VERIFICATION OF THE CONSISTENCY OF THE PROPOSED TRANSFORMATION OF GLOBAL GEOID METHOD ACCURACY FOR LOCAL GEOID MODEL OF NIGERIA DETERMINATION

***[1]Oduyebo, O. F., [1]Ono, M. N. and [2]Eteje, S. O.**

[1]Department of Surveying and Geoinformatics, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria
[2]Eteje Surveys and Associates, Benin City, Edo State, Nigeria

Corresponding Author Email: jimioduyebo@yahoo.com

ABSTRACT

The proposed transformation of the global geoid model method for the determination of the local geoid model of Nigeria has only been applied in part of the Federal Capital Territory, Abuja. To determine the consistency of the accuracy of the method for the intended purpose, there is a need to apply it in some other parts of the country. As a result, this study presents the verification of the consistency of the proposed transformation of global geoid method accuracy for local geoid model of Nigeria determination. DGNSS observations were carried out to obtain the coordinates of the used points. The processed global geographic coordinates were used with online software (GeoidEval) to obtain the EGM 08 geoid heights of the points. The global geographic coordinates, the global geoid heights of the points and the transformation parameters from WGS 84 to Minna datum were applied to obtain the transformed (local) geoid heights of the points using a Microsoft Excel program. The transformed geoid heights were compared with their corresponding geoid heights from the gravimetric-geometric local geoid model of the study area to obtain the model RMSE (accuracy). The obtained accuracy (2.0172 m) was compared with those of the gravimetric-geometric geoid model of the study area (0.675 m) and the transformation of global geoid heights when the method was applied in part of Abuja (0.0014 m). The comparison results showed the inconsistency of the accuracy of the proposed method. It is recommended that the method should not be applied for the intended purpose.

Keywords: accuracy, consistency, geoid, model, transformation

INTRODUCTION

One of the most fundamental concepts in geodesy is the geoid, which is defined as an equipotential surface that coincides with the mean sea level (MSL) and extends below continents. It is the surface adopted in each country as a datum or reference for the vertical coordinate system. In Nigeria, various local geoid models have been determined in some parts of the country but there is still no unified geoid model which will serve as the vertical datum for the entire country. The Global Positioning System (GPS) which gives accurately three-dimensional coordinates of points on the earth surface does that by using a specified computational surface known as the ellipsoid. The heights determined by the GPS are geometric heights and do not have the physical meaning as they are not determined directly with respect to the geoid which is the datum for a vertical coordinate system. According to Moka *et al* (2017), today in Nigeria there is no acceptable geoid model a number of factors have led to the unacceptability of the results of geoid which include; inadequate data coverage, low accuracy of geoid model, etc. As a developing country, accurate height system which represents the form of the earth is an indispensable tool for all construction works for both near and offshore purposes. Moka *et al* (2017) further stated that the absence of a generally officially published geoid model has made it difficult, among other problems to create a connection between Land and Sea Datum which is analogous to Vertical datum in the US and Canada and Vertical Offshore Reference Frame (VORF) in the United Kingdom for seamless bathymetry in the near and offshore zone of our coastal waters (Moka *et al*, 2017). This has resulted in the adoption of different height systems that are incompatible with one another. Thus, the most geodetic, engineering and hydrographic applications are either referenced to the ellipsoid or other arbitrary height systems and all of these do not represent the actual form (geoid) of the earth over Nigeria (Moka *et al*, 2017).

The transformation of global geoid model to local which has to do with the transformation of global geoid heights to local has been proposed by Okeke and Nnam (2017) for the determination of the local geoid model of Nigeria. The method involves the application of the Kotsakis (2008) model for the transformation of global geoid heights to local geoid heights. This method has been applied in part of the Federal Capital Territory, Abuja by Okeke and Nnam (2017) with the use of the EGM2008 geoid heights and RMSE of 0.14 cm was obtained when compared with the existing geometric geoid model of the study area. Given that the proposed method will be applied to the entire country there is a need to verify the consistency, as well as the accuracy of the method in some other parts of the country. To do that, the method has to be applied for the determination of the local geoid model of an area or region and compared with the existing local geoid model of the area or region. Consequently, this paper verifies the consistency of the proposed transformation of the global geoid method for local geoid model of Nigeria determination.

Here, the proposed method was applied to determine the local geoid model of Benin City and the results were compared with those of the existing local geoid model of the study area (Benin City) which was determined with the gravimetric-geometric method by Oduyebo *et al.* (2019). Benin City was selected for this study for easy comparison as its local geoid model has already been determined.

The Study Area

According to Oduyebo *et al.* (2019), Benin City is the capital of Edo State in Southern Nigeria. It is a City approximately 40 kilometres north of the Benin River. The City is also linked by roads to Asaba, Sapele, Siluko, Okene, and Ubiaja

and is served by air and the Niger River delta ports of Koko and Sapele (Oduyebo *et al.,* 2019). The City is made up of three Local Government Areas, Oredo LGA, Ikpoba Okha LGA and Egor LGA. It has a total population of 1,782,000 according to the 2021 NPC projection. It covers a total area

of about 1,204 km². Benin City is bounded by UTM zone 31 coordinates 660000 mN and 712500 mN, and 770000 mE and 815000 mE (Oduyebo *et al.,* 2019). Figures 1a and b show the maps of the study area.
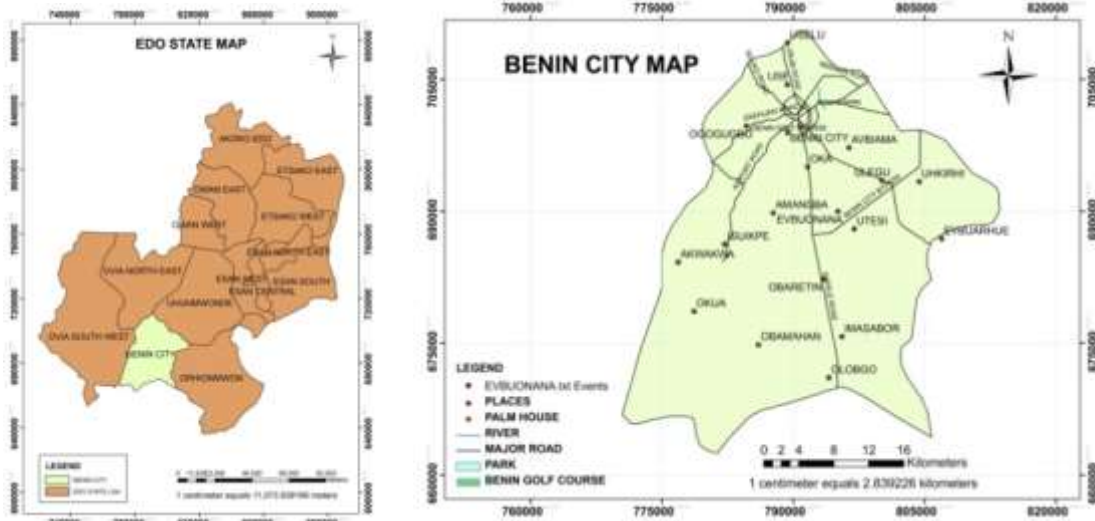
Figure
1a: Map of Edo State   Figure 1b: Map of Benin City
Source: Ministry of Lands and Surveys, Benin City

Kotsakis Model for Transformation of Global Geoid Height to Local

The model for the transformation of global geoid heights to local as given by Kotsakis (2008) is

$$N' - N = \delta N(t_x) + \delta N(t_y) + \delta N(t_z) + \delta N(\varepsilon_x) + \delta N(\varepsilon_y) + \delta N(\delta s) + \\ + \delta N(\delta a) + \delta N(\delta f)$$

(1)

Where,

$$\delta N(t_x) = t_x \cos\varphi \cos\lambda$$

(2)

$$\delta N(t_y) = t_y \cos\varphi \sin\lambda$$

(3)

$$\delta N(t_z) = t_z \sin\varphi$$

(4)

$$\delta N(\varepsilon_x) = -\varepsilon_x N e^2 \sin\varphi \cos\varphi \sin\lambda$$

(5)

$$\delta N(\varepsilon_y) = \varepsilon_y N e^2 \sin\varphi \cos\varphi \cos\lambda$$

(6)

$$\delta N(\delta s) = (aW + N)\delta s$$

(7)

$$\delta N(\delta a) = -W\delta a$$

(8)

$$\delta N(\delta f) = \frac{a(1 - f)}{W} \sin^2 \varphi \delta f$$

(9)

$$W = \sqrt{1 - e^2 \sin^2 \varphi}$$

(10)

N in equations (5) and (6) is the radius of curvature in prime vertical and it is given by Eteje *et al.* (2019) as

$$N = \frac{a}{\sqrt{1 - e^2 \sin^2 \varphi}}$$

(11)

The quantities $\delta a = a' - a$ and $\delta f = f' - f$ correspond to the difference in the numerical values for the semi-major axis and the flattening of the reference ellipsoid, as these are used in the respective reference frames, GRF1 and GRF2 (Kotsakis, 2008).

Transformation Parameters between WGS 84 and Minna Datums

The transformation parameters from WGS 84 to Minna datum as given by Okeke (2014) and Okeke *et al* (2017) are:
Transformation Parameters from WGS 84 to Minna Datum

        Tx= 93.809786 m ± 0.375857310 m
        Ty = 89.748672 m ± 0.375857310 m
        Tz = -118.83766 m ± 0.375857310 m

α = 0.000010827829 ± 0.0000010311322
β = 0.0000018504213 ± 0.0000015709539
γ = 0.0000021194542 ± 0.0000013005997
S = 0.99999393 ± 0.0000010048219

Properties of the WGS 84 and Clarke 1880 Ellipsoids
The equatorial radius (*a*) and the flattening (f) of the WGS 84 and the Clarke 1880 ellipsoids are respectively 6378137 m and 1/298.257223563, and 6378249.145 m and 1/293.465 (Eteje *et al*., 2019).

EGM08 Geoid Height
The earth gravity model EGM08 developed and released by the National Geospatial Intelligent Agency is a significant achievement in global field mapping (Lyszkowicz, 2009). This gravitational model is complete to spherical harmonic degree and order 2159 and contains additional coefficients extending to degree 2190 and order 2159 (Abdelrahim, 2013). Computing the geoid undulation values are realized with respect to WGS 84 ellipsoid (Idrizi, 2013).

According to Idrizi (2013), harmonic synthesis software provided by NGA applies a constant, zero-degree term of -41cm to all geoid undulations computed using EGM2008 with the height anomaly to geoid undulation correction model. Idrizi (2013) further posited that all the pre-computed geoid undulations include this constant zero-degree term. This term converts geoid undulations that are fundamentally referenced to an ideal mean-earth ellipsoid into undulations that are referenced to WGS 84. The value of -41 cm derives from a mean-earth ellipsoid WGS84 (Idrizi, 2013). This new model makes possible with high spatial sampling resolution computation of mean gravity anomalies, geoid ellipsoid separations and other characteristics of gravity field for the entire globe (Lyszkowicz, 2009).

Gravimetric-Geometric Geoid Model of Benin City
The gravimetric-geometric geoid model of Benin City was determined using the combination of the gravimetrically and geometrically obtained data. The realization, as well as the determination of the model, is detailed in Oduyebo *et al*. (2019). In Oduyebo *et al*. (2019), three gravimetric-geometric geoid models were determined and the one with the highest accuracy (third-degree gravimetric-geometric geoid model with RMSE of 0.6746 m among the three models was recommended for application in Benin City.

METHODOLOGY

Data Acquisition
The coordinates, as well as the positions and the ellipsoidal heights of the points used in the study, were obtained from Differential Global Navigation Satellite System (DGNSS) (See Figures 2 and 3). The observation was carried out using CHC 900 dual-frequency GNSS receivers.

Figure 2: Base Receiver at Control Station XSU92

Figure 3: Rover Receiver at One of the Selected Points (RR01) at Ring Road

Data Processing
The observations were respectively downloaded and processed with HcLoader and Compass post-processing software (See Figure 4). The geographic coordinates of the points were processed in the WGS 84 datum. It was done to enable the global positions of the points used to obtain the global geoid heights of the points from EGM 08 using the GeoidEval online software (See Figure 5) to be obtained.
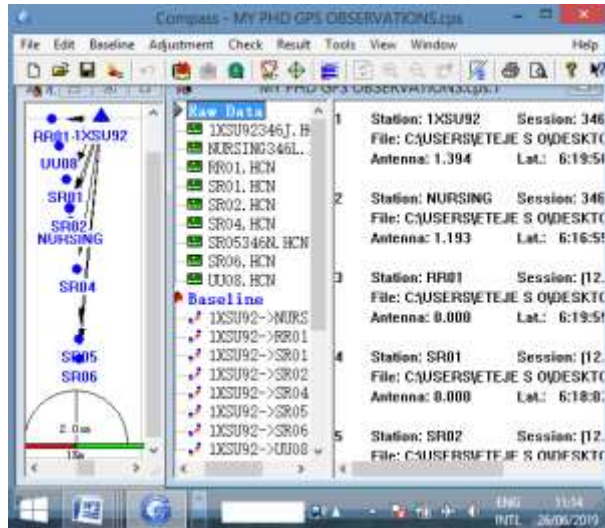
Figure 4: Processing of the GNSS Data Using Compass Software

Figure 5: Computation of the Global Geoid Heights of the Points Using GeoidEval Software

The local geoid heights of the points were computed with the properties of the WGS 84 and the Clarke 1880 ellipsoids, the transformation parameters, the global geographic coordinates and the EGM 08 geoid heights of the points using the transformation method, as well as equation (1). The computation was done using a Microsoft Excel program developed in the study (See Figure 6).

Figure 6: Computation of Geoid Heights of the Points Using the Transformation Method

RESULTS AND DISCUSSION

Table 1 presents the comparison between the gravimetric-geometric model geoid heights and the global geopotential model (EGM08) local geoid heights of the points. It was done to determine the agreement of the transformation geoid model with the gravimetric-geometric geoid model of the study area. The closer the Root Mean Squares (RMS) error obtained from the comparison of the local geoid heights of the points from the gravimetric-geometric geoid model with their corresponding local geoid heights from the transformation of global geoid height to local method using the global geopotential model (EGM08), the more the agreement between the two local geoid models. From Table

1, it is seen that the accuracy, as well as the RMS error of the transformation geoid model, is 2.0172 m while that of the gravimetric-geometric geoid model determined by Oduyebo *et al.* (2019), is 0.675 m. This implies that the two geoid models are not in agreement. The RMS error of the transformation method when it was applied in part of the Federal Capital Territory is 0.0014 m. Comparing this with the RMS error of the transformation method applied in this study implies that the accuracy of the proposed method for the determination of the local geoid model of Nigeria is not consistent in every part of the country. Thus, it cannot be applied for the proposed purpose

Table 1: Comparison between the Gravimetric-Geometric
Geoid Heights and the Transformed EGM08, Local Geoid Heights

Point	Gravimetric-Geometric Geoid Heights (m) (A)	Transformed EGM08 Geoid Heights (m) (B)	Diff. b/w A & B (m)	Diff. b/w A & B Squared (m²)
XSU92	2.086	0.3180	3.1257	3.1257
RR01	2.420	0.3624	4.2338	4.2338
SR01	1.588	0.1663	2.0213	2.0213
SR02	1.978	0.0811	3.5984	3.5984
SR04	2.520	-0.0963	6.8448	6.8448
SR05	2.802	-0.2845	9.5267	9.5267
SR06	3.266	-0.3349	12.9667	12.9667
XSU100	2.098	0.0444	4.2171	4.2171
AR01	0.685	0.3399	0.1191	0.1191
AR02	0.720	0.3075	0.1702	0.1702
AR03	1.436	0.2146	1.4918	1.4918
AR04	1.439	0.1932	1.5521	1.5521
UU01	4.658	0.9586	13.6854	13.6854
UU02	3.498	0.8172	7.1869	7.1869
UU03	1.981	0.6410	1.7957	1.7957
UU04	1.276	0.5155	0.5783	0.5783
UU05	1.346	0.4380	0.8245	0.8245
UU06	1.489	0.3497	1.2981	1.2981
UU07	1.329	0.2977	1.0635	1.0635
UU08	1.263	0.2735	0.9792	0.9792
AD01	2.986	0.4225	6.5717	6.5717
AD02	4.019	0.4531	12.7154	12.7154
AD03	4.420	0.4721	15.5858	15.5858
AK01	1.376	0.3985	0.9555	0.9555
AK02	1.473	0.4210	1.1067	1.1067
AK03	2.252	0.4076	3.4017	3.4017
AK04	3.101	0.3629	7.4971	7.4971
AK05	3.954	0.3141	13.2487	13.2487
MR01	1.300	0.4310	0.7552	0.7552
MR02	1.488	0.4973	0.9816	0.9816
MR03	1.614	0.5597	1.1116	1.1116
MR04	4.037	0.5626	12.0715	12.0715
MR05	4.313	0.5164	14.4145	14.4145
SK01	1.500	0.2793	1.4902	1.4902
SK02	2.035	0.1866	3.4166	3.4166
SK03	2.379	0.1084	5.1556	5.1556
EKS	0.665	0.4142	0.0629	0.0629
SLK0	0.668	0.4646	0.0414	0.0414
SLK01	0.781	0.5198	0.0682	0.0682
SLK02	1.326	0.6127	0.5089	0.5089
SLK03	1.736	0.6764	1.1227	1.1227
SLK04	2.688	0.7884	3.6083	3.6083
SLK05	3.357	0.8819	6.1261	6.1261

EK01	0.078	0.4159	0.1142	0.1142
EK02	0.983	0.4289	0.3070	0.3070
EK03	1.729	0.3861	1.8035	1.8035
EK04	2.001	0.3261	2.8053	2.8053
EK05	2.516	0.2838	4.9827	4.9827
AIRPORT	0.578	0.3160	0.0687	0.0687
MEAN OF DIFFERENCES =			**1.6882 m**	
RMS Error of Transformation Model = SQRT of Average =				**2.0172 m**
RMS Error of Gravimetric-Geometric Model =			**0.6746 m**	
RMS Error of Transformation Model as obtained by Okeke and Nnam (2017) =			**0.0014 m**	

Figures 7 and 8 respectively present the contour maps of the gravimetric-geometric geoid model and that of the transformation geoid model. It was done to present graphically and compare the shapes of the two local geoid models (gravimetric-geometric and transformation geoid models) of the study area. It can be seen from Figures 7 and 8 that the contour maps of the two local geoid models of the study area are not identical. It is as a result of the low accuracy (2.0172 m) of the transformation geoid model.
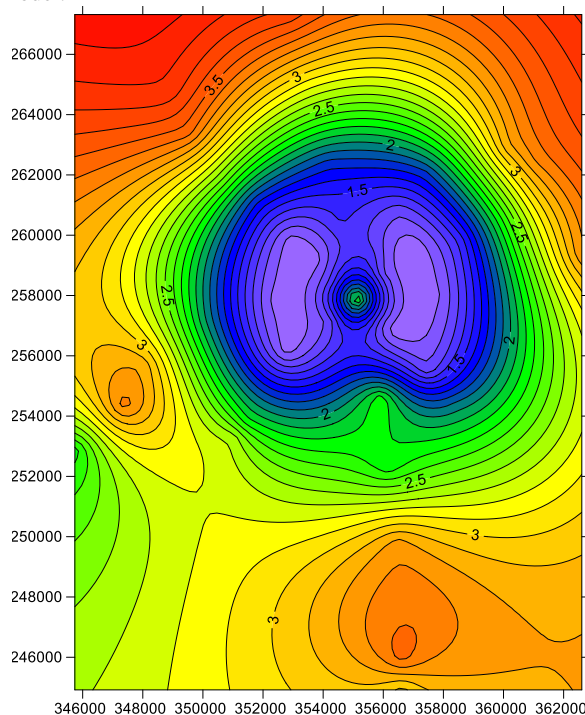

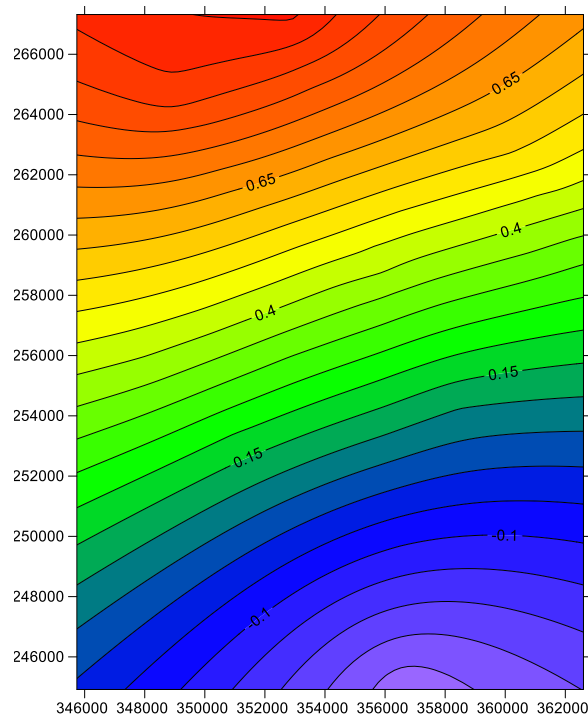Figure 7: Contour Map of the Gravimetric-Geometric Model

Figure 8: Contour Map of the Transformation Model

CONCLUSION AND RECOMMENDATION

Having verified the consistency of the accuracy of the proposed transformation method of local geoid model determination for local geoid model of Nigeria, the following conclusion and recommendation were made: The study has shown disagreement in shape and accuracy between the local gravimetric-geometric and the transformation methods geoid models of the study area. The obtained results also revealed the inconsistency of the proposed method accuracy for the determination of the local geoid model of Nigeria. Since the accuracy of the proposed method is not consistent in various parts of the country, it is recommended that it should not be applied for the intended purpose.

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