Advanced Journal of Science, Technology and Engineering
ISSN: 2997-5972
Volume 4, Issue 3, 2024 (pp. 14-31)
www.abjournals.org

APPLICATION OF MOBILE APP FOR ON-SITE GEOID AND ORTHOMETRIC HEIGHT DETERMINATION

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Cite this article:

M. G. Daniel, K. F. Aleem, I. F. Funtua, Y. S. Haruna, I. U. Effiom (2024), Application of Mobile App for On-Site Geoid and Orthometric Height Determination. Advanced Journal of Science, Technology and Engineering 4(3), 14-31. DOI: 10.52589/AJSTE-O01VCCWX

Manuscript History

Received: 26 Jun 2024

Accepted: 30 Aug 2024

Published: 9 Sep 2024

ABSTRACT: *Determining the vertical component is an essential step. However, due to the exact elevations in relation to a reference surface (e.g., mean sea level), obtaining it is expensive and technically difficult. Through the integration of mobile app technology for surveying and geodetic applications, this research investigated a novel way to on-site geoid calculation. The study, which was carried out in Port Harcourt, Lagos, and Bauchi, effectively created a mobile application utilizing the EGM2008 model and showed that it was more accurate than previous models at capturing geoid and orthometric heights. Despite some non-linear variances brought on by topographical characteristics, the app demonstrated a good correlation between app-generated and observed orthometric heights. In particular, the EGM08 model app routinely beat the SATLEVEL (MAE = 0.011983 in Port Harcourt and 0.060568 in Lagos) and 7-parameters models (MAE = 0.584951 in Port Harcourt and 2.140581 in Lagos). The study concluded that this integrated approach could revolutionize geodetic fieldwork by giving surveyors precise and dependable tools. It also suggests practical implementation, collaboration, and ongoing testing.*

KEYWORDS: Geoid, ellipsoidal height, orthometric height, EGM08, mobile app.

INTRODUCTION

Determining the vertical component is critical in the early phases of application for engineering. However, obtaining it is difficult both economically and technologically due to the exact heights in relation to a standard surface, like the mean sea level (Orejuela, Iván, César, Xavier & Toulkeridis, 2021). Global Navigation Satellite Systems (GNSS) have significantly improved global, regional, and local 3-dimensional location. One of the most frequently used GNSS in Earth sciences is the Global Positioning System (GPS). With the advent of GPS technology, which employs the 1984-adopted World Geodetic System (WGS84) as its reference system, the computation of relative and absolute heights on Earth's surface has experienced a revolution (Kemboi & Odera, 2016). Applying the WGS-84 ellipsoidal heights obtained from GNSS and the orthometric elevations from geodetic levelling, one may determine the geoidal undulation or the separation between the geoid and the ellipsoid in the survey region (Aleem, 2013). The most widely used GNSS, commonly referred to as the Global Positioning System (GPS), uses the vertical coordinate known as ellipsoid height (h), which is computed on the normal to the ellipsoid and has a three-dimensional relative positioning accuracy of 0.1 ppm (Luna, Staller, Toulkeridis & Parra, 2017).

The ellipsoidal height is determined using a non-physical reference surface because of its insufficient use in practice. Research studies in the geosciences need actual elevations like orthometric (H), which refers to the geoid and is the basic reference for this kind of elevation. It is difficult to detect this surface, though, and it can be found by tracking the mean sea level during an 18.6-year period. If the geoid is less than the given period, it is assumed to be relatively close to the mean sea level (Odera & Fukuda, 2015). Orthometric height (Hn), or height above mean sea level, is a vertical coordinate that is mostly measured utilizing differential leveling techniques along with the inclusion of orthometric adjustment. These two heights at the same position can be used to calculate the geoidal undulation, or the separation between the geoid and ellipsoid, as shown in Fig. 1 through Equation (1) (Eshagh & Zoghi, 2016):

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

where:

H = Orthometric height

h = Ellipsoidal height

N = The Geoid-Ellipsoid separation/Geoidal undulation

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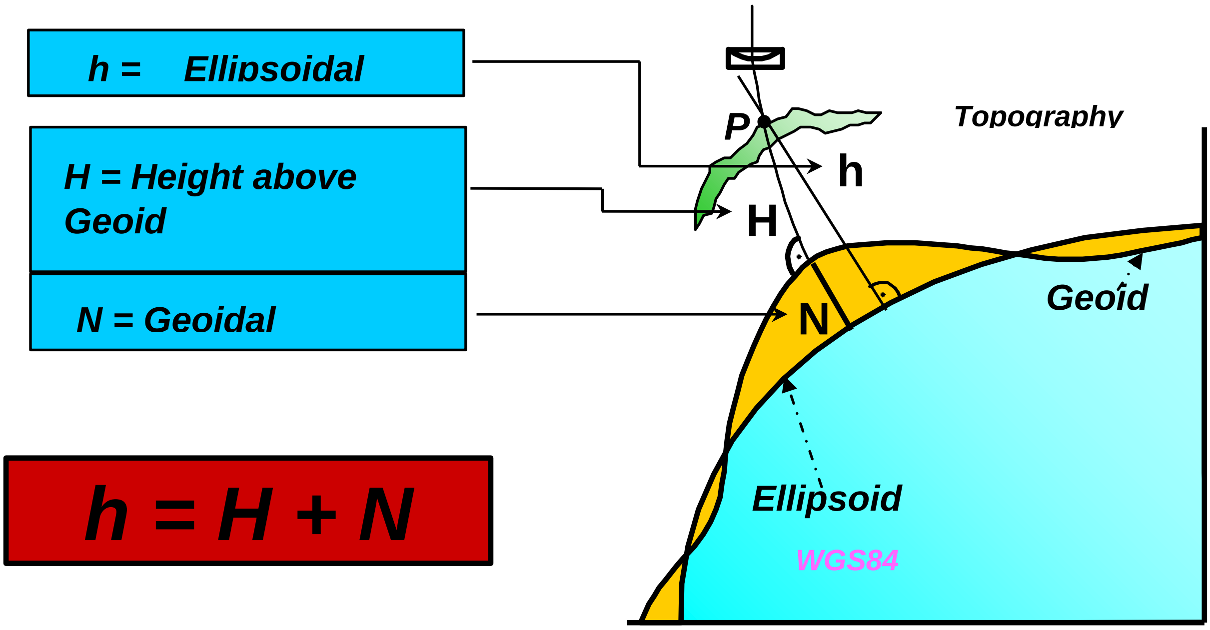

Figure 1: Showing Ellipsoidal, Orthometric and Geoidal Undulation

(**Source:** *Eshagh & Zoghi, 2016*)

A multitude of mobile navigation applications have been introduced as a result of the advancement of information technology and the widespread adoption of mobile devices. One of the apps is called NavToPref, and it may direct and suggest users to the closest stores carrying the products they most want (Indunil et al., 2017). Context-aware solutions are provided via phone-based applications, which identify locations using the Global Positioning System (GPS) (Xiao & Liu, 2022). Data sources, computation strategies, and result dissemination approaches are the key elements of a typical navigation application (Saravjeet et al., 2023). The handset, or user, and the web server, or host, are the two main parts that make up their system (Hernández-Lamas, Cabau-Anchuelo, de Castro-Cuartero & Bernabéu-Larena, 2021).

The height obtained through the GNSS method is the ellipsoidal height and to have an efficient application in surveying, it has to be converted into orthometric height. To achieve this conversion, the determination of the geoidal undulation is very important. The conventional way of determining orthometric height is difficult, labour intensive, and costly. Also, the usual way of determining geoidal undulation, such as using the EGM2008 model, can be tasking at times. Several authors have assessed the performance of EGM2008 across the globe (Featherstone & Olliver, 2013; Odera & Fukuda, 2013; Abeho, Hipkin & Tulu, 2013; Kemboi & Odera, 2016). Also, efforts have been put in place by various researchers to determine geoidal heights and orthometric elevations using various models (Arana, Camargo & Guimarães, 2017; Orejuela*et al.*, 2021; Oduyebo, Ono & Eteje, 2019; Kyamulesire, Eteje & Oluyori, 2020; Abdulrahman, 2021). Despite these efforts, replacing levelling heights with orthometric heights generated from ellipsoid and geoid undulations remains a bone of contention in the field of surveying and engineering, especially in jobs where accuracy is well

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emphasized. Hence, levelling heights have to be further processed with the application of orthometric correction.

Furthermore, many surveyors in Nigeria continue to use analog surveying computing methodologies, even in the face of the global nature of the digital transformation in the surveying industry (Ugwuanyi & Anejionu, 2022). This problem is related to the fact that the majority of software packages now in use, which are created or owned by foreign businesses, are either overly costly, do not always satisfy the fundamental needs of surveyors in the nation, or require additional user training before being used. Therefore, in developing nations, it is imperative to provide an automated method that is both inexpensive and simple to use in order to expedite the collection of information from field data. This study explored the application of mobile software for onsite geoid and orthometric heights determination.

LITERATURE/THEORETICAL UNDERPINNING

Moreu (2024) created land user-generated maps, which are a socio-technical strategy to popularize land use mapping by means of instant messaging. The research also produced an online and offline mapping application that uses GPS and imagery from satellites, which brings mapping to the places where people who use land connect in the real world (in-field, at social events, and at homes), digital (mobile instant messaging), and societal (locally relevant pictorial interfaces and subtitles). Results from the Ethiopian case study indicate that, compared to user-generated and machine-generated maps (such as Google & WRI's Dynamic World map), user-generated maps of land can be more comprehensive (both spatially and conceptually), locally pertinent, and applicable.

Google Earth was shown to be a dependable source of network topologies and data in a timely manner by Yuvaraj (2017). The author used Google Earth's place mark and added path commands to locate different network nodes. In 2006–2016, Liang et al. (2018) carried out a thorough investigation into the uses and effects of Google Earth, which served as a prototype for the first iteration of Digital Earth. By evaluating the many aspects, the study sought to create a structured comprehension of the effect and contribution that is related to Google Earth. Ngom Vougat et al. (2019) studied the Maroua (Far North Region-Cameroon) scenario using Google Earth and Geographic Information System data as a tool to determine sample zones for metropolitan household polls.

Ilie, Balotă, Iordan, and Nicoară (2022) conducted a study in Romania, “Using Official Equations and Quasigeoid Model." In order to achieve an accurate transformation of the LiDAR point clouds in the national coordinate systems, the study created a Python program that made use of the precise transformation of NCC. Then, using the standard version 1.2, the technique was put into practice in a creative piece of software to convert the LiDAR LAS files. The program was designed to process large amounts of LiDAR data in batches without causing any interruptions. Furthermore, the application had the ability to precisely and accurately apply the most recent national quasigeoid to the LiDAR point files. Ultimately, the exact and accurate transformation of the Romanian coordinate systems made the produced LiDAR point cloud more suited for use in any sector.

Ugwuanyi and Anejionu (2022) developed a geomatics program called "Survey Companion," built on Python; it was created as part of the project to help expedite the conversion of survey

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field data into useful spatial information. In order to accomplish this, area computation, resection, intersection, and bathymetric operations—as well as data processing from critical geomatics activities like traverse and leveling networks—were all done using Python routines. This application is predicted to expedite data processing, which would lower total project costs, and significantly enhance survey operations in underdeveloped nations. A comparative evaluation of various interpolation techniques for GNSS/leveling geoid surface prediction utilizing scattered control data was conducted by Erol, S. and Erol, B. (2021). In terms of local geoid modelling in the western part of Turkey, the study offered a thorough evaluation of four surface interpolation techniques with varying mathematical backgrounds. GNSS/leveling data with excellent accuracy from the dispersed control benchmarks on topography were used in the testing. Less-squares adjustment (LSA)-based multivariate polynomial regression (MPR) analysis, stochastic least-squares collocation (LSC), finite elements based bivariate (BIVAR) interpolation, and learning-based wideband neural network (WNN) techniques were the algorithms that were examined. BIVAR was the algorithm among them that was used in the study for the first time for local geoid modeling. In addition to being more accurate than the other three approaches, the algorithm based on finite elements was also much more successful in maintaining the continuity of the surface model. A gravimetric geoid model for the region was contrasted with the local geoid models that were computed using interpolation techniques. Overall, the BIVAR interpolation algorithm outperformed the other geoid models that were put to the test. Therefore, it was strongly advised to use it for local geoid modeling. 2.65 cm was the precision of the local geoid model computed using the BIVAR method.

Marotta and Vidotti (2017) conducted research for their project, "Development of a Local Geoid Model." The Remove-Compute-Restore Method, which follows Helmert's Condensation Method, was used to determine the geoid at The Federal District, Brazil, patch by patch. The geoid heights were accurately determined by using the Remove-Compute-Restore (RCR) approach. This method considers wavelength components of short, medium, and long wavelengths, which are produced from elevation data acquired from global geopotential models, ground gravity data, and digital terrain models (DTM), respectively. This method was seen to be utilized following the adoption of the processes for computing gravity anomalies and the geoid model, taking into account the integration of the various wavelengths specified and their suitability with the chosen vertical datum. The RCR technique, which involves Helmert's condensation method, was reported in the study along with its utilization in computing a single local geoid model for the Federal District of Brazil. Consequently, the local geoid model that was calculated for the area under study agreed with the geoid height values that could be obtained by the geometrical leveling approach with GNSS positioning input.

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METHODOLOGY

Study Area

Three areas were used for this research, namely, Port Harcourt, Lagos, and Bauchi State.

Along the Bonny River, Port Harcourt is located between latitudes 4°45'N and 5°02'N and longitudes 6°52'E and 7°09'E. In Nigeria's oil-rich Niger Delta, it serves as the headquarters of the Rivers State Government. Corporate offices of numerous businesses, associations, and governmental bodies are situated and run in Port Harcourt. For projects requiring height data, many of these organizations have employed surveyors. In order to complete the task, the surveyors just create a local datum if they are unable to connect with a benchmark. As a result of this approach, there are now numerous, incompatible height values in the region. As a result, a straightforward technique for determining the accurate values for the benchmarks is required.

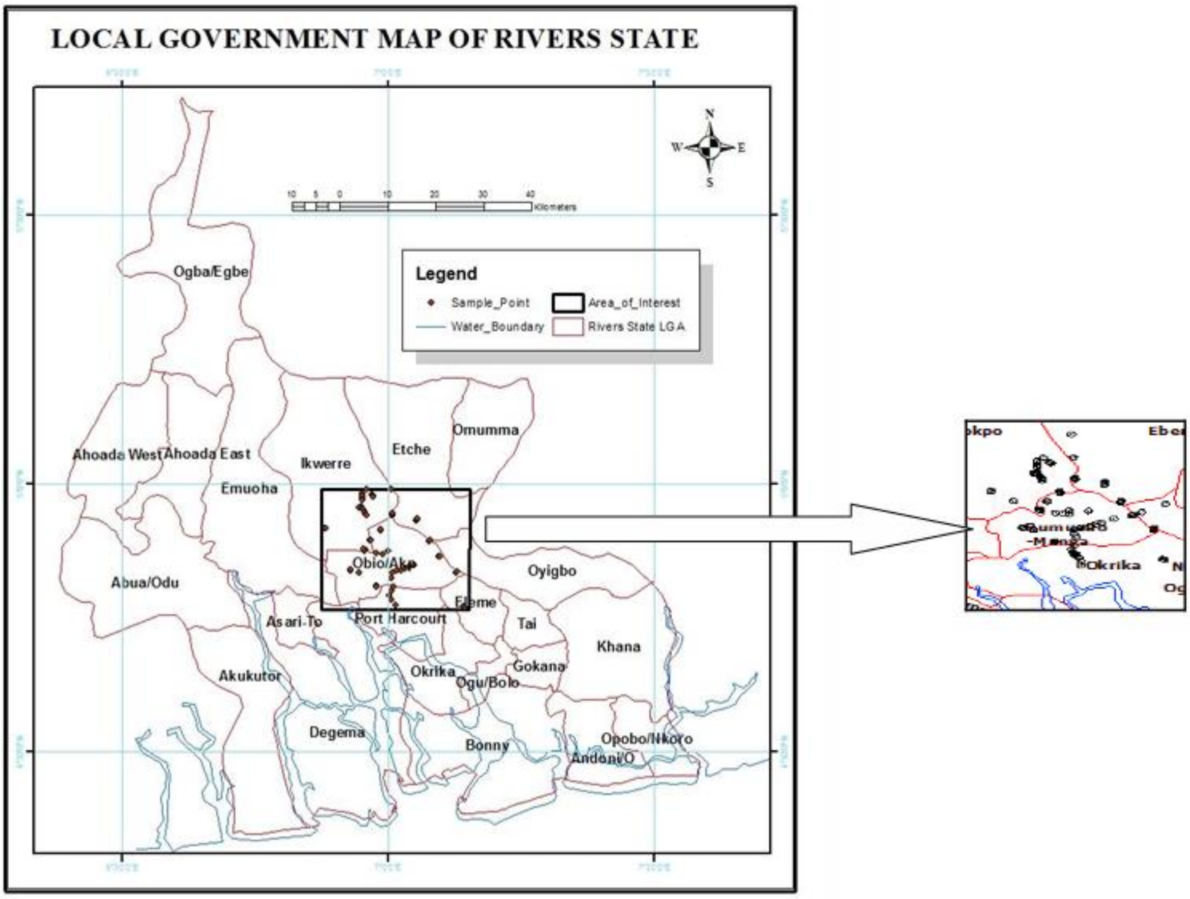

*Figure 2: Showing the Map of the Study Area in Port Harcourt (**Source:** Aleem, 2013)*

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Lagos is roughly located between longitudes 2°42' and 3°42' East of the Greenwich Meridian and latitudes 6°22' and 6°52' North of the Equator. Lagos State is bordered on the north and east by Ogun State, on the south by the 180 km long Atlantic coastline, and on the west by the Republic of Benin.

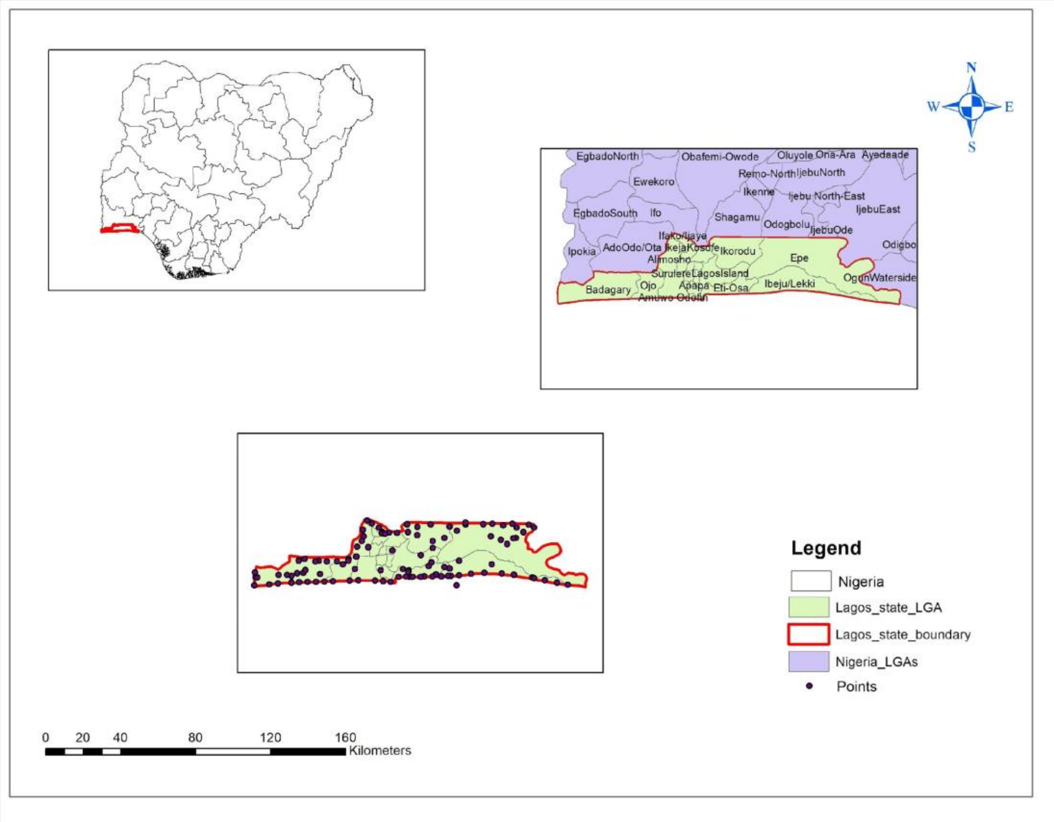

Figure 3: *Showing the Map of Nigeria and the Map of Lagos (produced by the authors)*

Originally known as Yakoba, Bauchi is a city in northeastern Nigeria that serves as the main administrative center of the Bauchi Local Government Area, Bauchi State, and the erstwhile Bauchi Emirate. At an elevation of 616 meters, it is situated on the Jos Plateau's northern border. A population of 493,810 people lived in the 3,687 km² local government area in 2006. One of the twenty local government areas in the state of Bauchi is Bauchi City.

The wet season is unpleasant and foggy in Bauchi, while the dry season is hot and partly cloudy all year round. The yearly average temperature lies between 57 to 100 degrees Fahrenheit, with rare excursions when it drops below 51 or soars to over 104. Bauchi has a tropical savanna climate, designated as "Aw" on climate maps, according to the Köppen Climate Classification system. Additionally, Bauchi is home to a wealth of naturally occurring resources that are employed both for commercial and industrial purposes. These consist of gypsum, limestone, iron ore, crude oil, and lignite.

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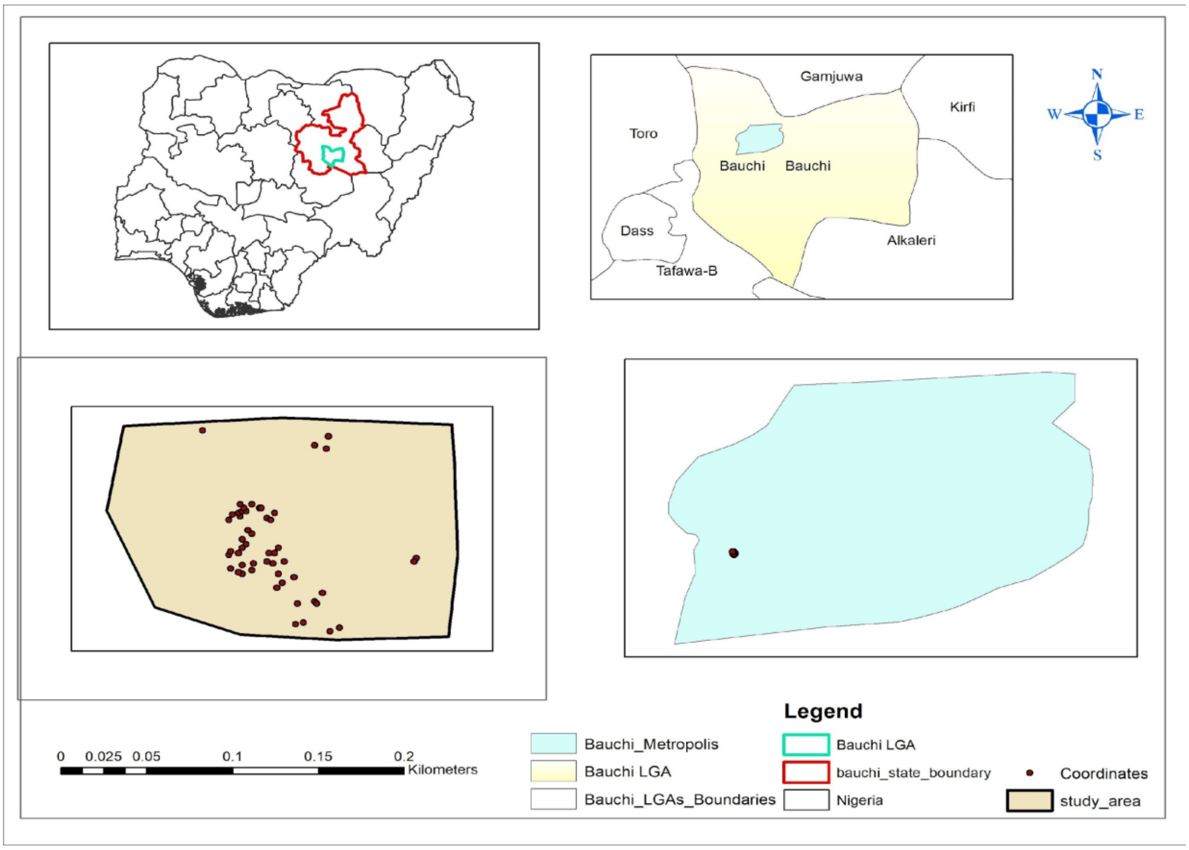

Figure 4: *Showing the Maps of Nigeria, Bauchi State, Bauchi and the Study Area (produced by the authors)*

Development of Prototypes

Equation 1 was used to create a straightforward DART program that calculated the geoid and orthometric heights of particular sites. The application was interfaced with the "GeographicLib" software, which connects directly to the official NGA websites to obtain the EGM2008 model, in order to ensure correctness and uniformity. This script functions as the application's prototypes for geoidal undulation.

Including Pertinent Utilities in the Program
This was accomplished by utilizing the cross-platform features of the Flutter framework in conjunction with the initial creation of a new Dart project. GeographicLib was then introduced to the Dart project as an external dependency. By adding the required Dart packed GeographicLib libraries, this was accomplished.

```
import 'package:geographiclib/geoid.dart'; // Import the necessary Geog

// Function to calculate geoidal height and orthometric height
Future<void> calculateHeights(double latitude, double longitude) async
```


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After adding the dependency, there was a need to run **flutter pub get** in the project directory to fetch and install the package. Once the **geographiclib** package was included, the necessary libraries (**geodesic.dart** and **geoid.dart)** were imported in the Dart code. Check the sample code on Dart below.

User Interface Design

The user interface (UI) for the mobile app was designed by considering including elements for user input (coordinates) and display areas for geoidal height and orthometric height. The design is presented below:

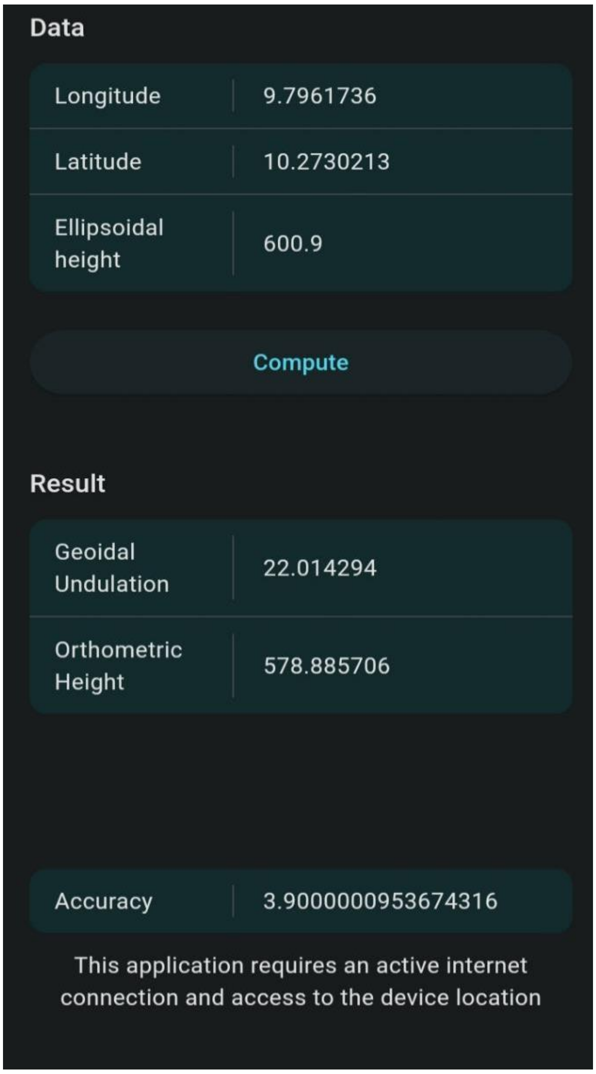

Figure 5: *Showing the user interface of the mobile app*

Implementation of GeoidEval Integration

Functions to manage the integration with GeoidEval were built when the required GeographicLib libraries were imported into the Dart code. This required submitting coordinates to GeoidEval in order to obtain the geoidal heights that corresponded. The GeographicLib utility library contains a section called "GeoidEval" that is responsible for evaluating geoid heights at given geographic coordinates using a predetermined model.

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Geodetic Coordinates Input and App's Working Principle

The mobile app was designed in such a way that it automatically generates the ellipsoidal height, longitude and latitude of a particular location through the UI provided access to the location is being granted by the device on which it is being installed. It works in such a way that the automatically generated input coordinates call the appropriate functions in GeoidEval from the GeographicLib library using and the results are returned by GeoidEval while the result (Geoidal height and orthometric heights) are being displayed by the UI. For the app to effectively function, it must fulfill the following requirements:

a. It must be installed on an android or IOS device.

b. It must have a storage capacity of at least 1 gb.

c. The device's access to location must be granted.

d. Access to the internet must be granted on the device.

e. The device must be charged or connected to a power source.

Testing

To guarantee the precision and dependability of the results, the app underwent extensive testing using various sets of geodetic coordinates.

Comparative Analysis

Before being fully incorporated into an app, the app's accuracy was evaluated by first utilizing the Dart program to compare it to pre-existing models, such as the EGM 2008 Desktop app, Satlevel, and 7-parameters geoid model, at particular sites in Lagos and Port Harcourt. The completely deployed application and an existing app called "correct altitude," created by Michal Jakl in 2021, were tested in Bauchi, the capital of Bauchi State, over terrain in order to determine the app's sensitivity and reliability. Excel Spreadsheet was used to perform the analysis's numerical computation.

Statistical Analysis

In order to further interpret the results from the testing above and to show how the app agreed with other existing models and apps, mean absolute error and root mean square error were computed using Excel spreadsheet.

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RESULTS AND DISCUSSION

Table 1: Showing Comparisons between Three Geoid Models in Port Harcourt (Contact authors for full data)

SATLEVEL	EGM2008	7 PARAMETERS
0.0268	0.0249	0.5849
0.0226	0.0221	0.6113
0.0327	0.0426	0.6134
0.0252	0.0314	0.5985
0.0006	0.0128	0.5795
0.045	0.0474	0.6342
0.0011	0.0182	0.5861
0.0071	0.0249	0.59
0.0168	0.012	0.5673
0.0169	0.009	0.6056
0.0296	0.002	0.6185
0.0255	0.0396	0.6166
0.0087	0.0409	0.5671
0.0111	0.0822	0.5884
0.0099	0.0033	0.5897
0.0093	0.0142	0.5847
0.0114	0.0124	0.5899
0.0098	0.0013	0.5904
0.0084	0.0008	0.5919
0.0075	0.0018	0.592
0.0101	0.0036	0.5937
0.0051	0.0366	0.5844
0.0055	0.0028	0.5843
0.0047	0.0037	0.5834

Table 1 presents a comparative analysis of various geoid models, including Satlevel, 7-parameters, and EGM2008, that are being used for the current study. These models were tested in the backend prior to being properly deployed into an app. The local geoid was used as the reference model to calculate each model's mean absolute error, which was necessary in order to fulfill the goal of comparing the models. The outcome is shown below:

Mean absolute error for SATLEVEL model = 0.011983

Mean absolute error for EGM08 model = 0.008048

Mean absolute error for 7-parameters model = 0.584951

Three models—SATLEVEL, the EGM08 prototype model, and the 7-parameters model—can be clearly compared with reference to the local geoid using the mean absolute error analysis of

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the geoid models in Port Harcourt, as previously mentioned. The mean absolute error (MAE) figures provide information about each model's precision and accuracy. Since they represent lesser deviations from the reference data, lower MAE values are indicative of greater performance.

The results showed that the EGM08 model has the lowest MAE of 0.008048, indicating that it is highly accurate in predicting the geoid values for the Portharcourt sites that were provided. This is a good result and shows that the new app is working better than the SATLEVEL, using the local geoid as baseline. However, the MAE of 0.584951, which is much greater for the 7-parameters model, is different. This suggests a higher departure from the reference data, suggesting that the accuracy of this model may be lower than that of the EGM08 model. With a mean absolute error of 0.011983, the SATLEVEL model is in the middle. It still shows a little greater inaccuracy, indicating that even while it is closer to the EGM08 model, it may not be as accurate.

According to the research, these findings suggest that the EGM08 model, which is incorporated into the app, offers the most precise geoid value forecasts for the designated Port Harcourt sites. The accuracy of the geoid information provided by the app can be trusted by users. The comparative study of the three models concludes that the EGM08 model is a better fit for the application due to its higher accuracy in predicting geoid values for the specified sites.

Table 2: Showing Comparisons between Three Geoid Models in Lagos (Contact authors for full data)

SATLEVEL	EGM2008	7PARAMETERS
0.0696	0.3049	2.2606
0.0768	0.2081	2.1085
0.0028	0.1337	2.1724
0.0142	0.4	2.3405
0.0405	0.1638	2.1175
0.0064	0.3567	2.1875
0.0081	0.3472	2.1803
0.0102	0.2622	2.1892
0.0059	0.2716	2.1613
0.0156	0.2729	2.1401
0.0279	0.3485	2.1938
0.0524	0.3254	2.1653
0.0514	0.3182	2.1622
0.0337	0.3145	2.1822
0.0116	0.3124	2.1931
0.0051	0.3515	2.1999
0.0494	0.3327	2.1612
0.1076	0.2813	2.1067

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Table 2 depicts the comparisons between the local geoid of selected points in Lagos as computed from the observed ellipsoidal and orthometric heights as well as other geoid models such as Satlevel, 7-parameters model and the EGM2008 model adopted for the ongoing study as tested in the backend before deploying properly into an app. To achieve the purpose of comparison among the models, it was necessary to compute the mean absolute error of each model using the local geoid as the reference model and the result is presented below:

Mean absolute error for Satlevel = 0.060568

Mean absolute error for EGM08 = 0.269333

Mean absolute error for 7-parameters = 2.140581

With a value of 0.060568, the Satlevel model showed the lowest MAE in Lagos. Given that the Satlevel model closely matches the Local geoid, this suggests that it is reasonably accurate in forecasting geoid values for the designated places in Lagos. The MAE of the EGM08 model, on the other hand, is greater at 0.269333. This result is still much lower than the MAE for the 7-parameters model, even though it is greater than the Satlevel model. This implies that while the Satlevel model is more accurate than the EGM08 model, the latter performs somewhat better. The model with 7 parameters has the highest MAE: 2.140581. This substantial departure from the reference data suggests that this model may not be appropriate for precise geoid predictions in the designated areas. Using this methodology could lead to less dependable results for users.

The Port Harcourt results are comparable to the findings of Peprah and Kumi (2017), who used the EGM08 model to determine geoid elevations and compared them with 328 distinct geometrical elevations derived from co-located GPS and total station orthometric heights of the University Primary Levelling Networks. The techniques used are a geometric method, an EGM08 model for calculating geoidal heights, and a polynomial mathematical model for optimizing the estimated EGM08 geoid heights values. The geometric approach's generated geoid heights and the matching geoid heights derived from the geoid model (EGM08) differ statistically, indicating that the EGM08 model was the most appropriate at the time.

According to Herbert and Olatunji (2021), orthometric heights derived using EGM2008 geoid heights provide more precise results with a standard deviation of 9.530 m and a standard error of 1.361 m. This is because the addition of a spherical harmonic coefficient to the geoidal height values, broadened to degree 2190 and order 2159, makes this gravity model the most appropriate for determining the orthometric height of the chosen points within the study area. The RMSE, Mean Error, and Standard Deviation of their geoidal height differences were 0.120825 m, 2.18823 m, and 3.47678 m, which is better in the area of interest. EGM2008 has a great deal of potential for geoid modeling across Kenya, according to Odera (2016)'s findings. The study concluded with the suggestion that local gravity data sets and EGM2008 can be combined to create an initial high resolution gravimetric geoid model over Kenya.

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Table 3: Showing Comparisons between Geoid Heights Observed Using the Designed App and an Existing Mobile App (Correct Altitude) for Geoid at Selected Points in an Undulated Terrain in Bauchi LGA, Bauchi State (Contact authors for full data)

Stations	G_height mobile app	G_height_OTHER_APP	Differences	D^2
U1	22.0304	22	0.0304	0.000924
U2	22.0305	22	0.0305	0.00093
U3	22.0345	22	0.0345	0.00119
U4	22.0346	22	0.0346	0.001197
U5	22.0347	22	0.0347	0.001204
U6	22.0351	22	0.0351	0.001232
U7	22.0351	22	0.0351	0.001232
U8	22.0359	22	0.0359	0.001289
U9	22.0359	22	0.0359	0.001289
U10	22.0359	22	0.0359	0.001289
U11	22.0361	22	0.0361	0.001303
U12	22.0363	22	0.0363	0.001318
U13	22.0363	22	0.0363	0.001318
U14	22.0364	22	0.0364	0.001325
U15	22.0305	22	0.0305	0.00093
U16	22.0365	22	0.0365	0.001332
U17	22.0366	22	0.0366	0.00134
U18	22.0367	22	0.0367	0.001347

The app's dependability was evaluated on a variety of terrains, and the data presented in Table 3 above shows the geoid elevations of each point that was collected from an undulating terrain at Sabon Kaura, Bauchi State, using both the G_height app that was designed and the G_height_OTHER_APP app that was already in use.

Article DOI: 10.52589/AJSTE-O01VCCWX
DOI URL: https://doi.org/10.52589/AJSTE-O01VCCWX

Advanced Journal of Science, Technology and Engineering
ISSN: 2997-5972
Volume 4, Issue 3, 2024 (pp. 14-31)

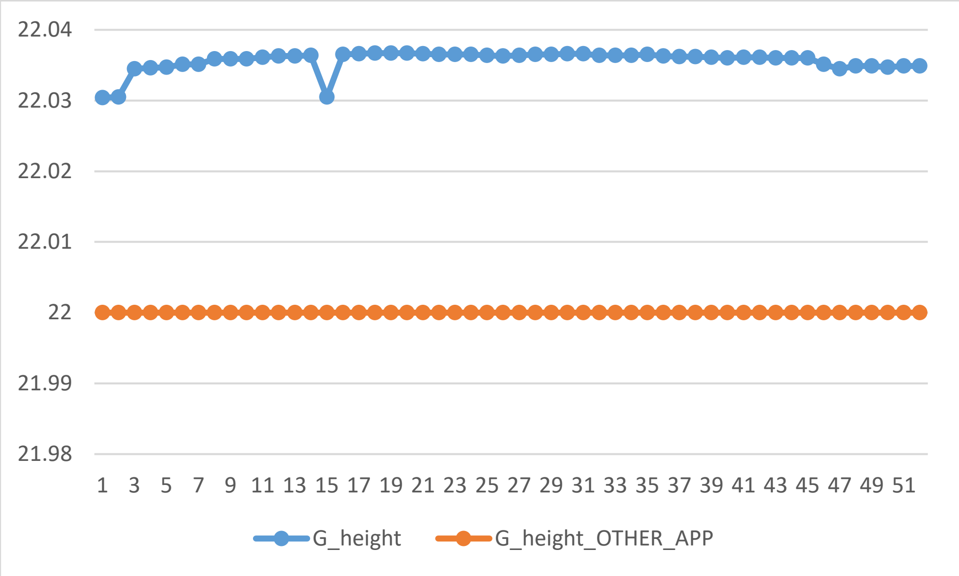

Figure 6: Showing Comparison between Geoid Heights from the App and an Existing App for Geoid Computation on an Undulated Terrain

From a quick glance, the values from the designed app and the existing app are very close, with minimal variation.

IMPLICATION TO RESEARCH AND PRACTICE

This study gives a cheaper and easier method for on-site geoid and orthometric height computation by utilizing the EGM2008 model within an intuitive mobile application. This technological breakthrough improves the precision and efficacy of geodetic measurements, potentially revolutionizing surveying practices, especially in areas with difficult terrain. Researchers can use this approach as a solid tool for further investigation in geodesy, allowing for more accurate data collection and analysis. The success of this model motivates future research on integrating other sophisticated geospatial datasets and machine learning algorithms to further improve the accuracy of geoid computation. Practically speaking, this development lowers the technical and cost hurdles connected with conventional geoid computation methods by providing surveyors and geodesists with a dependable, deployable instrument that can be easily incorporated into fieldwork; enhanced accuracy of data and broad acceptance in numerous geospatial solutions could result from this.

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www.abjournals.org

CONCLUSION

When compared to other models, the comparison analysis clearly demonstrated the superiority of the EGM2008 model in the mobile app, demonstrating its accuracy and dependability in predicting geoid values. Notably, the study not only tackled important issues about the effectiveness and precision of the mobile application, but it also established the foundation for a hardware idea that has the potential to completely change the geodetic fieldwork environment.

The app's accuracy has been improved by integrating the EGM08 model, which makes it appropriate for a range of land surveying and GIS applications with tolerable errors of centimeters to meters. The suggestions made highlight the pragmatic use of these technological developments, placing a strong emphasis on teamwork, ongoing testing, and capacity building to guarantee a smooth transition into the workplace. The accomplishment of this research opens the door for revolutionary changes in on-site geoid computation, promising improved accuracy and efficiency in the ever-evolving area of surveying and geodetics, as we traverse an era of technological evolution.

FUTURE RESEARCH

The following recommendations were made based on the study:

It is essential to continuously test the mobile app in a variety of environments and on a variety of terrains in order to verify its dependability and accuracy. To ensure the app's efficacy, regular upgrades and enhancements should be performed based on user input and developing technology.

Additionally, cooperation with professional associations and geospatial agencies engaged in surveying and geodesy ought to be pursued. Through this partnership, the created technology may be more easily incorporated into the geodetic frameworks and standards already in place, increasing industry acceptance and uptake.

Furthermore, it is imperative to create training courses that will acquaint surveyors, geodesists, and other pertinent experts with the use of the mobile application and related gear. Initiatives aimed at increasing capacity can hasten the geodetic community's adoption of this technology.

Lastly, current research and development projects should be launched to investigate developments in mobile app technology, hardware design, and geoid computing methods. This will guarantee that, in the quickly developing field of geodetic uses, the produced solutions stay at the cutting edge of innovation.

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