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Accuracy Assessment of Satellite Derived Bouguer Gravity in Comparison with Terrestrial bouguer Gravity of Gongola Basin, Nigeria.

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Abstract

Since the advent of the geophysics field, terrestrial gravity observation has been one of the traditional methods of gravity acquisition. One of its shortcomings is a sparse network of data for a broad survey, which restricts how much they may be used. Satellite gravity on the other hand provides dense data for regional surveys. The availability of plenty of satellite gravity models causes the dilemma of choosing an accurate model for research. One of the techniques for isolating good satellite gravity models is to determine their accuracy in particular areas. Therefore, this research assesses the accuracies of 21 satellite gravity models in the Gongola basin by utilizing Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE) as performance indicators in their evaluation of the accuracies. Results obtained showed XGM2019e 2159 model produced the best value for this region's performance metrics as a result of the statistical analysis for the Gongola Basin. Because XGM2019e 2159 has the lowest MAE (4.710), MAPE (14.26%), and highest correlation (0.787) with the terrestrial bouguer anomalies, it is assessed to be the most appropriate for use in this study. The next best contestants were, XGM2016, GECO, EGM-2008, EIGEN-6C4 and GGM05C in decreasing order of accuracy.

Keywords: Correlation, Gongola, Gravity, Satellite, XGM2019e_2159.

INTRODUCTION

Terrestrial gravity observation has been the traditional and only method of gravity acquisition during the advent of the field of geophysics. For a large survey, they produced sparse network of points which limits the extent to which they are employed. This is due to the expense and time spent in the acquisition of the data (Apeh *et al.,* 2018). Some of the applications of these gravity methods includes basin wide evaluation that covers thousands of square kilometres which is extremely cost to acquire and mostly not freely accessible to research (Doğru, 2021). Auspiciously, advancement in spaceborne technology has come to the rescue, it is now possible to observe gravity values from space. Remarkably, technological advancement and improvement have persisted, making life easier for people in general and geoscientists in particular (Šprlák *et al.,* 2011). As a result, our understanding of earth dynamics has improved. It is obvious that several Global Gravity Field Models (GGMs) are being created by various scientific research teams, with more and more applications in the geosciences (Pouliquen *et al.,* 2017).

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Spherical harmonics are typically used as the foundation for global gravity models (GGMs), which reflect the *gravity* field globally (Hirt *et al.*, 2013; Šprlák *et al.*, 2011). Any functional of the gravitational potential may be evaluated from a GGM of this kind. The International Centre for Global Earth Models (http://icgem.gfzpotsdam.de/ICGEM) has provided the scientific community with access to a number of GGMs (Sinem *et al.*, 2019; Šprlák *et al.*, 2011). The CHAMP, GRACE, and GOCE satellite gravity missions have made a significant contribution to the modelling of the entire earth's gravitational field. The European Space Agency's main satellite missions anticipated to deliver a geoid model with good accuracy and spatial resolution, focusing on the static component of the global gravity field (Apeh *et al.*, 2018). Accuracy and Spatial resolution of satellite gravity models can be improved with the use of terrestrial data and thus the most representative satellite gravity model which has the best performance may be determined for a region. Models acquired from such methods usually have the lowest error. The availability of plenty of satellite gravity models causes the dilemma of choosing an accurate model for research (Putri *et al.*, 2019). One of the techniques for isolating good satellite gravity models is to determine their accuracy in particular areas.

The gravity field models are generated with varying degrees of precision using a variety of resources, resulting in a variety of models appropriate for various purposes. In order to verify their correctness, (Barthelmes, 2013) underlined the necessity of evaluating gravity field functional using terrestrial data. Similar studies using terrestrial data to assess the accuracy of the gravity functional acquired from satellites have been conducted in several parts of the world (Apeh *et al.*, 2018; Balmino *et al.*, 2012; Huang & Véronneau, 2009; Odera, 2016; Saari & Biljer-Koivula, 2017; Šprlák *et al.*, 2011; Yılmaz *et al.*, 2010). The accuracy of the gravity models is evaluated in all the referenced studies using different performance indicators such as standard deviation and root mean square error among others. Therefore, in the absence of any research to assess the accuracies of gravity models in Gongola basin, we utilized Mean Absolute Error and Mean absolute Percentage Error to evaluate the accuracy of the 21 satellite models.

In this research, EGM 2008, EIGEN-6C4, GECO, XGM2019e-2159, EIGEN-CG03c, XGM2016, GIF48, GGM05S, GGM05G, GGM05C, GFZ97, GEMT3s, GEM10a, GAO2012, EIGEN-GRGS.RL04, EIGEN-GRACE02S, EIGEN, GL04S1, EIGEN-CHAMP05S, AIUB-GRACE03S, DEOS_CHAMP-01C and DGM-1S were compared with terrestrial gravity anomalies. Boths structural and statistical methods were applied.

Location of the Study Area

This study focuses on the Gongola arm of the Upper Benue Trough in northeastern Nigeria, which falls between longitude 10° 00′E to 12° 30′E and latitude 9° 30′N to 11° 30′ N. The geology of the study area comprises Precambrian Basement rocks, Cretaceous to recent sedimentary sequences and tertiary volcanics (Olakunle & Abdulmumin, 2019). The Basement rocks that underlain the study area especially those that occur as exposures are of the Older Granite category which comprises granites, granodiorites and mylonites. The sedimentary sequences have Bima Formation as the oldest formation, which is immediately overlain by the Yolde, Pindiga, Gombe and Kerri-Kerri Formations. The dominant basaltic rocks form the Biu Plateau in the northeastern while the Longuda Plateau is situated in the southeastern part of the study area (Figure 1). Detailed record of the geology, stratigraphy and tectonic evolution of the Gongola arm of the Upper Benue trough in northeastern Nigeria has been documented by (Abubakar *et al.*, 2010; Salako & Udensi, 2015; Shemang *et al.*, 2005) among other authors.

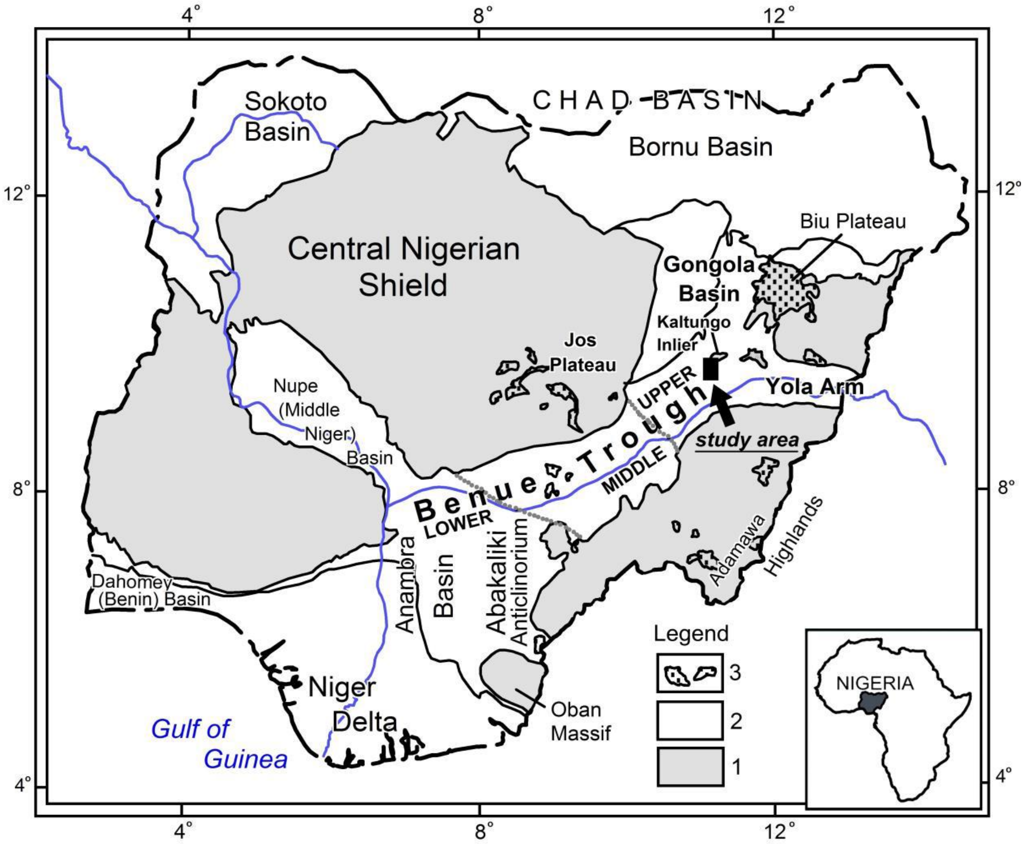

Figure 1. Location map of the study area on the background of general geological division of Nigeria: 1 – Precambrian basement, crystalline rocks, 2 – sedimentary basins (Cretaceous to Quaternary), 3 – Cenozoic volcanics (Musa, Kurowska, Schoeneich, Alagbe & Ayok, 2016).

Correlation

In its widest definition, correlation is a measurement of the link between variables. In correlated data, a change in one variable's magnitude is connected to a change in another variable's magnitude, either in the same direction (positive correlation) or in the opposite (negative correlation). The Pearson product-moment correlation is the most common way to define a linear connection between two continuous variables when the term "correlation" is used. (Schober & Schwarte, 2018).

$$r = \frac{n\sum x\,y - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2]\,[n\sum y^2 - (\sum y)^2]}} \qquad (1)$$

Where r is the Perasons correlation coeffieient, x and y are the values of variables which in our case are the terrestrial ang satellite gravity values.

MAE (Mean Absolute Error) and MAPE (Mean Absolute Percentage Error).

The mean absolute error (MAE), or average absolute error, is the difference between actual and projected values. A row-level error computation called MAE, sometimes referred to as L1 loss, calculates the non-negative difference between the prediction and the reality. In order to analyze the model performance throughout the entire dataset, we may use MAE, which is the average of these errors. Being that the error value is simple to understand, MAE is a well-liked measurement. Because the value and the target you are forecasting for are on the same scale, this is the case. Calculating MAE uses the following formula (Despotovic *et al.*, 2016):

$$MAE = \frac{1}{N}\sum_{i=1}^{N} |(H_{mi} - H_{ei})| \qquad (2)$$

Where H_e and H_m are the terrestrial bouguer gravity and satellite bouguer gravity respectively.

MAPE, or mean absolute percentage error, is the name given to the MAE when represented as a percentage (MAPE). This indicator represents the average absolute difference between the terrestrial bouguer gravity and satellite bouguer gravity (Despotovic *et al.*, 2016).

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{(H_{mi} - H_{ei})}{H_{mi}}\right| \qquad (3)$$

Terrestrial Gravity Data Acquisition

Gravimétrique International (BGI) (http://bgi.omp.obsmip.fr) provided the data for Terrestrial Gravity. It is made up of 235 data points that were scattered over the whole study region. British Antarctic Survey, Geological Survey of Nigeria, University of Ibadan Nigeria (Department of Geology), and Geophysical Survey of The Southwestern Part of The Chad Basin are all acknowledged for providing the data.

Satellite Gravity Models Data Acquisition

The International Centre for Global Earth Models (ICGEM) was the source of the satellite gravity data (Sinem *et al.*, 2019). It is one of the five services overseen by the International Gravity Field Service (IGFS) of the International Association of Geodesy (IAG), housed at the GFZ German Research Centre for Geosciences (GFZ). The most recent global gravity field models, as well as those from the 1960s to the 1990s, are available from ICGEM. These models were created using data from satellite gravity missions like CHAMP, GRACE, and GOCE, as well as advanced processing techniques and additional data sources like satellite altimetry and terrestrial gravity. EGM 2008, EIGEN-6C4, GECO, XGM2019e-2159, EIGEN-CG03c, XGM2016, GIF48, GGM05S, GGM05G, GGM05C, GFZ97, GEMT3s, GEM10a, GAO2012, EIGEN- GRGS.RL04, EIGEN-GRACE02S, EIGEN, GL04S1, EIGEN-CHAMP05S, AIUB-GRACE03S, DEOS_CHAMP-01C and DGM-1S.

Procedure

The initial stage involves importing the satellite gravity models into excel followed by comparison of each satellite model with terrestrial gravity based on the, MAE, MAPE and Pearsons correlation coefficient. The 21 models were plotted individually against terrestrial bouguer gravity to visually infer their structural similarities.

RESULTS AND DISCUSSION

The 21 gravity models indicate range of values for the model accuracy indicators MAE, MAPE and R_values as shown in Table 1. Values of the correlation coefficients show the structure whether in phase or out of phase between the terrestrial data signals and the satellite Bouguer anomalies at test points. The structure of the signal between the terrestrial and the best six satellite Bouguer anomalies are illustrated in Figure 1. Among the 21 satellite gravity models, EGM-2008, EIGEN-6C4, GECO, XGM2019e-2159, XGM2016 and GGM05C has the highest R-value (correlation coefficient) above 0.628 indicating strongest relationship between these satellite models with terrestrial gravity. This is similar to the work of (Apeh *et al.*, 2018). They also have good structural relationship with the terrestrial gravity data as presented in Figure 1a to Figure 1e. XGM2019e-2159 stand exceptionally unique with a peak R_value of 0.787 making it the best model based on structural comparison (Figure 1d), this reinforced the findings of (Dogru *et al.*, 2021). The values MAE in Table 1 shows the level of accuracy of different satellite Bouguer anomalies in comparison with the terrestrial Bouguer anomalies. With an MAE value of lessthan 5.847 mGal, EGM-2008, EIGEN-6C4, GECO, XGM2019e-2159, XGM2016 and GGM05C are still the best models so far with respect to Gongola basin. The MAPE represent the percentage error in the data, a value of MAPE below 14.93% was exhibited by the six (6) best model signifying a deviation of the said percentage by the residual to the terrestrial data.

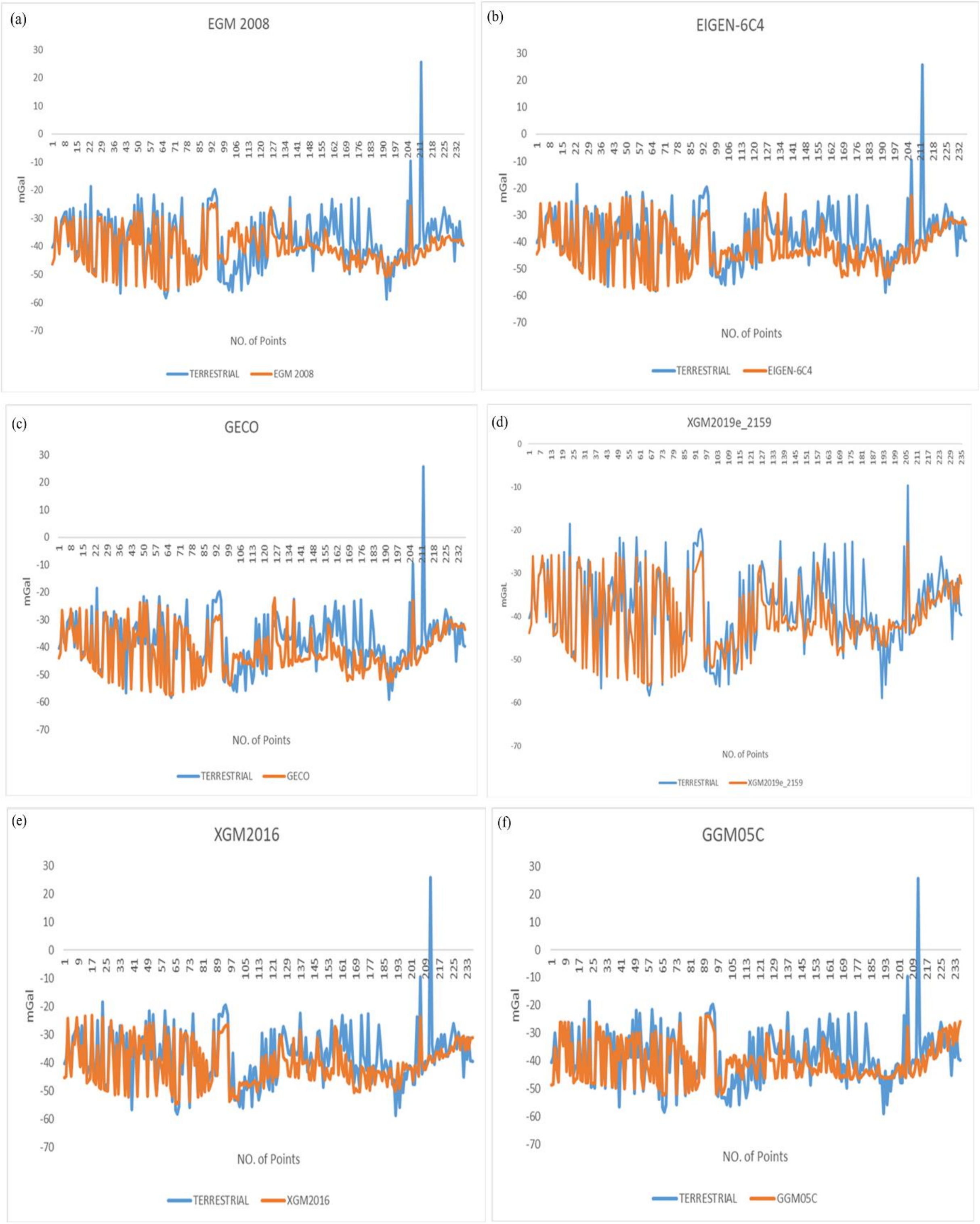

Figure 1. Terrestrial Bouguer Anomalies vs 6 Satellite Derived Bouguer Anomalies

Intermediate value of 0.627 to 0.442 on the R_values column of Table 1 coincides with EIGEN-CG03c, GIF48, GGM05G, GFZ97, GAO2012, EIGEN- GRGS.RL04 and DGM-1S that is seven

(7) models. The structure of the signal between the terrestrial and the moderate eight satellite Bouguer anomalies are illustrated in Figure (2a) through (2h). These satellite models have moderate relationship with the terrestrial gravity making them less desirable for geophysical investigation than the previous best six models in Figure 1a through 1e. MAE value of less than 7.503 mGal demarcate the moderate satellite models as the lower threshold. The MAPE threshold perfectly isolates the intermediate Models with a percentage threshold capped at 23.62% corresponding to DGM-1S. This showed that both MAE and MAPE performed superb in the accuracy assessment.

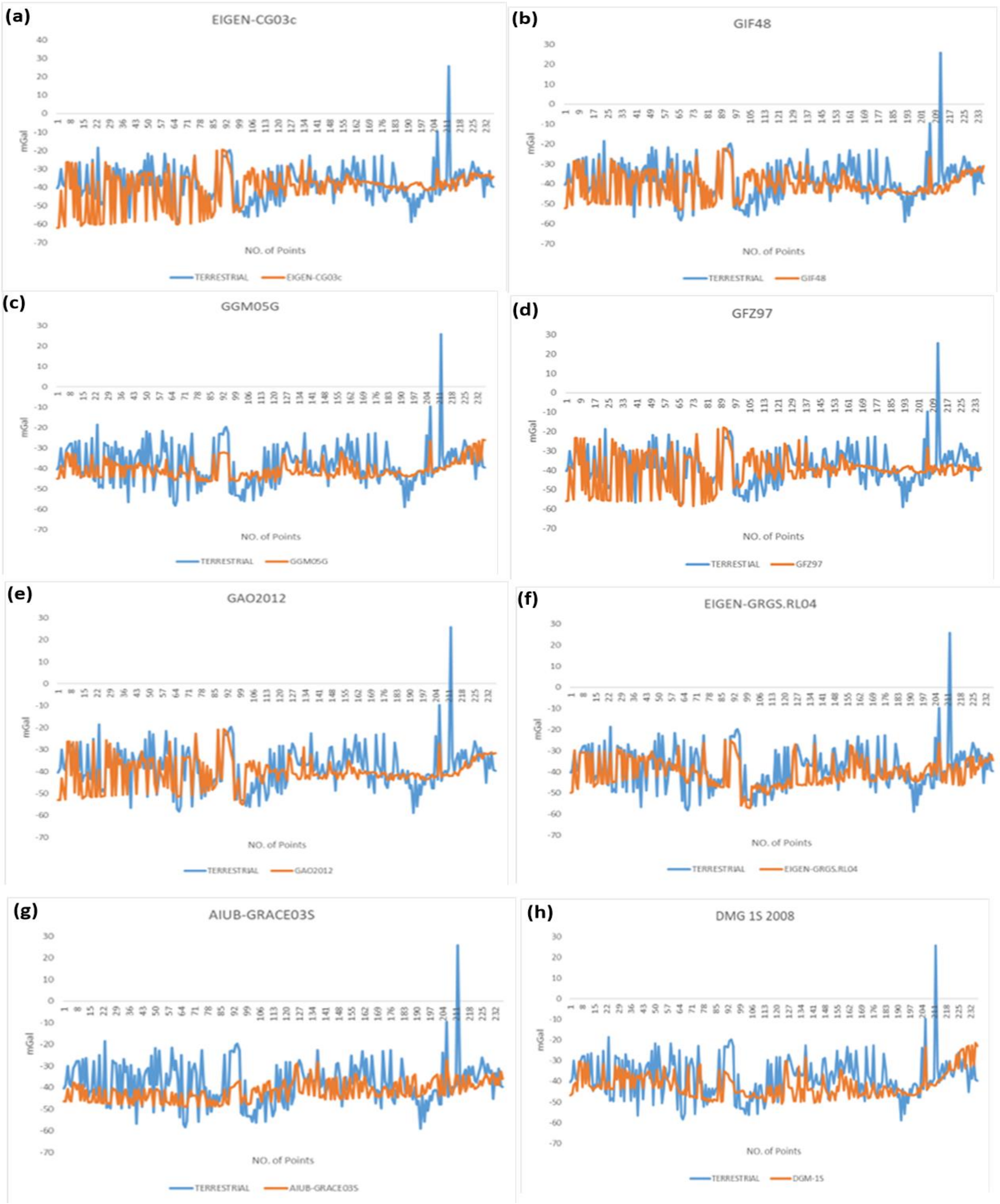

Figure 2. Terrestrial Bouguer Anomalies vs 8 Satellite Derived Bouguer Anomalies

The remaining eight (8) satellite models AIUB-GRACE03S, GGM05S, GEMT3s, GEM10a, EIGEN-GRACE02S, EIGEN-GL04S1, EIGEN-CHAMP05S and DEOS_CHAMP-01C have R_values ranging below 4.4 to negative 0.289 indicating poor and in extreme case inverse relationships respectively. The structure of the signal between the terrestrial and the worst seven satellite Bouguer anomalies are illustrated in Figure 3a to Figure 3g. These models also have MAE and MAPE values above 7.505 mGal and 23.63% respectively. With regards to this research, they should be avoided for geophysical observations. Of all the 21 models XGM2019e_2159 has the least general indicator MAE (4.710), MAPE (14.26%) and highest correlation (0.787) with the terrestrial bouguer anomalies which is supported by (Dogru *et al.*, 2021), for this reason, it is deemed most suitable for the application of this research.

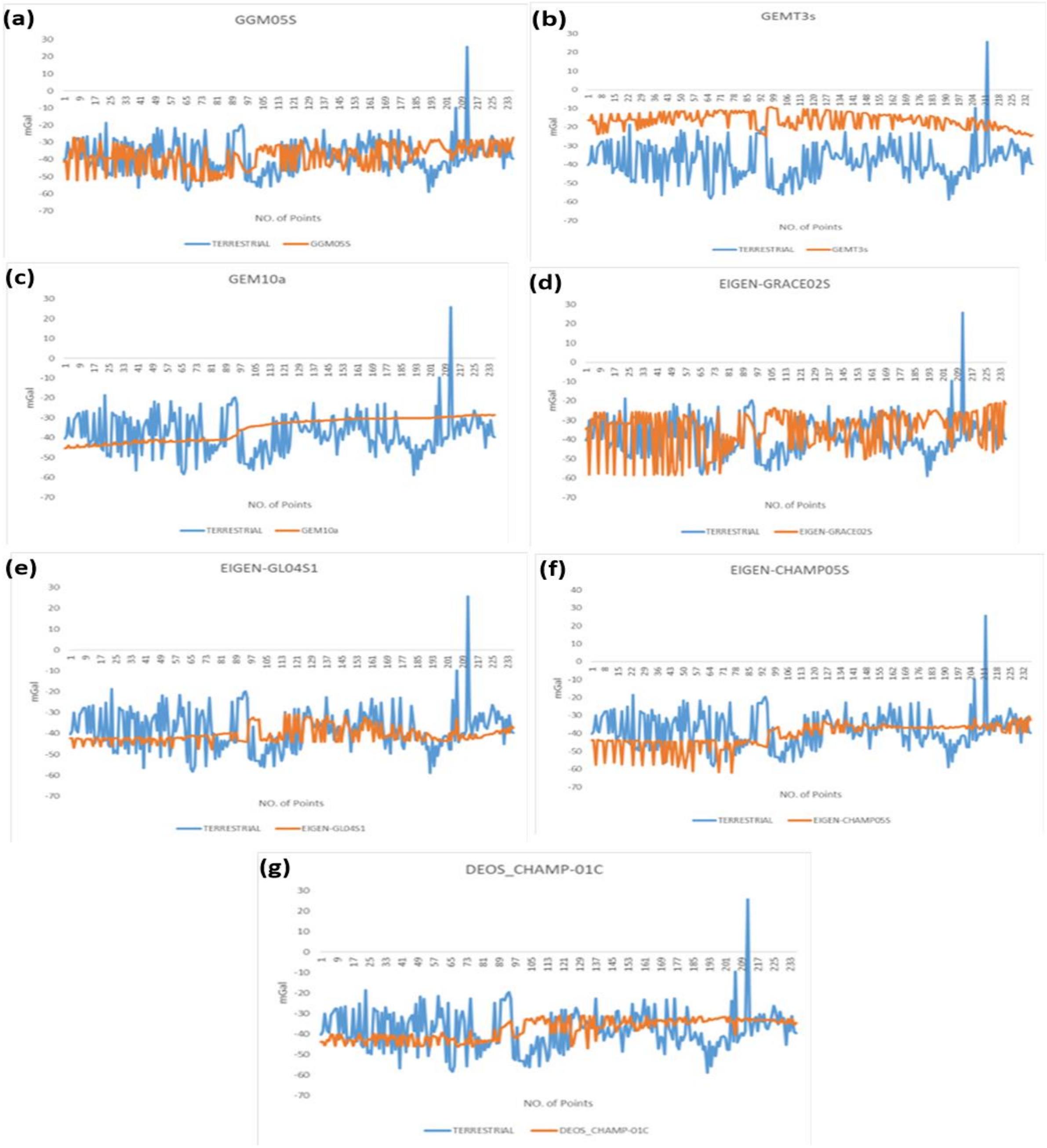

Figure 3. Terrestrial Bouguer Anomalies vs 7 Satellite Derived Bouguer Anomalies

Table 1: Statistical Result of the Satellite Derived Bouguer Anomalies

Satellite Gravity Model	E	PE(%)	elation Coefficient
EGM 2008	7	7	9
EIGEN-6C4	7	2	6
GECO	0	8	4
XGM2019e-2159	0	6	7
EIGEN-CG03c	1	9	3
XGM2016	6	5	9
GIF48	7	6	9
GGM05S	77	9	40
GGM05G	3	2	3
GGM05C	8	2	3
GFZ97	7	9	5
GEMT3s	62	2	15
GEM10a	8	6	1
GAO2012	9	9	8
EIGEN- GRGS.RL04	7	3	7
EIGEN-GRACE02S	79	9	39
EIGEN-GL04S1	7	5	6
EIGEN-CHAMP05S	6	0	77
AIUB-GRACE03S	8	8	4
DEOS_CHAMP-01C	5	9	39
DGM-1S	4	2	2

CONCLUSION

Using terrestrially observed Bouguer anomalies at 235 test sites in the Gongola Basin, Nigeria, the research has assessed and validated the precision of 21 satellite gravity models. The XGM2019e 2159 model produced the best value for this region's performance metrics as a result of the statistical analysis for the Gongola Basin. Because XGM2019e 2159 had the lowest MAE (4.710), MAPE (14.26%), and highest correlation (0.787) with the terrestrial bouguer anomalies, it was assessed to be the most appropriate for use in this study. The next best contestants were, XGM2016, GECO, EGM-2008, EIGEN-6C4 and GGM05C in decreasing order of accuracy.

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