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An Assessment of Geoidal Undulations Determined From GPS/LEVELLING Method and EGM2008

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Abstract
The Earth Geopotential Model of 2008 (EGM2008) is the product of the effort by the National Imagery and Mapping Agency (NIMA), USA at generating an accurate global geoid height model which will facilitate accurate conversion of geocentric ellipsoidal heights to their corresponding orthometric equivalent. This research assesses the Geoidal undulations determined from GPS/Leveling method and EGM2008 at 19 stations established on the ground surface. The assessment was done by comparing Geoidal undulations determined from GPS/Leveling and EGM2008 and using t-test statistical operation to find out whether there is a significant difference between the two methods. The results obtained shows significant difference between the two techniques with an accuracy of ± 0.501m (std. dev.) and 0.4630 (RMSE) within the study area , however an effect size test shows that the effect of the difference is small judging by the Cohen's d Pearson's Correlation Coefficient and the odds ratio of 0.1. The standard deviation obtained was checked against the specification given by American Society of Photogrammetry and Remote Sensing (ASPRS 1993) which indicated that it can be used to produce topographical plan of 1m contour interval for less accurate surveys such as feasibility studies and preparation of master plan or land use classification maps but inadequate for survey applications where a high accuracy is required.
Key Words: *Geoidal Undulations, Ellipsoidal Heights, Orthometric Heights, Leveling, Comparing*

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I. 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 height is conventionally determined by the use of spirit levelling and defined by the vertical distance above the geoids as measured along plume line. GPS elevations are obtain directly from the geo-centre 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, 2014).

GPS elevation can be converted to orthometric heights using geoidal models (Uzodinma, 2014). 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);

i. semi-major, a = 6378137.00 m
ii. flattening, f = 1/298.257223563
iii. Earth's mass and the Gravitational Constant, GM = 3.986004418 x 1014 m3s-2
iv. Earth's angular velocity, ω = 7292115 x 10-11 radians / sec.

Most geodetic applications like determining the topographic heights of points on the globe require the geoid which approximates Mean Sea Level (MSL), as the datum/reference surface. In this satellite era one is capable of obtaining a sufficiently accurate model of the gravity field over the surface of the earth. This is a great achievement in the fields of geodesy and geophysics since we can achieve heights with physical meaning without necessarily carrying out the tedious and time-consuming procedures of obtaining these heights by geometric or trigonometric leveling (Abeho *et al.*, 2014).

The release of the new Earth Gravitational Model EGM2008 by the US National Geospatial Intelligence Agency (Pavlis et al., 2008) is a big achievement in determination of the earth's gravity field. EGM2008 is a spherical harmonic model complete to degree and order of 2159, with additional spherical harmonic coefficients extending up to degree of 2190 and order 2159. This offers a spatial sampling resolution of approximately 9km for the recovery of gravity field functions over the entire globe (Kotsakis et al., 2008). EGM2008 incorporates 5x5 min gravity anomalies and altimetry-derived gravity anomalies and has benefited from the latest GRACE based satellite gravity field model (Pavlis et al., 2008). For this model to be used for geodetic activities anywhere on the globe, there is need to quantify its accuracy using several validation data sets such as geoid heights through the combination of GPS and levelling, airborne and local surface gravity measurements, marine geoid heights from mean oceanographic surface topography models and altimetry observations among others (Kotsakis et al., 2008; Kılıçoğlu et al., 2008). For better assessment, however, these external data sets should be independent of the estimation procedures that were used in the development of the model. This study focuses on assessing the accuracy of geoidal undulations obtained from GPS/ Levelling method and the EGM2008 model in Modibbo Adama University, Yola.

The Earth: In geodesy, the figure of the earth which means surfaces with close approximation to the physical size and shape of the earth can be represented with different figures for the purpose of computational convenience. Basically the earth can be treated as a *sphere, ellipsoid and a geoid.* The surface that corresponds to a stretched sphere is the physical terrain of the earth surface, which is characterized by hills and valleys. Due to its irregular surface, the sphere cannot be used for mathematical computations (Wolf, 2008).

The ellipsoid: is a solid figure generated by rotating an ellipse about its minor axis, this figure is a smooth elliptical model of the earth's surface. Due to the close approximate of this figure to the earth it is mostly used in geodesy and can be represented mathematically and analytically (Charles and Wolf, 2012).

The Geoid: is an equipotential surface or of constant potential energy which coincides with the mean sea/ ocean level of the Earth if the ocean surface is at equilibrium i.e. when forces like tides, ocean currents do not exist. This surface extends through the continents such as very narrow canals. The geoid is a mathematical figure of the earth, smooth but highly irregular surface that corresponds not to the earth actual surface, but to a surface which can only be known through extensive gravitational measurement and computations (Gauss). The geoid is better described as the true physical surface of the earth in contrast to the mathematically generated figure of the ellipsoid (Charles and Wolf, 2012).

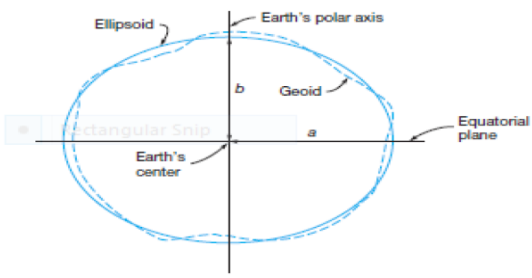

Figure 1: Ellipsoid and the geoid

Geoid Undulations: As discussed earlier, the geoid is an equipotential surface defined by gravity. If the Earth was a perfect ellipsoid without internal density variations, the geoid would match the ellipsoid perfectly. However, this is not the case, and thus the geoid can depart from some ellipsoids by as much as 100 m or more in certain locations. Traditional surveying instruments are oriented with respect to gravity and thus observations obtained with them are typically made with respect to the geoid (Charles, 2012).

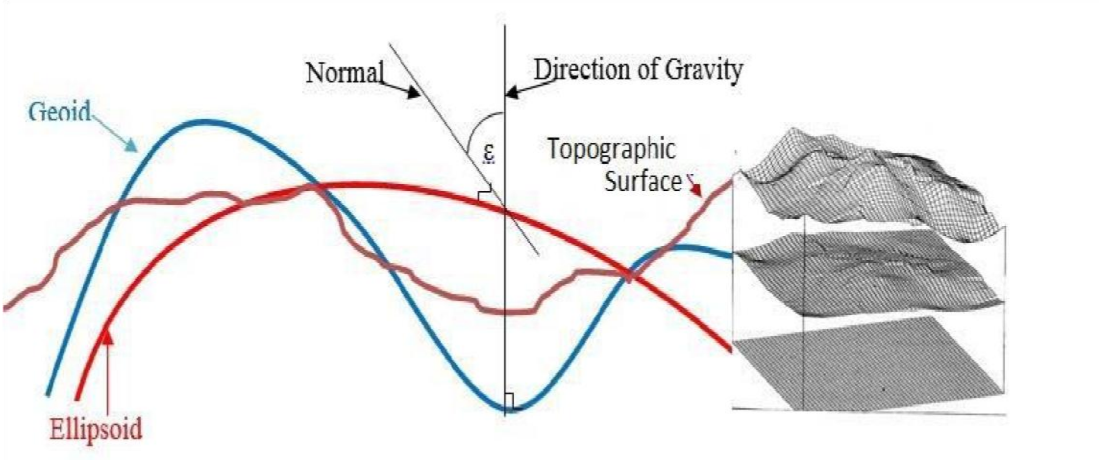

Figure 2: Relationship between physical surface of the earth, geoid, and ellipsoid

As can be seen in Fig.2, the separation between the geoid and the ellipsoid creates a difference between the height of a point above the ellipsoid (*geodetic height*) and its height above the geoid (*orthometric height*, which is commonly known as *elevation*). This difference, known as *geoid height* (also called *geoidal separation*), can often be observed when comparing the geodetic height of a point derived by GNSS surveys, with its elevation as determined by differential leveling. The relationship between the orthometric height *H* and geodetic height *h* at any point is:

$h = H + N$ Where *N* is the geoidal height.

Height Systems: Spirit Leveling: This is usually applied when height difference δHAB between two points A and B is required. To measure this height difference, vertical rods are set up at each of these points and a level between the set ups. Since the line AB is horizontal, difference in rod readings from the level is the height difference. Geopotential number C: of a point is the proper expression for the potential of a point on an equipotential surface. The Geopotential number is defined as a negative difference in the potential of a point and the potential of the geoid or the difference between the potential of the geoid and that of the point A. Let O be a point at sea level, (geoid) usually a point on the seashore is taken. Let A be another point connected to O by a leveling line. The Geopotential number C is considered as a natural measure of height even though the unit is not related to length. It is measured in Geopotential units (g.p.u.).

Dynamic Heights: Dynamic heights are simply Geopotential number divided by a reference gravity value usually gravity value at 45 degrees. The only difference between dynamic height and Geopotential number is in the unit which is caused by the division of Geopotential number by the constant. This converts the Geopotential number into length. It should be noted that two points with the same dynamic height will be on the same equipotential surface. Dynamic heights are used mainly for hydrological studies.

Orthometric Heights: To obtain true orthometric height, height differences determined from leveling must be corrected (either added or removed). We denote the intersection of the geoid and the plumb line through point P by Po, where C is the Geopotential number of P.

Normal Heights: Normal heights are orthometric height heights where for a moment the gravity field is assumed to be normal (i.e. W=U, g=ϒ, T=0). Normal heights are denoted by H'.

The EGM2008 Model: 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).

II. The Study Area

Location: The study area is a compound at the Modibbo Adama University, Yola that lies between latitude 09^0 21′ 18″ and longitude 12^0 30′ 30″ at the South and latitude 9^0 20′ 59″ and longitude 12^0 30′ 36″ at the North. The area is situated along the Yola-Maiduguri highway and is about 4km away from Girei town, the Girei Local Government headquarter of Adamawa state, Nigeria.

Climate: The climate, the study area exhibits typical tropical climate (Adebayo, 1999; Zemba, 2010). The study area has average sunshine hours of about 7-8 hours daily and the wind speed average of 76.1Km/hr. The air temperature in the state as a whole is a typical West African Savannah Climate. Temperature in this region is generally high throughout the year. Yola has a seasonal change in temperature, from January – April; the temperature increase because of the clearer sky view which permits the reception of solar radiation. The maximum temperature is 43°C which occur in April and the minimum temperature is 18°C between December and January. There is a distinct drop in temperature at the onset of rains due to the effects of cloud cover. The temperature decreases at the beginning of the raining season to the end which is as a result of the cloud effect. The temperature again increases after the cessation of the season (October - November) before the arrival of harmattan which leads to drop in temnpersture (Adebayo, 1999).

III. Materials and Method

The equipment used for the study is made up of hardware and software. The hardware include; i. Differential Global Positioning System (DGPS) receiver and ii. Automatic level instrument and Leveling staff. The software include; i. GIS software (AutoCAD 2007, Altar's Earth Gravitational Model 2008 (EGM2008) Calculator and Surfer 10.0) ii. Statistical Package for the Social Sciences (SPSS 16.0) iii. Microsoft Word 2007 and Microsoft Excel 2007 and iv. Internet facilities.

Data Type and Source:

There are four types of data used, these include; i. Ellipsoidal heights obtained from DGPS receiver ii. Orthometric heights obtained by Spirit levelling iii. Geoidal undulations calculated from Ellipsoidal and Orthometric heights ($N_{GPS/Level}$) iv. Geoidal undulations interpolated by EGM2008 ($N_{EGM2008}$) and v. Cartesian and Geographical coordinates obtained from DGPS receiver.

Data Acquisition and Processing:

In order to obtain the data for the assessment, nineteen (19) points were established on the ground made up of two loops such that loop 1 has points; YSA001, YSA002, YSA003, YSA004, YSA005, YSA006, YSA007, and EJS001, EJS001 being the control points whose X,Y,Z coordinates are known. The second loop has points; EJS001, YSA007, YSA006, YSA005, YSA008, YSA009, YSA010, YSA011, YSA012, YSA013, YSA014, YSA015, YSA016, YSA017, and YSA018 as shown in figure 3 below.

Having established 19 points on the ground, field survey was carried out on those points to obtain the orthometric and ellipsoidal heights of the points using sprit leveling and DGPS receiver respectively and hence a set of Geoidal undulations from those heights were calculated. Another set of Geoidal undulations were obtained using EGM2008. These sets of Geoidal undulations were assessed to determine whether EGM2008 which is the latest method of determining Geoidal undulations can yield accurate results when compared with the conventional method of determining Geoidal heights.

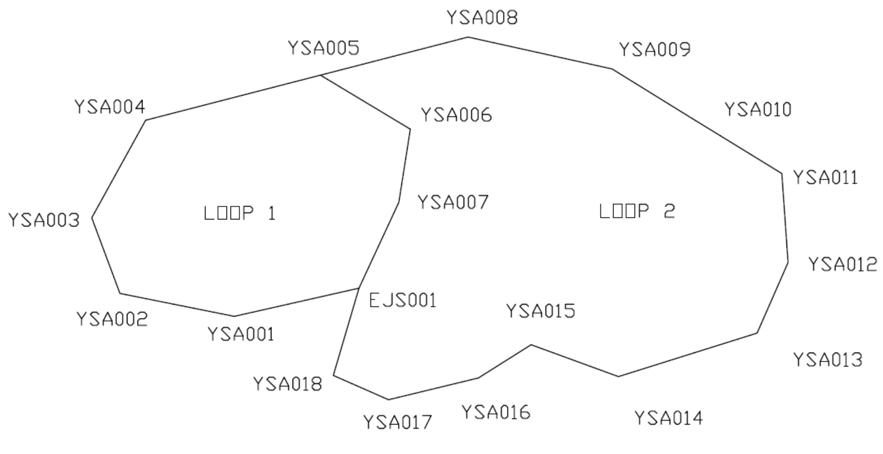

Figure 3: 19 established points on the Ground Surface

The data acquisition and processing is therefore are in four (4) stages; 1. Determination of orthometric height from spirit leveling 2. Determination of ellipsoidal heights from Differential Global Positioning (DGPS) 3. Determination of Geoidal undulations from orthometric and ellipsoidal heights 4. Determination of Geoidal undulations from EGM2008 and finally 5. Assessment of Geoidal undulations determined from GPS/Leveling and EGM2008.

1. Determination of Orthometric Heights:

The orthometric heights were determined using leveling method. Leveling is the operation required in the determination, or more strictly, the comparison of heights of points on the surface of the Earth (Bannister et al, 1992). The leveling height datum used in Nigeria is the Mina datum. There are various methods of determining difference in elevation of points, they include; taping method, differential leveling, barometric leveling, trigonometric leveling, spirit leveling and the modern method such as GPS leveling. However, spirit leveling was employed in this project. To obtain the heights of the established points, an automatic level instrument was for instance set midway between EJS001 and YSA001 and a back sight reading was taken on the leveling staff held vertically on the control point and then fore sight reading to YSA 001, the procedure continued in a clockwise movement with back sight reading to preceding point and fore sight reading to the next point until all the points in the two loops were observed and their heights were computed using rise and fall method of computing heights.

2. Determination of Ellipsoidal Heights from DGPS:

The GPS observations of the established points as shown in figure 3 above was carried out with DGPS equipment, this is to obtain the three dimensional coordinates of the points established. Real Time Kinematics (RTK) method of observation was adopted; the data were saved in the memory unit of the GNSS receiver and later exported to a computer. In this method, the base rover was set at the control station EJS001 while the rover receiver was moved from one established point to another and their ellipsoidal heights as well as horizontal coordinates were read and recorded.

3. Determination of Geoidal Undulations from Orthometric and Ellipsoidal Heights:

Orthometric and Ellipsoidal Heights were obtained and the difference between the two for any point was thus computed as a Geoidal height. The measured ellipsoidal height (h) from the DGPS and the Orthometric heights (H) obtained from the spirit leveling for that point. This was obtained from the relations;

$$N_{GPS/lev} = h - H \quad (1)$$

Where: h is the ellipsoidal height, H is the orthometric height and $N_{GPS/lev.}$ is the Geoidal height determined by GPS/leveling method.

4. Determination of Geoidal Undulations from EGM2008

The Geoidal undulations from EGM is the distance between the ellipsoid and the geoid. This distance is also often called Geoidal separation and Geoidal height. The distance is measured along the ellipsoidal prime vertical. It is positive (+) if the geoid is above the ellipsoid and negative (-) if the geoid is below the ellipsoid. To obtain this distance between the ellipsoid and the geoid for each point, EGM 2008 was used to interpolate Geoidal undulations. EGM is an acronym of official Earth Geopotential Model which has been publicly released by the U.S. National Geospatial Intelligence Agency (NGA) EGM development team. The model represents a very significant improvement in precision over earlier geoid models. It is available in 1, 2.5 and 10 minutes grids. To obtain geoid undulations for the points established, the software Alltrans EGM2008 was downloaded from http://www.altrans.soft112.com/. This software comes with a default 10minutes grid file. But 2.5 minutes grid file was downloaded for the purpose of accuracy and the horizontal coordinates of all the points as obtained from the DGPS. Latitude longitude of the each established point were fed in to the EGM2008 calculator and the software calculated the undulation of each point by interpolation.

5. Assessment of Geoidal Undulations determined from GPS/Levelling and EGM2008

The differences of Geoidal heights from the GPS/Levelling derived Geoidal heights and those from the geoid models at co-located points provide discrete geometric control for assessment purposes. In this section, the Geoidal heights differences between the geoid models against the GPS/Levelling derived Geoidal heights at the 19 points were obtained.

In order to evaluate the adequacy of the EGM08, several statistical indicators were utilized. These include Root mean square error (RMSE) and standard deviation (SD). Their mathematical expressions are given in Equation 4 and 5 respectively. In computing the differences between the geoid models, the assumption made here is that, the Geoidal undulations obtained from the GPS/Levelling are standard to which the Geoidal heights provided by the EGM08 was compared. The Geoidal undulation difference, ΔN between the GPS/Levelling Geoidal undulations, $N_{GPS/Levelling}$ and the computed Geoidal undulations referred to EGM08.

$$\Delta N = N_{GPS/Levelling} - N_{EGM2008} \quad (2)$$

Where ΔN is the Geoidal height difference between Geoidal heights obtained from geometrical techniques (NGPS/Levelling) and EGM approach (NEGM2008).

The mean difference, $\Delta N\ mean$ is the average of the Geoidal height differences, Δ_j for the EGM08 model. The mean is computed as denoted by Equation (3):

$$\Delta N_{mean} = \frac{1}{n}\sum_{j=1}^{n} \Delta N_j \quad (3)$$

The root mean square (RMSE) value of the differences in the model is computed from as denoted by Equation (4) The RMSE gives a sense of the typical size of the value. The standard deviation from the mean of the differences (error) in Geoidal undulations in the model was computed using Equation 5:

$$RMSE = \sqrt{\frac{\sum_{j=1}^{n}(\Delta N_j)^2}{n}} \quad (4)$$

The RMSE gives a sense of the typical size of the value.
The standard deviation from the mean of the differences (error) in Geoidal undulations in the model was computed using equation 5 below:

$$SD = \sqrt{\frac{\sum_{j=1}^{n}(\Delta N_j - \Delta N_{mean})^2}{n-1}} \quad (5)$$

Where *n-1* is the degree of freedom. The standard deviation measures how closely the data are clustered about the mean.

Hypothesis of the Problem: A hypothesis is a statement about the parameters of a distribution. A test of a hypothesis is a rule that, based on the sample values, leads to a decision to accept or reject the null hypothesis. Normally, a test statistic is computed from the sample values (observations) and from the specification of the null hypothesis. If the test statistic falls within a critical region, the null hypothesis is rejected otherwise it is accepted. However, the null hypothesis is that the differences have a normal distribution with mean, φ and variance ζ^2. The sample mean, ΔN_{mean} and sample variance, S^2 were tested to see if they really belong to normal distribution N (φ, ζ2).

Independent Sample t-test: Independent samples *t*-test is used to compare two groups whose means are not dependent on one another (University of Arizona Military Reach, 2009). Two samples are independent if the sample values selected from one population are not related or somehow paired or matched with the sample values selected from the other population. An independent sample t-test tells the researcher whether there is a statistically significant difference in the mean scores for the two groups or not. In statistical terms it means that the researcher is testing the probability that the two sets of data came from the same population. In other words, an independent sample is the sample in which the participants in each group are independent from each other. In this study, Hypothesis;

H_0: $N_{GPS/Lev\ (mean)} = N_{EGM08\ (Mean) =}$ (there is no statistically significant difference between the two sample means)

$H_{1:}$ $N_{GPS/Lev\ (mean)} \neq N_{EGM08\ (Mean)}$ = (there is a statistically significant difference between the two sample means). At 95% Confidence interval.

Independent sample t-test was calculated using Statistical Package for Social Science (SPSS). Alternatively, this can be done using the following formula:

$$t = \frac{(mean1 - mean2)}{\sqrt{\frac{\sum_{i=1}^{n} xi1^2 - \frac{\left(\sum_{i=1}^{n} xij^2\right)^2}{n1} + \sum_{i=1}^{n} xi2^2 - \left(\frac{\left(\sum_{i=1}^{n} xi2^2\right)^2}{n2}\right)}{n1\, n1\, (1 - \frac{2}{n1+n2}}}} \quad (6)$$

From the formula above, n1 is the sample size of the first group and n2 is the sample size of the second group. Mean1 is the sample mean of the first group and Mean2 is the sample mean of the second group
$\sum_{i=1}^{n} xij$ Is the sum of scores of the first group and $\sum_{i=1}^{n} xi2$ is the sum of score of the second group.
$\sum_{i=1}^{n} xij^2$ is the sum of squared scores of the first group and
$\sum_{i=1}^{n} xi2^2$ is the sum of squared scores of the second group.

IV. Results

Having acquired and processed the field data, results were obtained and presented in a tabular forms. The results include; Cartesian and geographical coordinates and ellipsoidal and Orthometric heights from DGPS and spirit leveling observations, Geoidal undulations computed from ellipsoidal and orthometric heights, Geoidal undulations computed by EGM2008 calculator reference to the WGS 84 ellipsoid, summary of computed Geoid heights from GPS/Leveling and Geoid heights from EGM2008. The results are presented thus;

Table 1: Cartesian and Geographical coordinates and ellipsoidal and Orthometric heights from DGPS and Spirit Leveling Observations

Station	E(m)	N(m)	Latitude	Longitude	Ellipsoidal height (h) m	Orthometric height (H) m
EJS 001	225252.3	1034423	9.349100	12.49865	242.5266	226.1346
YSA 001	224989.7	1035067	9.354903	12.49622	227.3118	210.9276
YSA 002	225347.8	1035134	9.355537	12.49948	228.0528	210.6436
YSA 003	225484.0	1034770	9.352250	12.50074	235.5106	218.9226

YSA 004	225766.9	1034879	9.353257	12.5033	235.9608	218.9736
YSA 005	225884.9	1034492	9.349767	12.5044	241.8952	226.5066
YSA 006	225890.3	1034124	9.346441	12.50448	250.0666	232.9706
YSA 007	225891.0	1034042	9.345696	12.50449	250.8018	233.4046
YSA 008	225688.6	1034025	9.345531	12.50265	253.1600	236.7646
YSA 009	225496.8	1034028	9.345551	12.5009	247.4704	231.0766
YSA 010	224940.5	1034104	9.346202	12.49584	236.9090	220.714
YSA 011	224868.9	1034639	9.351028	12.49515	233.6714	217.361
YSA 012	225027.1	1034809	9.352572	12.49658	231.5958	215.453
YSA 013	225139.7	1034970	9.354040	12.49759	229.5186	213.186
YSA 014	225315.5	1035031	9.354597	12.49919	228.5396	212.204
YSA 015	225289.2	1034853	9.352987	12.49896	232.1586	215.755
YSA 016	225222.4	1034718	9.351765	12.49836	234.7656	218.358
YSA 017	225070.6	1034646	9.351109	12.49698	234.653	218.288
YSA 018	224979.6	1034743	9.351979	12.49615	232.0962	215.811

Table 2: Geoidal Undulations computed from Ellipsoidal and Orthometric Heights

Station	Latitude	Longitude	Ellipsoidal height (h) m	Orthometric height (H) m	Geoidal Undulations (h-H)
EJS 001	9.349100	12.49865	242.5266	226.1346	16.392
YSA 001	9.354903	12.49622	227.3118	210.9276	16.3842
YSA 002	9.355537	12.49948	228.0528	210.6436	17.4092
YSA 003	9.352250	12.50074	235.5106	218.9226	16.588
YSA 004	9.353257	12.5033	235.9608	218.9736	16.9872
YSA 005	9.349767	12.5044	241.8952	226.5066	15.3886
YSA 006	9.346441	12.50448	250.0666	232.9706	17.096
YSA 007	9.345696	12.50449	250.8018	233.4046	17.3972
YSA 008	9.345531	12.50265	253.1600	236.7646	16.3954
YSA 009	9.345551	12.5009	247.4704	231.0766	16.3938
YSA 010	9.346202	12.49584	236.9090	220.714	16.195
YSA 011	9.351028	12.49515	233.6714	217.361	16.3104
YSA 012	9.352572	12.49658	231.5958	215.453	16.1428
YSA 013	9.354040	12.49759	229.5186	213.186	16.3326
YSA 014	9.354597	12.49919	228.5396	212.204	16.3356
YSA 015	9.352987	12.49896	232.1586	215.755	16.4036
YSA 016	9.351765	12.49836	234.7656	218.358	16.4076
YSA 017	9.351109	12.49698	234.653	218.288	16.365
YSA 018	9.351979	12.49615	232.0962	215.811	16.2852

Table 3: Geoidal Undulations Computed by EGM 2008 reference to WGS 84 ellipsoid

Station	Latitude	Longitude	Geoidal Undulations
EJS 001	9.349100	12.49865	16.392
YSA 001	9.354903	12.49622	16.384
YSA 002	9.355537	12.49948	16.384
YSA 003	9.352250	12.50074	16.389
YSA 004	9.353257	12.5033	16.388
YSA 005	9.349767	12.5044	16.392
YSA 006	9.346441	12.50448	16.395
YSA 007	9.345696	12.50449	16.396
YSA 008	9.345531	12.50265	16.396
YSA 009	9.345551	12.5009	16.396
YSA 010	9.346202	12.49584	16.394
YSA 011	9.351028	12.49515	16.389
YSA 012	9.352572	12.49658	16.388
YSA 013	9.354040	12.49759	16.387
YSA 014	9.354597	12.49919	16.385
YSA 015	9.352987	12.49896	16.388
YSA 016	9.351765	12.49836	16.389
YSA 017	9.351109	12.49698	16.389
YSA 018	9.351979	12.49615	16.388

Table 4: Summary of Computed Geoidal Heights obtained from GPS/Leveling and Geoidal Heights from EGM2008

Model	Minimum	Maximum	Mean	Standard Deviation
GPS/Leveling	16.3104	17.3972	16.48471	0.465702
EGM 2008	16.384	16.396	16.38995	0.003965

Table 4 above, shows the statistical summary of the EGM2008 Geoid heights of established points. The standard deviation of 0.003965 signifies that the EGM2008 data are closely distributed around the mean, which generally implies that the data don't change frequently. While in the statistical summary of GPS/Leveling Geoid heights of established points, the standard deviation of 0.465702 signifies that the GPS/Leveling data are widely distributed around the mean, which generally implies that the data change frequently when compared to the EGM2008.

V. COMPARISMS OF RESULTS

In order to achieve a direct comparison of EGM2008 Geoidal undulations ($N_{EGM2008}$) with their GPS/leveling equivalent, the EGM2008 derived orthometric height value for EJS 001 was adopted as the datum for computing spirit level orthometric heights of the points. The comparison was done by obtaining the difference between the GPS/leveling geoid height and the EGM2008 geoid height at each station, i.e. $\Delta N = N_{GPS/Leveling} - N_{EGM2008}$ the result obtained is shown in Table 5 below:

Table 5: Difference between GPS/Leveling and EGM 2008 Geoid Heights

Station	GPS/Leveling ($N_{GPS/Lev}$)	EGM2008 ($N_{EGM2008}$)	Difference (ΔN)
EJS 001	16.392	16.392	0
YSA001	16.3842	16.384	0.0002
YSA002	16.4092	16.384	1.0252
YSA003	16.588	16.389	0.199
YSA004	16.9872	16.388	0.5992
YSA005	16.3886	16.392	-1.0034
YSA006	17.096	16.395	0.701
YSA007	16.3972	16.396	1.0012
YSA008	16.3954	16.396	-0.0006
YSA009	16.3938	16.396	-0.0022
YSA010	16.195	16.394	-0.199
YSA011	16.3104	16.389	-0.0786
YSA012	16.1428	16.388	-0.2452
YSA013	16.3326	16.387	-0.0544
YSA014	16.3356	16.385	-0.0494
YSA015	16.4036	16.388	0.0156
YSA016	16.4076	16.389	0.0186
YSA017	16.365	16.389	-0.024
YSA018	16.2852	16.388	-0.1028

Comparison of Geoid Heights from GPS/Levelling and the EGM2008

The Geoidal heights differences between the EGM2008 against the GPS/Levelling derived Geoidal heights at the 19 established points were obtained. The computed Geoidal heights from the GPS/levelling and the corresponding computed and predicted Geoidal heights from the EGM08 are illustrated in Figure 4 below.

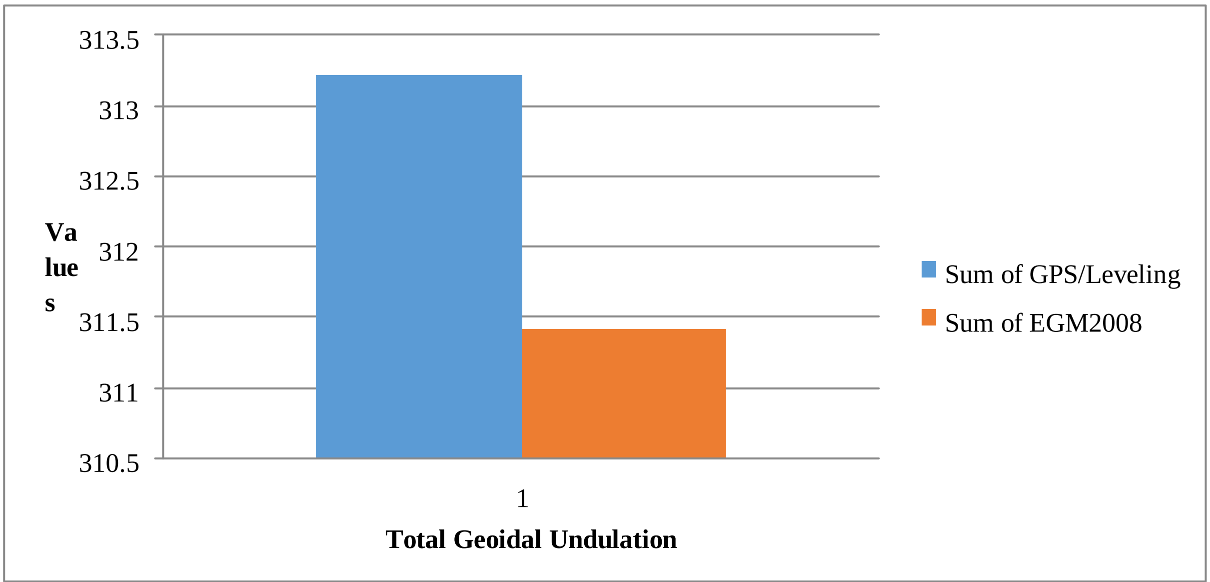

Figure 4: A Graph depicting the Geoid Height of EGM2008 and GPS/Leveling

The summary of the results obtained from the differences between the two Geoidal undulations are shown in Table 6 below. The statistics of the differences are also shown with respect to minimum differences, maximum differences, mean of the differences, Root Mean Square Error (RMSE) of the differences and the standard deviation from the mean of the difference.

Table 6: A Summary of Geoid Heights Differences

Height	Minimum	Maximum	Mean	Standard Deviation	RMSE
ΔN	-1.0034m	1.0252m	0.948m	0.501m	0.4630m

The results obtained in this study show that there are differences between GPS/Levelling derived Geoidal heights and those obtained from the Earth Gravitational Model 2008. With reference to Table 6 above, it was observed that the Geoidal height differences from the GPS/levelling Geoidal heights and those from the EGM2008 model ranges from -1.0034 m to 1.0252 m, the mean differences are 0.948 m, the Root Mean Square Error of the differences is 0.4630 m and the standard deviation differences is 0.501m.

VI. Hypothesis Testing

These tests were performed in order to ascertain if there is a significant difference between the two data sets.
H_0: $N_{GPS/Lev\ (mean)} = N_{EGM08\ (Mean)} =$ (there is no significant difference between the two sample means)
H_1: $N_{GPS/Lev\ (mean)} \neq N_{EGM08\ (Mean)} =$ (there is a significant difference between the two sample means).

Independent Sample Test

Independent sample test was performed in SPSS 16.0 at 95% Confidence Interval. The Independent Sample Test results that defined the hypothesis are thus: *df* = 18.003, *t value*= 0.887 and ***p value*=0.0387**.

The significance level (also called the probability or *p*-value) tells us the likelihood that our results have occurred by chance. If this value is smaller than **.05** then we reject the null hypothesis. If it is larger, then we accept our null hypothesis. Therefore, from the result obtained, it can be concluded that the *t*-test *is* significant as the p-value is less than 0.05 ($p < .05$). This led to the rejection of the null hypothesis (H_0). Hence, there is significant difference between GPS/leveling and EGM2008 geoid heights.

However, according to Pallant (2007), there is more to research when results are significant than just obtaining statistical significance. Effect size explains the degree to which the two variables are associated with one another. Effect size of independent sample t-test is given by Cohen's *d*, Pearson's correlation coefficient *r* and the odds ratio:

$$r = \sqrt{\frac{t^2}{t^2 + n1 + n2 - 2}} \quad (7)$$

Where t =is the calculated value of the independent sample t-test, n =is the sample size.

When: r = 0.1 (Small effect), r= 0.3 (Medium effect), r= 0.5 (Large effect).

Therefore, imputing the t test result in (7). $r = 0.14 \approx 0.1$ hence the effect of the difference between GPS/Leveling and EGM2008 geoid height in the study is a small effect.

Check against Global Standard for Topographic Survey

The American Society of Photogrammetry and Remote Sensing (ASPRS 1993) has given a specification for topographic survey shown in the table below. The Standard Deviation obtained was checked against the specification.

Table 7: 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)

It is seen that EGM2008 with σ=0.501, checked against the specification above, can be used to produce topographical plan of 1m 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. The results from this study have confirmed the investigation of Oluyori *et al* (*2018*) in the evaluation of EGM 2008 in FCT Abuja (a value 0.419), 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. In Thailand, an accuracy of 1.012m was reported by Dumrongchai, *et al*, *(*2012) in the evaluation of EGM 2008.

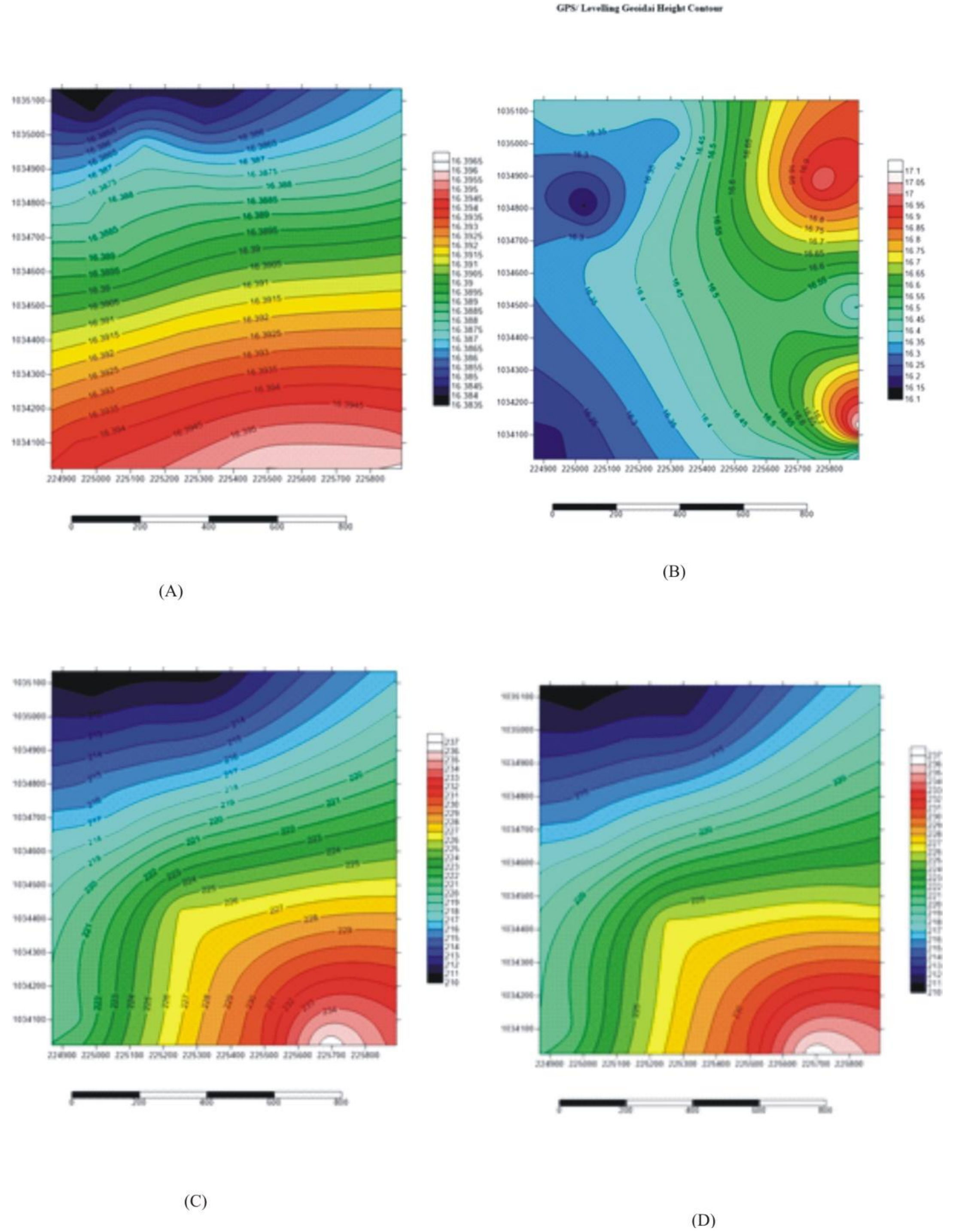

Fig 5(A-D): (A) EGM2008 Geoidal. Map (B) GNSS/Leveling Geoidal Map (C) Spirit Level Orthometric Height (D) EGM2008-based Orthometric height

Figure 5(A) and (B) above, show the Geoidal map of the study area from the EGM2008 model and GPS/Leveling model respectively; this shows that the EGM2008 model yields a more homogenous surface than the GPS/Leveling model.

The contours of the EGM2008-based and GPS/Leveling orthometric heights were plotted with Surfer 10 software. From the plotted contours, it was observed that the orthometric height were identical to some extent. The resemblance is more evident between 225000mN – 2258000mN and 1034400mE – 1034900mE. As seen in Figures C and D.

VII. Findings

1. From the statistical summary of the EGM2008 Geoid heights of interpolated points, the standard deviation of 0.003965m signifies that the EGM2008 data are closely distributed around the mean, which generally implies that the data don't change frequently when compared to GPS/Leveling Geoid heights with standard deviation of 0.4657m.
2. An independent sample test indicated that there is a significant difference between the two means, however an effect size test shows that the effect of the difference is small judging by the Cohen's d Pearson's correlation coefficient r and the odds ratio of 0.1.
3. The results obtained shows that the standard deviation of σ=0.501 computed when checked against the APSR table (1993) shows that at the very best only topographical survey of 1m contour interval can be produced using EGM 2008 geoid model and this may not be accepted for surveying, mapping, engineering and environmental studies that requires high accuracy.
4. This study has also discovered that use of GNSS with local geoid model is preferable to using EGM2008 global Geoid for orthometric height determination. However, EGM2008 is the best alternative option and can be used when the specification of accuracy for a particular survey work is not high.

VIII. Summary

The research assesses Geoidal undulations determined from GPS/Leveling method and EGM2008. The assessment was made by comparing the Geoidal undulations obtained from GPS/Leveling and EGM2008 at co-located points. To achieve the aim of the research, a network of 19 points were established on the ground surface and a conventional spirit leveling operation was carried out on the points to obtain the orthometric heights of those points. GNSS observations were carried out on the same established points as well using DGPS instrument to obtain WGS84 coordinates of the points which include the latitude, longitude and the ellipsoidal heights of the established points. The Geoidal undulations, $N_{GPS/leveling}$ of those points were calculated from the combined GPS and leveling observation from the relation $N_{GPS/leveling}$ = h-H where h is ellipsoidal height and H is orthometric height. In the same vain, the EGM2008 data was downloaded from the internet and the Geoidal undulations of the established points were interpolated by inputting the curvilinear coordinates obtained from the GNSS observations and the Geoidal undulations values $N_{EGM2008}$ were displayed on the computer screen. The assessment was done by comparing the Geoidal undulations obtained from GPS/Leveling ($N_{GPS/Leveling}$) and those obtained from EGM2008 ($N_{EGM2008}$) statistically and subjecting the results obtained against specification for topographical survey given by American Society of Photogrammetry and Remote Sensing (ASPRS 1993).

IX. Conclusion

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 research makes an assessment of geoid heights from the EGM2008 and GPS/Leveling methods. The assessment was done by comparing the two methods and using t-test statistical operation to find out whether there is a significant difference between the two methods. The results obtained shows significant difference between the two and the standard deviation of σ=0.501 computed when checked against the APSR table (1993) shows that at the very best only topographical survey of 1m contour interval can be produced using EGM 2008 Geoid Model and this may not be accepted for surveying, mapping, engineering and environmental studies that requires high accuracy. This study also discovered that, use of GNSS with local geoid model is preferable to using EGM2008 global geoid for orthometric height determination.

X. Recommendations

1. It is recommended that EGM 2008 Geoid heights should be used only for surveys that do not require high accuracy.
2. For uniformity of results, it is recommended that GNSS and geodetic leveling observations be carried out at the same time, so that better height differences can be obtained.
3. Efficient utilization of GNSS in almost all applications require development of an appropriate geoid model for transformation of ellipsoidal height to orthometric height. Since GNSS (GPS) observations were used for determination of Geoid undulation, polynomial models may use the values for the modelling of Geoid for local application.
4. It is recommended that the incorporation of GPS height corrector surface into the Nigerian datum be embraced as possible approach for direct transformation of ellipsoidal height to orthometric height anywhere.

References

[1]. Abeho, D.R.,Hikpin, R. and Tulu B.B. (2014); Evaluation of EGM08 by means of GPS levelling Uganda, *South African Journal of* Geomantic, Vol. 3, No. 3, PP. 272-284.

[2]. Adebayo, A.A. (1999); *Climate: Sunshine. Temperature, Evaporation and Relative Humidity.* Paraclete Publishers. Yola, Nigeria.

[3]. Adebayo, A.A., Zemba, A.A. (2003); Analysis of Micro Climatic Variations in Jimeta-Yola, Nigeria. *Global Jurnal of Social* Science. 2(1): 19-88

[4]. Dumrongchai, P. (2012); "Assessment of Gravity Requirements for Precise Geoid Determination in Thailand", The 33rd Asian Conference on Remote Sensing, Ambassador City Jomtien Hotel, Pattaga, Thailand, 12 PP.

[5]. Featherstone, W. E., and Dentith, M. C., (1997); A Geodetic Approach to Gravity Data Reduction Geophysics. Journal of Computers & Geosciences, Vol.23, No.10, PP. 1063-1070.

[6]. Forsberg, R. and A.H.W. Kearsley, (1989); Precise Gravimetric Geoid Computations Over Large Regions, National Survey and Cadastre, Denmark.

[7]. Ghilani, C.D. and Wolf, P.R. (2008); Elementary Surveying- An Introduction to Geomatics 12th edition. Pearson Prentice Hall, USA.

[8]. Kemboi, K.E. and Odera, P.A. (2016); Estimation of Orthometric Height using EGM2008 and GPS over Nairobi County and its Environs. Journal of Agriculture studies and Technology Vol. 17(2).

[9]. Kilicoglu, A., Direnc, A. Simav M, Lenk O, Aktu, B, Yıldız H (2009). Evaluation of the Earth Gravitational Model 2008 in Turkey. Newton's Buletin No 4.

[10]. Kotsakis, C., Katsambalos, K., Ampatzidis, D. and Gianniou, M. (2009); "Evaluation of EGM2008 Using GPS and Leveling Heights in Greece", www.users.auth.gr/kvek/crete- paper-2008.pdf.Accessed: June 2021.

[11]. National Imagery and Mapping Agency (NIMA) (2008); United States National Geospatial Intelligence Agency (EGM2008, Released in July 2008. [Online] Available: http//earthinfo.nga.mil/GrandG/wgs84/gravitymode/egm2008/index.html (June, 2021).

[12]. Nwilo, P. C., Opaluwa, Y. D., Adejare, Q. A., Ayodele, E. G. and Ayeni, A. M. (2009); Local Geoid Modelling of Lagos Island Area Using the Geometrical Interpolation Method. Nigerian Journal of Surveying and Geo-Informatics. October, 2009, Vol. 2, No, 2, PP. 68-82.

[13]. Okiwelu, A.A., Okwueze, E.E. and Udev, I.o. (2011); Determination of Nigerian Geoidal Undulations from Spherical Harmonic Analysis. Applied Physical Research Journal. May, 2011, Vol. 3, No. 1.

[14]. Oluyori Dare, P. (2008); Computation of Geoid Undulation from Comparison of GPS/Leveling with EGM2008 for Geodetic Applications. International Journal of Scientific Research Publication. Volume 8.

[15]. Palvis, N. K., Holmes, S. A., Kenyon, S. C. and Factor, J. K. (2008), "An Earth Gravitational Mode to Degree 2160", EGU General Assembly 2008, Vienna, Australia, PP. 13-18.

[16]. Reguzzoni M., Sampietro D., and F. Sanso, (2011); "Updating EGM08 Mediterranean Geoid Using Local GOCE Data from the Space-Wise Solution". Proc. Of 14th International GOCE User Workshop, Munich, Germany.

[17]. Uzodinma, V. N., Oguntuase J. O., Onah E., Chike C. and Ehigiator, R. (2014); Validation of EGM2008-Based Orthometric Heights in a Micro Environment in Nigeria. FIG Congress 2014, Engaging the Challenges – Enhancing the Relevance Kuala Lumpur, Malaysia 16-21 June, 2014.

[18]. Zemba A.A; Adebayo A.A; and Musa A.A. (2010): Evaluation of the Impact of Urban Expansion on Surface Temperature Variations using Remote Sensing-GIS Approach.

Samuel Yohanna, et. al. "An Assessment of Geoidal Undulations Determined From GPS/LEVELLING Method and EGM2008." *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, 16(05), (2022): pp 01-12.