ISSN 2250-3153

Computations of Geoid Undulation from Comparison of GNSS/Levelling with EGM 2008 for Geodetic Applications

Oluyori, P. D., Ono, M. N. and Eteje, S. O.

Department of Surveying and Geoinformatics
Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.

DOI: 10.29322/IJSRP.8.10.2018.p8230
http://dx.doi.org/10.29322/IJSRP.8.10.2018.p8230

ABSTRACT
*Consistency is an important characteristic in height systems which the mean sea level (msl) surface cannot guarantee. Only a geoid surface can provide height consistency. The quality of geoid undulation (**N**) will obviously affect the resulting orthometric height (**H**) determined from GNSS. The geoid undulation may be global, regional/national and local. Online software CSRS-PPP was used for post processing rinex data. $N^{EGM2008}$was computed from AllTrans EGM2008 geoid calculator while h was used to compute N^{GPS} from the relationship **N= h-H**. H is the existing orthometric height. Twenty-four controls with FCT 260 P as base reference station were used for this study. The computed standard deviation of differences in$N^{GPS} - N^{EGM2008}$ (**σ**) is used as accuracy indicator and **σ** =0.419**m** .The root mean square error (RMSE) is 0.934m. This indicates the quality and reliability of the geoid undulation from the EGM2008 model. Comparing the observed $N^{GNSS}$and $N^{EGM2008}$, the use of global models may not satisfy the accuracy level of orthometric height desired for local applications in the FCT, Abuja. GNSS (GPS) may be used along with local geoid model as a way to acquire acceptable orthometric height. The smaller the N^{GPS}-$N^{EGM2008}$ makes it better model. The range of 1.585m from (N^{GPS}-$N^{EGM2008}$) in this study is a strong indication that global models should be avoided as much as possible in local applications.*

***Keywords**: Geoid undulation, Ellipsoidal height, Orthometric height, EGM2008, Accuracy*

INTRODUCTION

Geospatial data are acquired by space or conventional techniques. The space techniques of GNSS produce ellipsoidal heights (h) based on mathematical best-fit ellipsoid model of the earth surface. GNSS is presently used for coordinate (N, E, H) determination of points of interest on the earth. The orthometric height (H) is determined from the relationship given by Abdulkahdum (2015) and Eteje *et al* (2018) as:

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

The N is termed geoid undulation that is the difference between ellipsoid and geoid surface used for the conversion of ellipsoidal height to orthometric height. The N is given by Heiskanen and Moritz (1967) and Eteje *et al* (2018) as:

$$N = h - H \quad (2)$$

Geoid undulation may be determined from global, regional and local geoid models. GNSS, by default is integrated with global model e.g. EGM 2008. Global models are classified into satellite only (GRACE) and satellite combined with terrestrial gravity data e.g. EGM 2008. For practical geodetic data applications, there is the need for evaluation of global geoid by comparison with another model, the accuracy achievable before use in geospatial data acquisitions. Odera and Fukuda (2015) observed that global models are too generalized to be adopted for local geo-data measurements. In a place like Nigeria with no official national geoid model and unreliability of global geoid models, the need for local geoid development is very important for GPS user community.

Pavlis *et al.* (2008) confirmed that lack of gravity data contribution from Nigeria in the development of EGM 2008 geoid model implies that generated gravity was used and hence reliability of geoid undulations are very poor and hence lead to unreliable orthometric height. This can also be viewed from the worldwide EGM 2008 geoidal map where Nigeria falls within the gravity fill-in category as shown in Figure 1. To remedy the effect in local applications, local geoid is imperative. Local geoid model can be determined by gravimetric, astro-geodetic, geometric methods. This study adopted the geometric method due to the availability of controls in the F.C.T. with orthometric heights (H) whose coordinates (N, E, H) were collected from Survey and Mapping department of Federal Capital Development Authority (FCDA).

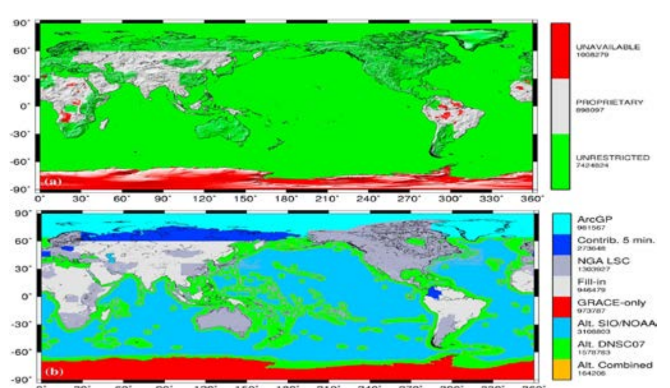


Figure 1. Geographic display of some of the characteristics of the 5 arc-minute area-mean gravity anomalies in the merged file used to develop the EGM2008 model.
Source: Nikolaos K. Pavlis, Simon A. Holmes, Steve C. Kenyon, and John K. Factor (2012)

GNSS is integrated with global model (EGM2008, EGM 96) by default. EGM2008 was developed by the US National Geospatial-Intelligence Agency according to Pavlis *et al*.(2008) with WGS84 as reference global ellipsoid to best –fit the earth surface for heights as vertical datum. The AllTrans 3.002 EGM geoid calculator was used to compute the geoid undulation for the observation points. Kotsakis et al. (2010) say the EGM2008 has a resolution of 9 km. The particular choice of EGM2008 was mainly due to its high resolution. Yi and Rummel (2014) opined that EGM2008 is the most comprehensive representation and the highest resolution of the Earth's gravitational field currently available.

With GPS/Levelling technique and existing orthometric height (H) in F.C.T, the geoid undulation was determined from equation (2). This procedure is referred to as geometric geoid approach and is very practicable especially with widespread use and acceptability of GPS by surveyors for geodetic applications. This study therefore presents the determination of geoid undulation using the EGM global model and DGPS levelling over 24 controls points. The static DGPS provided better ellipsoidal heights and logically, better ellipsoidal heights would lead to better estimates of geoid undulation and hence orthometric heights. Figure 2 shows the geodetic surfaces of ellipsoid, geoid and geoid undulation.

The earth surface is the physical surface and the geoid is an equipotential surface of the gravity vector which best-fits, in a least squares sense, global mean sea level ignoring oceanographic effects. Since the mass of the earth is not uniform at all points due to subsurface materials, the gravity value varies and hence the shape of the geoid is irregular. The geoid is very appropriate for orthometric height realization. The use of geoid became highly relevant with the development of GNSS space techniques which makes geoid (global, regional/national and local) determination one of the goals of geodesy. The ellipsoid is the mathematically generated surface used to approximate the actual earth surface and is used as reference in space techniques. The heights referred to ellipsoid and geoid are termed ellipsoidal orthometric heights respectively. (See Fig. 2.)

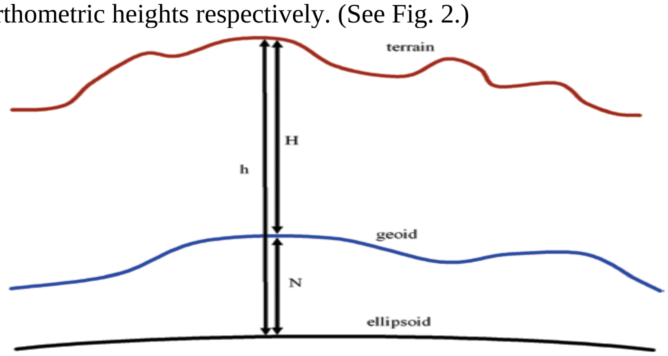


Figure 2: Terrain/earth surface, geoid and ellipsoid heights

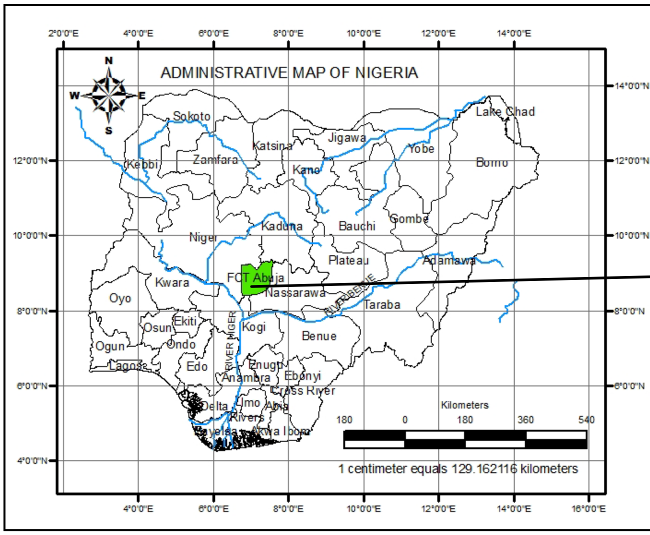
Geology of the study area

FCT is said to be predominantly underlain by metamorphic and igneous rocks of Precambrian age within the basement complex (Kogbe,1989). Precambrian Basement Complex rocks underlie three areas of Nigeria including the North-central area where FCT is located. FCT also lies outside the two zones suspected of tectonic activities in the country. The implication of this is that geodetic infrastructures/controls are geo-dynamically stable. Figure 3 shows the geological map of Nigeria.

Figure 3: Generalized geological map of Nigeria (MacDonald *et al.*, 2005).

Study area

Federal Republic of Nigeria consists of 36 states and Federal Capital, the FCT, Abuja. Nigeria is located between 4° and 14° latitude and 2° and 15° longitude occupying an area of 923768 km^2 Two major rivers in the country are Niger and Benue that meets at Lokoja. The FCT lies between 8° 15'N to 9° 12'N latitude and 6° 27'E to 7° 23'E longitude. Figures 4a and 4b are maps of Nigeria and Federal Capital Territory Area Councils respectively



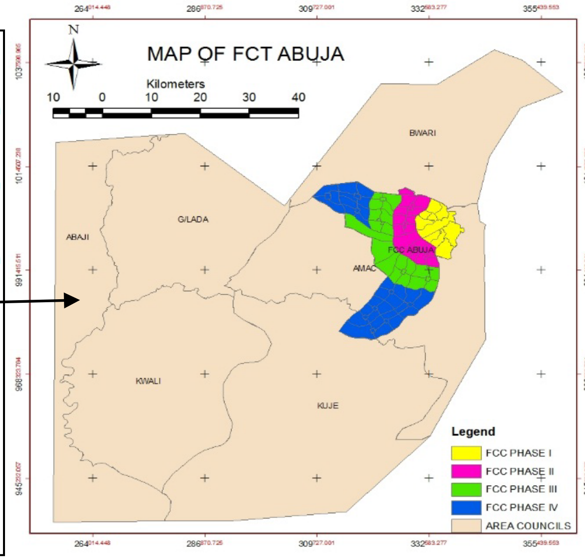


Fig. 4a: Nigeria map with thirty-six states and FCT. Fig. 4b: Map of FCT Area Councils

METHODS

The DGPS geodetic receivers were used and in relative mode on base reference station for a 2 hour duration of each rover observation positions. This provided primary data of latitudes, longitudes and ellipsoidal heights. The secondary data were collected from surveying and mapping department of F.C.D.A. which are the coordinate list, maps of Nigeria and Area councils of FCT. AllTrans EGM2008 geoid calculator was also used for geoid computation.

Data Sets

The datasets required for this study include: Orthometric height (H) shown in Table 1; Ellipsoidal height (h) from static DGPS measurements by relative technique; AllTrans3.002 EGM geoid calculator for geoid undulation (N) computation and GPS computed geoid undulation from N= h-H

Orthometric Height (H)

This is the height required for survey, mapping, engineering/environmental applications as well as geo-scientific studies. These heights are referred to the geoid surface which is a surface that is at all places on the surface at right angles to the gravity vector direction. The list of controls obtained from Surveying and Mapping Department of FCDA, Abuja. The orthometric heights are referenced to Mean Sea Level (MSL) approximation of the geoid surface. Table 1 shows a list of coordinates with orthometric height.

Table 1: List of coordinates with orthometric height.

	COORDINATE REGISTER VALUE		
CONTROL POINTS	**EASTINGS (m)**	**NORTHINGS (m)**	**ORTHOMETRIC HEIGHTS, H (m)**
FCC11S	331888.114	998442.043	485.447
FCT260P	255881.175	993666.807	201.944
FCT103P	340639.766	998375.578	532.558
FCT12P	333743.992	1008308.730	735.707
FCT19P	337452.408	996344.691	635.644
FCT2168S	310554.927	1009739.930	431.087
FCT24P	322719.776	1001884.850	453.804
FCT276P	351983.716	1025998.314	625.572
FCT4154S	329953.882	1003831.280	476.981
FCT4159S	326124.422	1003742.860	452.230
FCT66P	299148.035	998114.283	297.111
FCT9P	329821.512	1007612.091	497.253
FCT35P	322183.380	992926.363	427.171
FCT57P	303234.270	992916.402	323.844
FCT4028S	330164.634	1001388.240	449.592
FCT53P	308943.361	993406.773	351.943
FCT4652S	329441.767	997474.808	462.711
FCT162P	270791.291	934625.533	189.696
FCT130P	330982.584	952889.869	695.608
FCT2327S	282526.612	973821.470	183.287
FCT2652S	271370.273	945385.429	138.952
FCT2656S	272644.591	941062.460	204.724
FCT83P	332954.205	987231.606	568.752
XP382	284074.729	983364.863	274.586

Source: FCDA (Surveying& Mapping Dept.)

RESULTS AND DISCUSSIONS

The results from this study are highlighted below:

Ellipsoidal Height (h)

The dual frequency GPS Hi-Target V30 Pro geodetic receiver model was used in static mode for 2 hours session during the field work on a primary control base (FCT260 P) reference station in relative technique mode. The base receiver was constantly logging data throughout the duration of collecting fieldwork. Online post-processing software CSRS-PPP (Canadian Spatial Reference Service Precise Point Positioning) was used to post-process GNSS RINEX data submitted through internet.

Table 1: Ellipsoidal heights (m)

CONTRO L POINTS	EASTINGS (m)	NORTHIN GS (m)	CSRS-PPP HEIGHT ellipsoidal h (m)
FCC11S	331888.114	998442.043	509.410
FCT260P	255881.175	993666.807	224.753
FCT103P	340639.766	998375.578	556.851
FCT12P	333743.992	1008308.730	760.185
FCT19P	337452.408	996344.691	659.817
FCT2107S	308926.908	989748.256	342.063
FCT2168S	310554.927	1009739.930	455.290
FCT24P	322719.776	1001884.850	478.013
FCT276P	351983.716	1025998.314	649.851
FCT4154S	329953.882	1003831.280	501.247
FCT4159S	326124.422	1003742.860	476.442
FCT66P	299148.035	998114.283	321.126
FCT9P	329821.512	1007612.091	521.720
FCT35P	322183.380	992926.363	451.276
FCT57P	303234.270	992916.402	347.845
FCT4028S	330164.634	1001388.240	473.994
FCT53P	308943.361	993406.773	375.991
FCT4652S	329441.767	997474.808	486.992
FCT162P	270791.291	934625.533	215.073
FCT130P	330982.584	952889.869	719.411
FCT2327S	282526.612	973821.470	207.446
FCT2652S	271370.273	945385.429	163.774
FCT2656S	272644.591	941062.460	229.244
FCT83P	332954.205	987231.606	592.876
XP382	284074.729	983364.863	298.432

Geoid Undulation/height (N)

The geoid height (*N*), is required for the most notable and primary use of the transformation between Global Positioning System (GPS)-derived ellipsoidal heights and orthometric heights. After post-processing of the Rinex data from CSRS-PPP online software, the geoid undulation is computed from both global EGM 2008 global model and GPS observed ellipsoidal height.

i) From EGM2008.

The geoid undulation was computed from AllTrans 3.002 EGM 2008 geoid calculator. For the observed points, the calculator was used for global N and results are shown in Table 3.

Table 3: EGM 2008 geoid undulation.

CONTROL POINTS	EASTINGS (m)	NORTHIN GS (m)	$N^{EGM2008}$ m
FCC11S	331888.114	998442.043	23.1627
FCT260P	255881.175	993666.807	23.1113
FCT103P	340639.766	998375.578	23.0363
FCT12P	333743.992	1008308.730	23.2582
FCT19P	337452.408	996344.691	23.2566
FCT2168S	310554.927	1009739.930	23.3182
FCT24P	322719.776	1001884.850	23.2245
FCT276P	351983.716	1025998.314	23.1733
FCT4154S	329953.882	1003831.280	23.2209
FCT4159S	326124.422	1003742.860	23.2297
FCT66P	299148.035	998114.283	23.2793
FCT9P	329821.512	1007612.091	23.2566
FCT35P	322183.380	992926.363	23.2108
FCT57P	303234.270	992916.402	23.2789
FCT4028S	330164.634	1001388.24	23.1974
FCT53P	308943.361	993406.773	23.2256
FCT4652S	329441.767	997474.808	23.1635
FCT162P	270791.291	934625.533	23.5677
FCT130P	330982.584	952889.869	23.7235
FCT2327S	282526.612	973821.470	23.3336
FCT2652S	271370.273	945385.429	23.4997
FCT2656S	272644.591	941062.460	23.5846
FCT83P	332954.205	987231.606	23.2237
XP382	284074.729	983364.863	23.2752

From table 3 above, the EGM 2008 geoid undulation is noted to be nearly consistent which is desirable.

ii) From GNSS observations

The ellipsoidal height (h) from GNSS is combined with existing orthometric (H) from FCDA (Surveying and Mapping) to compute geoid undulation (N) from N=h-H and results are shown in Table 4.

Table 4: Geoid Undulation Map from GNSS Observations

	FCDA COORDINATE REGISTER VALUES				
CONTROL POINTS	EASTINGS(m)	NORTHINGS(m)	ORTHOMETRIC HEIGHTS(H) m	ELLIPSOIDAL HEIGHTS (h) m	N^{GNSS}(m)=h-H
FCC11S	331888.114	998442.043	485.447	509.388	23.941
FCT260P	255881.175	993666.807	201.944	224.742	22.798
FCT103P	340639.766	998375.578	532.558	556.836	24.278
FCT12P	333743.992	1008308.730	735.707	760.187	24.480
FCT19P	337452.408	996344.691	635.644	659.817	24.173
FCT2168S	310554.927	1009739.930	431.087	455.285	23.198
FCT24P	322719.776	1001884.850	453.804	477.994	24.190
FCT276P	351983.716	1025998.314	625.572	649.851	24.279
FCT4154S	329953.882	1003831.280	476.981	501.259	24.278
FCT4159S	326124.422	1003742.860	452.230	476.535	24.305
FCT66P	299148.035	998114.283	297.111	321.124	24.013

FCT9P	329821.512	1007612.091	497.253	521.716	24.463
FCT35P	322183.380	992926.363	427.171	451.291	24.120
FCT57P	303234.270	992916.402	323.844	347.807	23.963
FCT4028S	330164.634	1001388.240	449.592	473.960	24.368
FCT53P	308943.361	993406.773	351.943	375.964	24.021
FCT4652S	329441.767	997474.808	462.711	487.131	24.420
FCT162P	270791.291	934625.533	189.696	215.133	24.437
FCT130P	330982.584	952889.869	695.608	719.396	23.788
FCT2327S	282526.612	973821.470	183.287	207.504	24.217
FCT2652S	271370.273	945385.429	138.952	163.724	24.772
FCT2656S	272644.591	941062.460	204.724	229.228	24.504
FCT83P	332954.205	987231.606	568.752	592.849	24.097
XP382	284074.729	983364.863	274.586	298.381	23.795

It can also be noted that the geoid undulation is also nearly consistent like the EGM determined geoid model. This is also desirable for orthometric height determination for local applications.

The geoid undulation differences (N^{GNSS} -$N^{EGM2008}$)

From computations, the differences between both EGM and GNSS derived geoid undulations are shown in Table 5.

Table 5: N^{GPS} - $N^{EGM2008}$ Differences, Standard Deviation, RMSE

A	B	C	D=B-C	E	F	G
CONTROL POINTS	N^{GNSS}**(m)**	$N^{EGM2008}$ **m**	N^{GNSS}**(m)-** $N^{EGM2008}$	**D-0.836**	**E²**	**D²**
FCC11S	23.951	23.163	0.778	-0.058	0.003364	0.605284
FCT260P	22.798	23.111	-0.313	-1.149	1.320201	0.097969
FCT103P	24.278	23.036	1.242	0.406	0.164836	1.542564
FCT12P	24.480	23.258	1.222	0.386	0.148996	1.493284
FCT19P	24.173	23.257	0.916	0.080	0.006400	0.839056
FCT2168S	23.198	23.318	-0.120	-0.956	0.913936	0.014400
FCT24P	24.190	23.225	0.965	0.129	0.016641	0.931223
FCT276P	24.279	23.173	1.106	0.270	0,072900	1.223236
FCT4154S	24.278	23.221	1.057	0.221	0.048841	1.117249
FCT4159S	24.305	23.230	1.075	0.239	0.057121	1.155625
FCT66P	24.013	23.279	0.734	-0.102	0.010404	0.538756
FCT9P	24.463	23.257	1.206	0.370	0.136900	1.454436
FCT35P	24.120	23.211	0.909	0.073	0.005329	0.826281
FCT57P	23.963	23.279	0.684	-0.152	0.023104	0.467856
FCT4028S	24.368	23.197	1.171	0.335	0.112225	1.371241
FCT53P	24.021	23.226	0.795	-0.041	0.001681	0.632025
FCT4652S	24.420	23.164	1.256	0.420	0.176400	1.577536
FCT162P	24.437	23.568	0.869	0.033	0.001089	0.755161
FCT130P	23.788	23.724	0.064	-0.772	0.595984	0.004096
FCT2327S	24.217	23.334	0.883	0.047	0.002209	0.779689
FCT2652S	24.772	23.500	1.272	0.436	0.190096	1.617984
FCT2656S	24.504	23.585	0.919	0.083	0.006889	0.844561
FCT83P	24.097	23.224	0.873	0.037	0.001369	0.762129
XP382	23.795	23.275	0.520	-0.316	0.099856	0.270400
		SUM	20.083		4.043871	20.922041
		MEAN	0.836			
		STD DEV (σ)			0.419	

In Table 5, the computation of standard deviation (σ) was done and the value is given as σ = 0.419m.

Specifications for Topographical Survey

This step becomes necessary to determine from the standard deviation of the differences compared against the specifications given by American Society of Photogrammetry and Remote Sensing (ASPRS 1993) as shown in Table 6, the limits to what is expected from the use of each model.

Table 6: ASPRS Topographic Elevation Accuracy Requirement for Well-Defined Points

Contour Interval (M)	Class I(M) High Accuracy/ Standard Deviation Accuracy	Class II(M) Lower Than Class 1 Accuracy Standard Deviation	Class III(M) Lower Than Class 11 Accuracy Standard Deviation
0.5	0.08	0.16	0.25
1.0	0.17	0.33	0.5
2.0	0.33	0.67	1.0
4.0	0.67	1.33	2.0
5.0	0.83	1.67	2.5

Source: American Society of Photogrammetry and Remote Sensing (ASPRS 1993)

From Table 6, it is seen that EGM2008 with σ=0.419, checked against the specification above, can be used to produce topographical plan of 4m contour interval for less accurate survey, feasibility studies and preparation of master plan or land use classification maps but inadequate for survey applications where a high accuracy is required.

ANALYSIS AND DISCUSSIONS

Steps used for comparing the two methods of geoid undulations from global and observations. Twenty-four controls were used for these observations and the geoidal undulations from the two are shown in Table 5. From the Table 5, the standard deviation (σ) of the geoid undulation differences computed is σ = 0.419m.

Table7: Statistics of N^{GNSS} - $N^{EGM\ 2008}$ (m)

	MINIMUM m	MAXIMUM m	MEAN m	STANDARD DEVIATION (σ) m
EGM2008	-0.313	1.272	0.836	0.419

The range of the differences in the Table 7 above (1.585 m) obtained from this study is a pointer to the fact that for local applications, the global model (EGM 08) is not be an adequate source of orthometric height determination. This has buttressed the fact for the need for development of local geoid by geometric method using GNSS. This difference has serious implications for topographical mapping, cadastral survey, engineering/environmental studies and others.

Discussion

The static GNSS provided better ellipsoidal heights. It is logical that better geoidal undulation would lead to better estimates of orthometric heights. The results from this study have confirmed the investigation of Uzodinma *et al*.(2014) in the evaluation of EGM2008 in UNEC (a value of 1.019m), Okiwelu *et al*. (2011) and others that reported about 1m accuracy in global model using spherical harmonics over Nigeria. This study has shown a RMSE of 0.934m. In Thailand, an accuracy of 1.012m was reported in the evaluation of EGM 2008

The following conclusions are made from this study:

1) The smaller the range of values (between lowest and highest N^{GNSS}-$N^{EGM\ 2008}$) the better the orthometric heights obtained, in this instance, the range of 1.585m is clearly an indication that EGM2008 should not be adopted for orthometric height determination in the study area.
2) The standard deviation of σ=0.419 computed when checked against the APSR table (1993) shows that at the very best only topographical survey of 4m contour interval can be produced using EGM 2008 geoid model and this may not be accepted for surveying, mapping, engineering and environmental studies.
3) The standard deviation value or root mean square error is a confirmation of absence of gravity values from Nigeria being part of input data in the development of EGM2008. Actually a generated gravity was used for Nigeria from the classification depicted on EGM global geoid map
4) This study has also implied that use of GNSS with local geoid model is preferable to using EGM2008 global geoid for orthometric height determination.

This is considered as the accuracy indicator of the global EGM2008 model. This accuracy is definitely inadequate in the FCT study area for geospatial data acquisition for orthometric height using GNSS method. Though the EGM 2008 geoid model shows nearly consistent geoid undulation values, the resulting standard deviation proved the unacceptable and inadequate behavior of the global model in local applications in the FCT study area which may be attributed to the lack of gravity contribution from Nigeria during the development of EGM 2008. In Central Mozambique, Merry (2009) reported a 3m difference between EGM orthometric height and the levelled height.

RECOMMENDATIONS

1) Though Nigerian has no official geoid model, each state may be encouraged to develop a geometric geoid model for local applications instead of adopting a model that is inadequate for practical geo-data acquisitions.
2) Efficient utilization of GNSS in almost all applications requires development of an appropriate geoid model for transformation of ellipsoidal height to orthometric height.
3) Since GNSS (GPS) observations were used for determination of geoid undulation, polynomial models may use the values for the modelling of geoid for local applications.

REFERENCES

1. Odera, P. A. and Fukuda, Y (2015). Recovery of Orthometric Heights from Ellipsoidal Heights Using

Offsets Method, *Earth Planets and Space 67(1)*, 1, 2015.

2. Abdulkahdum, A. J. (2015). A comparison of National Orthometric Height with DGPS /Levelling and ITRF 00 Datum with WGS 84 (08) Geoid. *International Journal of Advancement in Research and Technology*, Vol. 4, Issue 11, November 2015.
3. ASPRS (1993). American Society of Photogrammetry and Remote Sensing (ASPRS 1993).
4. Eteje S. O., Oduyebo O. F. and Olulade S. A. (2018). Procedure for the Determination of Local Gravimetric Geometric Geoid Model. *International Journal of Advances in Scientific Research and Engineering (IJASRE)*. Vol. 4 No. 8, pp 206-214.
5. Eteje, S. O., Ono, M. N. and Oduyebo, O. F. (2018). Practical Local Geoid Model Determination for Mean Sea Level Heights of Surveys and Stable Building Projects. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) e-* Vol. 12, No.6, PP 30-37.
6. Francisco), pp. 370.
7. Heikanen, W. A. and Motitz, H. (1967). *Physical Geodesy* (W. H. Freeman and Company San
8. Karim, H. H., Aiwan, I. A, and Jasim, B. S. (2016). Accuracy Assessment of the Gravitation Geoid Model of Hilla area, Iraq. *International Journal of Current Engineering and Technology*, Vol. 6, No. 4, 2016.
9. Kogbe, C. A. 1989. *Geology of Nigeria*. Rock View (Nigeria) Limited. Jos, Nigeria.
10. Kotsakis, G and Katsambalos, K. (2010). Quality Analysis of Global Geo-Potential Models at 1542 GNSS/Levelling Benchmarks over the Hellenic Mainland. *Survey Review*, *H2*,318 pp, 327- 344,October 2010.
11. Merry, C. (2009). EGM 2008 Evaluation for Africa, Newtons Bulletin, Issue No.4, April 2009.
12. Okiwelu, A., Okwueze, E. and Ude, I. A. (2011). Determination of Nigerian Geoid Undulations from Spherical Harmonic Analysis, DOI:.5539/apr.v3n1p8.
13. Pavlis, N, K., Holmes, S. A., Kenyon, S. C. and Factor, J. K. (2008). An Earth Gravitation Model to Degree 2160: EGM2008 presented at the 2008 General Assembly of the European Geosciences Union, Vienna, Austria, April 13 – 18, 2008.
14. Uzodinma, V. N., Oguntuase, J. O., Alohan, N. O. and Dimgba, C. N. (2013). *Practical GNSS Surveying*. Enugu: Professor's Press Limited.
15. Yi, W. and Rummel, R. (2014). A Comparison of GOCE Gravitational Models with EGM2008. *J Geoid* 73:14–22. Doi:10.1016/j.jog.2013.10.004

AUTHORS

Oluyori Dare P. - Ph.D Candidate, Nnamdi Azikiwe University, Awka, Nigeria, dareoluyori@yahoo.com.
Ono Matthew N.- Professor, Nnamdi Azikiwe University, Awka, Nigeria, nwa_nno@yahoo.com.
Eteje Sylvester O. - Ph.D Candidate, Nnamdi Azikiwe University, Awka, Nigeria, eteje.sylvester@yahoo.com.

Correspondence Author – Oluyori Dare P., dareoluyori@yahoo.com, 08066526502.