.249

Table 3: WGS84 Coordinates Derived from Total Station Observations

S/N	STATION	LATITUDE	LONGITUDE	ELLP. HT (h)
1	UNEC8	6º 25' 33.451''	7º 30' 21.413''	237.163
2	6DPR3	6º 25' 32.212''	7º 30' 23.912''	233.557
3	G3	6º 25' 33.632''	7º 30' 19.001''	237.166
4	6DPR08	6º 25' 27.236''	7º 30' 21.217''	240.758
5	UNEC10	6º 25' 30.401''	7º 30' 18.996''	240.899
6	UNEC15	6º 25' 28.499''	7º 30' 18.019''	240.882
7	NK6R	6º 25' 21.970''	7º 30' 27.520''	235.353

Table 4: Spirit Levelled Height Differences between the Stations

S/N	LINE		LEVELED HEIGHT DIFF. (m)
	From	To	
1	NK1R	NK2R	-5.288
2	ADP1	7DPR1	-1.678
3	7DPR1	7DPR2	0.722
4	7DPR2	7DPR3	-0.070
5	7DPR3	7DPR4	8.947
6	7DPR4	7DPR5	-7.190
7	7DPR5	7DPR6	1.862
8	7DPR6	7DPR7	-4.522
9	7DPR7	7DPR8	3.939
10	7DPR8	6DPR13	5.365
11	6DPR13	G2	-0.730
12	G2	NK1R	-3.563
13	NK2R	UNEC7	-0.239
14	UNEC7	UNEC8	5.904
15	UNEC8	6DPR3	-3.588
16	6DPR3	G3	4.736
17	G3	6DPR08	2.652
18	6DPR08	UNEC10	-1.219
19	UNEC10	UNEC15	0.338
20	UNEC15	NK6R	-5.287

Table 5: EGM 2008-Derived Orthometric Heights of the Validation Stations

S/N	STATION	WGS84 ELLIPSOIDAL HEIGHTS (m)	EGM 2008 VALUES (m)	ORTHOMETRIC HEIGHT (H_{EGM08}) m
1	NK1R	236.840	22.172	214.668
2	ADP1	233.806	22.168	211.638
3	7DPR1	232.392	22.169	210.223
4	7DPR2	232.949	22.166	210.783
5	7DPR3	232.969	22.164	210.805
6	7DPR4	241.394	22.165	219.229
7	7DPR5	234.142	22.165	211.977
8	7DPR6	239.234	22.166	217.068
9	7DPR7	229.070	22.166	206.904
10	7DPR8	235.694	22.170	213.524
11	6DPR13	240.812	22.167	218.645
12	G2	241.293	22.170	219.123
13	NK2R	231.468	22.173	209.295
14	UNEC7	231.249	22.166	209.083
15	UNEC8	237.163	22.171	214.992
16	6DPR3	233.557	22.169	211.388
17	G3	237.166	22.171	214.995
18	6DPR08	240.758	22.168	218.59
19	UNEC10	240.899	22.170	218.729
20	UNEC15	240.882	22.169	218.713
21	NK6R	235.353	22.164	213.189

3.2 Discussion

In order to achieve a direct comparison of EGM2008-derived orthometric heights (H_{EGM08}) with their spirit level equivalent, the H_{EGM08} value for NK1R was adopted as the datum for computing spirit level-derived orthometric heights of the validation points. The comparison is shown in Table 6.

Table 6: Difference between EGM 2008- and Spirit Level-Derived Orthometric Heights

S/N	STATIONS	EGM2008-DERIVED HT (H_{EGM08}) m	LEVELLED HT (H_{SPL}) m	DIFF (m)
1	NK1R	214.668	214.668	0.000
2	ADP1	211.638	211.586	0.052
3	7DPR1	210.223	209.908	0.315
4	7DPR2	210.783	210.630	0.153
5	7DPR3	210.805	210.560	0.245
6	7DPR4	219.229	219.507	-0.278
7	7DPR5	211.977	212.317	-0.340
8	7DPR6	217.068	214.179	2.889
9	7DPR7	206.904	209.657	-2.753
10	7DPR8	213.524	213.596	-0.072
11	6DPR13	218.645	218.961	-0.316
12	G2	219.123	218.231	0.892
13	NK2R	209.295	209.380	-0.085
14	UNEC7	209.083	209.141	-0.058
15	UNEC8	214.992	215.045	-0.053
16	6DPR3	211.388	211.457	-0.069
17	G3	214.995	216.193	-1.198
18	6DPR08	218.59	218.845	-0.255
19	UNEC10	218.729	217.626	1.103
20	UNEC15	218.713	217.964	0.749
21	NK6R	213.189	212.677	0.512
Standard error, σ				± 1.019 m

3.2.1 Study of the Resolution of EGM2008

In our study, we also assessed the resolution of the EGM2008 geoid height model for a micro environment. To do this, we derived a geoid model (called UNEC Model) for the area of study from the spirit levelled heights (Table7).

The UNEC Model (N_{UNEC}) was derived from:

$$N_{UNEC} = h - H_{SPL}$$

Where,

h = height above WGS84 ellipsoid

H_{SPL} = spirit level-derived orthometric height by adopting the EGM2008-derived (H_{EGM08}) orthometric height of NK1R as dat

Table 7: "UNEC" Geoid Height Model Derived from Spirit-Levelled Heights

S/N	STATIONS	ELLPS. HT (h)m	LEVELLED HT (H)m	UNEC GEOID HEIGHT MODEL (m)
1	NK1R	236.840	214.668	22.172
2	ADP1	233.806	211.586	22.220
3	7DPR1	232.392	209.908	22.484
4	7DPR2	232.949	210.630	22.319
5	7DPR3	232.969	210.560	22.409
6	7DPR4	241.394	219.507	21.887
7	7DPR5	234.142	212.317	21.825
8	7DPR6	239.234	214.179	25.055
9	7DPR7	229.070	209.657	19.413
10	7DPR8	235.694	213.596	22.098
11	6DPR13	240.812	218.961	21.851
12	G2	241.293	218.231	23.062
13	NK2R	231.468	209.380	22.088
14	UNEC7	231.249	209.141	22.108
15	UNEC8	237.163	215.045	22.118
16	6DPR3	233.557	211.457	22.100
17	G3	237.166	216.193	20.973
18	6DPR08	240.758	218.845	21.913
19	UNEC10	240.899	217.626	23.273
20	UNEC15	240.882	217.964	22.918
21	NK6R	235.353	212.677	22.676

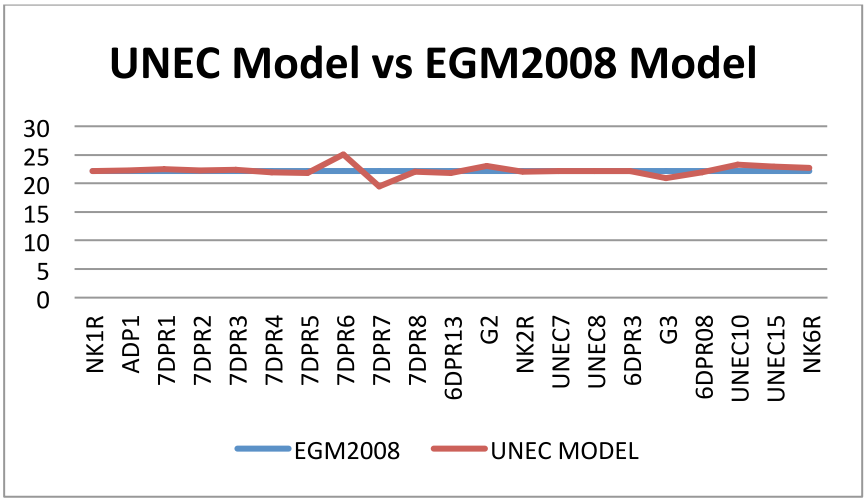

Fig5: Comparison of geoid heights from UNEC and EGM2008 Models

This UNEC model was compared with EGM2008 values at the validation points and shown in Table 6 and (Fig 5). The results show that the variations in the EGM2008 geoidal undulations occurred only at the millimetre level. What this implies is that the geoid and the reference ellipsoid (i.e. WGS 84) are approximately parallel within the area of study (varying from a minimum value of 22.164m to a maximum value of 22.173m). Fig 5 and Table 6 show that the UNEC model rises from a minimum value of 19.413m at 7DPR7 to a maximum value of 25.055m at 7DPR6. There are sharp rises at 7DPR6, G2 and UNEC10 and sharp drop at 7DPR7 and G3. We do not have an explanation for this yet (it is still under study).

The surfaces are plotted with procedures in (Anon, 2002) and shown in Figures 6 and 7.

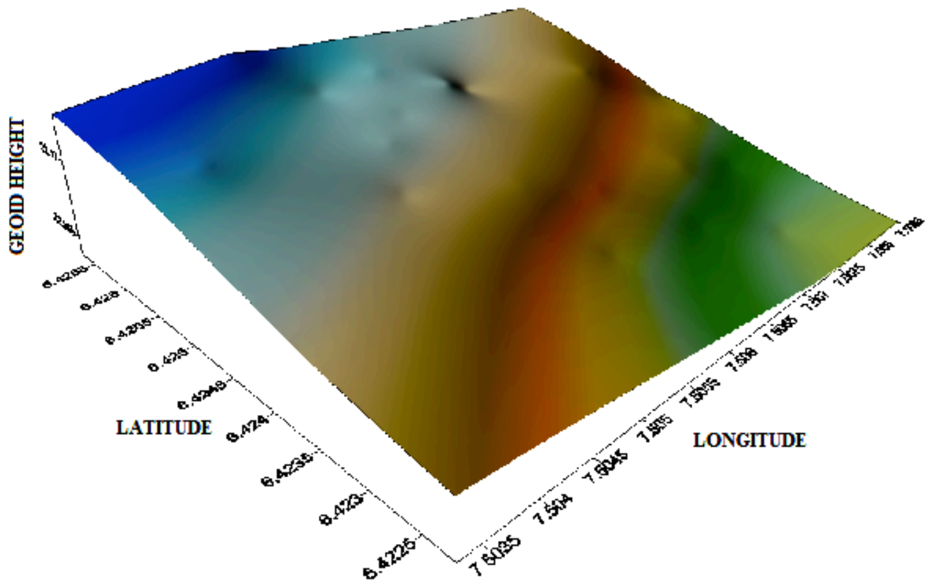

Fig 6: Surface of the EGM2008 Geoid

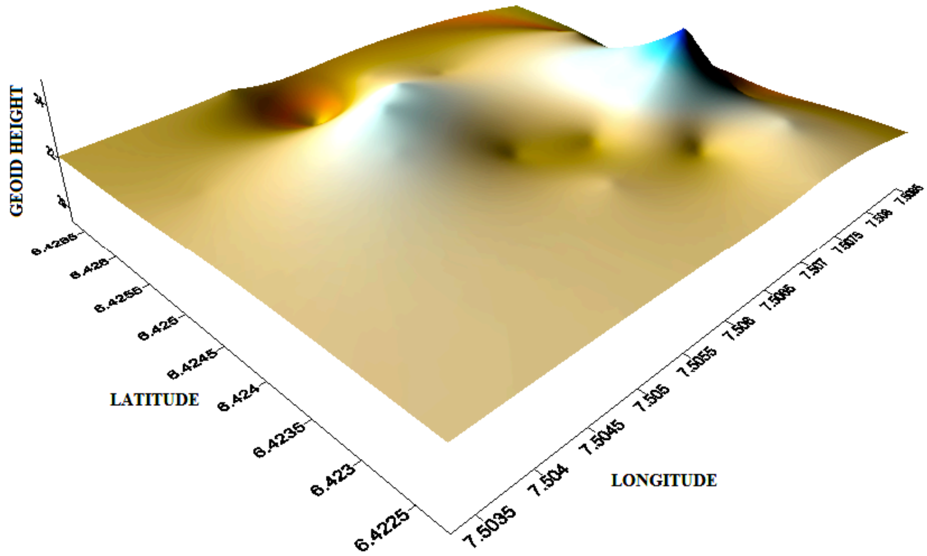

Fig 7: Surface of the UNEC-Model Geoid

4. CONCLUSION

The method of Spirit levelling is a very accurate means of obtaining height differences between two points. In this study we adopted the EGM2008-derived orthometric height of station NK1R as the datum for the spirit levelled heights. This was to enable us carry out a direct comparison between the EGM2008 –derived orthometric heights and spirit level-derived orthometric heights of the validation points. Our results show that the two sets of heights differ by a standard error of ± 1.019 m. Exclusion of the four stations (7DPR6, 7DPR7, G2 and UNEC 10) which are under further study gave a standard error of ±0.370m. These two results (± 1.019 m and ±0.370m) show that the EGM2008 geoid height model may not yield topographic map sufficiently accurate for precise engineering construction in a micro environment except they are augmented with a correction model (Uzodinma and Mohammed, 2013). The resolution study, on the other hand, shows that the EGM2008 model yields a more homogenous surface than the UNEC model.

5. REFERENCES

1. Anon (2002) "Surfer Version 8.01, Surface Mapping System". Golden Software, Inc. (www.goldensoftware.com)
2. Anon (2013) GeoidEval (http://geographiclib.sourceforge.net/cgi-bin/GeoidEval)

3. Featherstone, W. E., Denith, M. S. and Kirby J. F. (1998) “Strategies for the accurate determination of Orthometric Heights”, Survey Review, Vol. 34, No 267, January 1998,pp.278-296

3 Heiskanen, W. A., Moritz, H. (1967) “Physical Geodesy” W.H. Freeman and Company San Francisco.

4 Kavanagh, B.F. and Glenn Bird, S.J. (1996) .Surveying Principles and Applications. Prentice hall publisher.

5 Martensson, S-G, (2002). “Height Determination by GPS – Accuracy with Respect to Different Geoid Models in Sweden”. FIG XXII International Congress, Washington, D.C. USA, April 19-26.

6 NIMA (2008): United States National Geospatial- Intelligence Agency (EGM2008, Released in July 2008). [Online] Available: http://earth-info.nga.mil/GrandG/wgs84/gravitymod/egm2008/index.html (December, 2010).

7 Uzodinma, V.N. and S.O. Mohammed (2013). Determination of Improved Elevation Differences from GPS and Earth Geopotential Model 2008 (EGM2008) for Engineering Operations. Nigerian Journal of Space Research 11: 54-60. NASRDA Centre for Basic Space Science.