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ESTABLISHMENT OF ORTHOMETRIC HEIGHT CONTROLS IN THE EASTERN PART OF KOGI STATE USING GNSS AND EGM 2008

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ABSTRACT

The aim of this study was to model the orthometric heights in parts of Kogi East, Kogi State using GNSS and EGM 2008 with the objectives of establishing the best geoid undulation for height determination. The Hardwares used for this study include; Hi target V.30 dual frequency GNSS receiver and its accessories, Data logger, Computer hardware and software and Computer – HP Laptop and internet facilities. Softwares used included; Arc GIS, Google map, microsoft word, Microsoft excel, Hi target Geomatic offices, CSRS – PPP website andGeoid Eval Calculator. GNSS observations were conducted on 6 station monument. The dual frequency v30 Hi target instrument was used in the static mode to make observations on all the established points at an epoch rate of 30 seconds; for a period of one hour to one hour thirty minutes (session) per station. The secondary data were the EGM 2008, obtained from Geoid eval platform in https://www.geographiclib.sourceforge.ion/cgi-bin/GeoidEval. Geoid Eval platform makes provision for the geographical coordinates to be inputed before the geoidal-ellipsoidal separation values can be provided. Geoid Eval computes the height of the geoid above the WGS 84 ellipsoid using interpolation in a grid of values for the earth gravity models. To obtain the orthometric height, the geoid value is subtracted from the ellipsoidal height obtained from the GNSS-PPP observation. The accuracy of the geoid value is 1mm and that of the GNSS-PPP was adjudged to be 3cm respectively. It was recommended that, more orthometric heights be distributed for monitoring of the earth's dynamisms.

Keywords: Orthometric height, Ellipsoidal height, Geoid, GNSS, Geographical coordinate

INTRODUCTION

For earth measurement, different types of heights exist and they are orthometric heights, geoidal heights, dynamic heights, ellipsoidal heights and normal heights (Meyer *et al.,* 2016). FAO (2024) described height as the vertical distance above or below a surface of a reference plane. This reference plane could be mean sea level (geoid) or the ellipsoid. NGS, (2015) described height as the distance, measured along a perpendicular between a point and reference surface (datum), used as a computational reference surface. Height which is one of the outcomes of Global Navigational Satellite System (GNSS) coordinate values, is the vertical distance from the surface of any of the earth referenced point and it could be to the geoidal surface or the ellipsoidal surface (Hazelton 2020; Guma *et al.,* 2023).

Prior to recent technological era, Heights were determined using different traditional techniques like trigonometric, (spirit leveling and total station), geometric, barometric and tacheometric method (Pirti and Hosbas, 2019). Guma *et al.,* (2023) explained that, today's technology has greatly replaced the traditional methods of determining heights and one of these latest technologies the Global Navigation Satellite System (GNSS) receivers, networks, and post-processing strategies. Supej and Cuk (2014), in trying to compute heights, compared GNSS and other traditional leveling techniques, it was agreed that the GNSS technique is more cost effective over the conventional surveying methods like the geodetic leveling.

Brazeal (2014) wrote that, accurate heights, especially elevations, is of great importance to a number of scientific and engineering applications like mapping flood hazards, determining sea level rise, developing nautical charts, precise terrain mapping, monitoring vertical crustal movements, studying subsidence and other ground deformations. Deng (2008) and Burian *et al.,* (2004) observed that one of the major factors that make determining and recording accurate elevations vital, is understanding and predicting the effects of gravity at different places and the associated movement of water, soil, and other objects due to gravity's downwards pull toward lower elevations. Guma *et al.,* (2023) explained that, heights could help route Engineers understand the undulation of any terrain for movement of water and other liquids planning; also, telecommunication companies need height information for location of mast and other gadgets.

This study is justified by the motivation of obtaining heights that are devoid of spirit leveling measurement work, which is a conventional way of determining heights; determining accurate elevations for engineering and scientific applications through the use of GNSS which increases efficiency and significantly reduces the cost of field work as compared to precise geodetic leveling.

What necessitated this study is that, there are varied mining activities going on in the Eastern part of Kogi State where this study is focused. This mining exploitation is affecting the ground surface in the form of depression and subsidence. Moreover, the mining activities have gradually caused gully erosion which has birthed so many gullies in and around the areas. These gully menace required orthometric height control for the determination of the depth of the gully as well as its topographic nature for engineering calculation, monitoring, and constructions which will eventually save life and properties within the environment of the affected areas. Hence, this study aims at establishing the orthometric height controls in the Eastern part of Kogi State using GNSS and EGM 2008 with the objectives of making them available for height determinations and monitoring.

There are three heights that are critical to this study and they are defined by their relationships to each other. These heights are orthometric height (H), ellipsoidal height (h), and the geoid height (N). Orthometric height (H) represents a height on the ground above or below the reference geoid surface. As seen in figure 1.1, orthometric height is the distance from a point on the topographic surface to the geoid along a plumb line normal to the geoid (Zilkoski, 1990b). Because the path between these two points follows the plumb line, it is a slightly curved line due to the changes in the normal position from the geoid surface at different points (Zilkoski, 2010). The ellipsoidal height (h) is the distance from the topographic point to the referenced ellipsoid, and it is measured from the normal of the ellipsoidal surface up or down to the topographic point. Lastly, the geoid height (N) is the difference between the orthometric height and the ellipsoidal height for a particular topographic point. This height is also known as the geoidal undulation or the geoidal separation (Ghilani and Wolf, 2008.). The relationship among these heights is expressed in equation 1

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

where H is the orthometric height, h is the ellipsoidal height and N is the geoidal height.

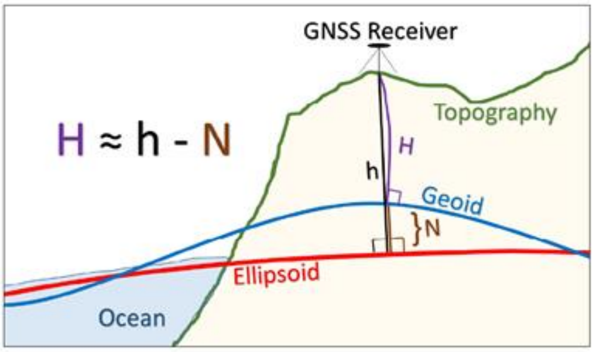

Figure 1: Relationship between orthometric, Geoid and Ellipsoid Height
Source: Brazeal, (2014).

Equipotential Geoid Model (EGM 2008)

Geoid models were created by National Geospatial intelligence Agency (NGA) to provide mean sea level universally (Guma *et al.,* 2023). Rapp (1998) described the EGM 2008 as a spherical harmonic model of the Earth's gravitational potential, which was advanced by a least squares combination of ITG-GRACE03S gravitational model, its error covariance matrix, and the gravitational information gotten from a global set of area-mean free-air gravity anomalies defined on a 5 arc-minute equiangular grid.

Over areas covered with high quality gravity data, the discrepancies between EGM 2008 geoid undulations and independent GNSS/Leveling values are on the order of ±5 to ±10 cm. The result of EGM 2008 indicates that it performs better with contemporary and detailed regional geoid models. It performs equally well with other GRACE-based gravitational models in orbit computations over EGM 96.

Kemboi and Odera, (2016) explained that, the value of N as seen in equation 1 is usually obtained from EGM 2008 even though it could be obtained by other means such as gravimetric means, astrogeodetic means and satellite geometric method, but the EGM 2008 is the most accurate. Guma *et al,* (2023) outlined also two methods that were adjudged to be accurate that the geoid could be determined and they include the Hotline integral and stoke's methods. The EGM 2008 geoid model is displayed as;

$$N_{EGM\ 2008} = \frac{GM}{r\gamma}\sum_{n=2}^{n_{max}}\left(\frac{a_{ref}}{r}\right)\sum_{m=0}^{n}(\bar{C}*_{nm}\ cosm\lambda + \bar{S}_{nm}\sin m\lambda)\bar{P}_{nm}(cos\theta) \quad (2)$$

Where $N_{EGM\ 2008}$ is the geoid undulation $\bar{P}_{nm}(cos\theta)$, is the fully normalized Legendre function of degree n and order m, $\bar{C}*_{nm}$ and $\bar{S}_{nm}$ are the spherical harmonic coefficient, a is equatorial radius of adopted reference ellipsoid, QR is the gravitational constant, *GM* is the scaling parameter, r is the mass of the earth, n_{max} is the finite maximum degree of a *GGM.* When the EGM 2008 is determined, to calculate the orthometric height, the equation 1 is further improved to,

$$H_{MSL} = h_{WGS\ 84} - N_{EGM\ 2008} \quad (3)$$

Global Positioning System (GPS)

Someswar *et al.* (2013) explained that, prior to the initiation of artificial satellites, navigation was carried out through radio navigation systems which used terrestrial long wave radio transmitters instead of satellites. These positioning systems broadcasted a radio pulse from a known master location, followed by repeated pulses from a number of slave stations. The delay between the reception and sending of the signal at the slaves was carefully controlled, allowing the receivers to compare the delay between reception and the delay between sending. From this the distance to each of the slaves could be determined, providing a position estimate.

The launch of Sputnik I by the Soviet Union which uses Doppler shifts in the signals transmitted by the satellite and measured from a single ground station at a known position was discovered to be enough to determine the orbit of the satellite. It was then deduced that if the satellite orbits were known, a radio receiver measuring the Doppler shifts could determine its position on earth. The first satellite based radio navigation system born from this concept was the U.S. TRANSIT, also known as NAVSAT (for Navy Navigation Satellite System). The shortcomings of NAVSAT and Sputnik led to the development of the GPS in the early 1970's. While GPS was under development, the Soviet Union undertook to develop a similar system called GLONASS. Other Global Navigation Satellite Systems (GNSS) are the European system Galileo and the Chinese system Beidou. Other regional systems are the Japanese uasi-Zenith Satellite System and the Indian INRS.

However, the involvement of two receivers was cost effective so, an absolute GNSS technique was introduced and it is called the Precise Point Positioning. Precise point positioning (PPP) is a positioning technique that removes or models GNSS system errors to provide a high level of position accuracy from a single receiver (Guma et al., 2023). A PPP solution denned on GNSS satellite clock and orbit correction generated from a network of global reference Station (Bisnath et al, 2018). Once the corrections are calculated, they are delivered to the end user via satellite or over the internet.

These corrections are used by the receiver, resulting in decimeter level or better positioning with no base stations required. The formula for PPP that corrects ambiguities is displayed in equations 4 to 7.

$$P_1 = \sqrt{(X_{S1} - X_U)^2 + (Y_{S1} - Y_U)^2 + (Z_{S1} - Z_U)^2 + c\delta t\mu} \quad (4)$$

$$P_2 = \sqrt{(X_{S2} - X_U)^2 + (Y_{S2} - Y_U)^2 + (Z_{S2} - Z_U)^2 + c\delta t\mu} \quad (5)$$

$$P_3 = \sqrt{(X_{S3} - X_U)^2 + (Y_{S3} - Y_U)^2 + (Z_{S3} - Z_U)^2 + c\delta t\mu} \quad (6)$$

$$P_4 = \sqrt{(X_{S4} - X_U)^2 + (Y_{S4} - Y_U)^2 + (Z_{S4} - Z_U)^2 + c\delta t\mu} \quad (7)$$

According to Bisnath *et al.*, (2018), PPP delivers accuracy up to 3 centimeters. A typical PPP solution requires a period of time to coverage to decimeter accuracy in order to resolve any local biases such as the atmospheric conditions, multipath environment and satellite geometry. The actual accuracy achieved and the convergence time required is dependent on the quality of the corrections and how they are applied in the receiver.

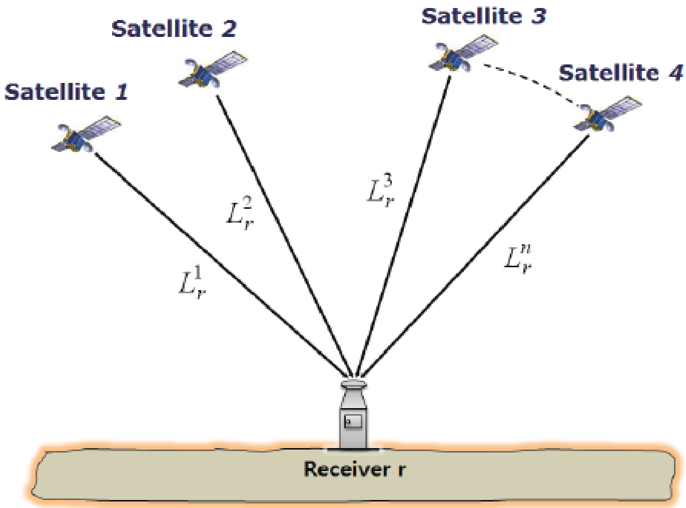

Figure 3: A typical illustration of PPP techniques

Determination of orthometric heights

Zilkoski (2015) wrote that, in order to know how to obtain centimeter level accuracy of GNSS-derived orthometric heights the expert need the knowledge of the types of heights and how these heights are determined. The needed knowledge is that of the ellipsoid, geoid and orthometric heights and their estimated accuracies.

Foroughi *et al.* (2017) used the local gravimetric geoid model of Auvergne that was computed by the Stokes–Helmert technique to determine the orthometric height. The result of the simulation showed a standard deviation (STD) of 3.2 cm of the values obtained from control leveling points. The gravimetric geoid height was computed for also using the Helmert's heights and standard deviation of 2.9 cm was achieved after rigorous orthometric height computation. Finally, when a quasi-geoid model of the Least-Squares Modification of Stokes method was used, a normal height was obtained to the accuracy of 3.4 cm.

Strange (1982) observed that, errors were always introduced in the computations of orthometric height via the use of formulas that first of all estimate mean gravity along plumb lines. Several measurements of gravity between the sea level and the surface of the Earth from borehole gravimetry were used to evaluate the magnitude of height errors. The result of the methods adopted showed errors in orthometric height which was due to the use of the Helmert method for computing mean gravity along the plumb line, in the tune of 2 cm. However, in some methods, the error was large to the range of 9.6 cm. The author concluded that, with more topographic information, that would help to compute terrain and density estimates, errors in mean gravity along the plumb line could be minimized to 3cm in orthometric height computation.

Fotopoulos et al., (2003) discussed the integration of global positioning system (GPS) heights with gravimetrically derived geoid undulations for the determination of orthometric heights above mean sea level. The accuracy was good. Greenfeld and Sens (2003) used the network of global positioning system (GPS) Continuously Operating Reference Stations (CORS) to determine heights. The essence of this process of height determination was because the National Geodetic Survey (NGS) that publishes coordinates for stations does not always publish accurate height data. The orthometric heights of CORS station were actually determined at a standard deviation of ±1 mm.

Wang *et al*., (2023) used the Bouguer's anomaly method of geoid-quasigeoid separation (GQS) to approximate the difference between the mean gravity and normal gravity along a plumb line. Because the approximation method is not accurate in high and rugged mountains, a higher order of corrections known as potential and gravity gradient was included to produce a 1 cm geoid computation experiment. Chua *et al*., (1991) carried out a field work to analyze the orthometric height as obtained from Seasat radar altimeter with that obtained from ground control data that were based on terrestrial survey observations. Ground heights were modeled using the bicubic spline surface and the RMS of the differences was about 0.4 m.

Herbert and Ono (2018) postulated that the determination of orthometric height has a significant role in the discipline of geodesy. The determination of orthometric heights was performed using the gravimetric method which included the simulation of Stokes integral and ellipsoidal heights through GPS measurements. Fifty-nine observation stations were used to acquire gravity observation. The difference between the tailor geoid height (NTaylor) and the ellipsoidal heights (hGPS) were finally computed for and the result showed a standard deviation value of 10.6121m with a standard error as 1.38159m.Herbert and Ono (2018) used stoke's integral as designated in equation 1.8 to compute absolute geoid and geoidal undulation,thus;

$$N = \frac{R}{4\pi G} \iint \Delta g \, S(\psi) d\sigma \quad (8)$$

Where:
$\iint$ = an integral extended over the whole earth
R= Mean radius of the earth
G=the universal gravitational constant = 6.673×10^{-11}ms-1
Δg = gravity anomaly known everywhere on the earth.
$S(\psi)$ = stoke'sfunction
$d\sigma$ = differential area on the geoid
The surface spherical radiusψ_0 is computed as;
$\cos\psi = \sin\varphi\sin' + \cos\varphi\cos\varphi'\cos(\lambda' - \lambda)$
Where;
φ = latitude 1 of the compartment
φ' = latitude 2 of the compartment
λ = longitude 1 of the compartment
λ' = longitude 2 of the compartment

$$S(\psi) = \csc\left(\frac{\psi}{2}\right) - 6\sin\left(\frac{\psi}{2}\right) + 1 - 5\cos\psi \text{In}\{\sin\left(\frac{\psi}{2}\right) + \sin^2\left(\frac{\psi}{2}\right)\}$$

The major setback with this formula is that it is expensive and consumes much time to accomplish.

Edan *et al.*, (2014) used GPS/Leveling data to determine orthometric height by adopting geometric interpolation and multiple regression analysis method. Field surveys were performed to obtain height data from spirit leveling. Ellipsoidal heights and positional data were obtained using Promark3 GPS receivers. The GPS was used in static relative mode for twenty minutes per station with epoch rate of fifteen seconds. Nevertheless, data for existing GPS controls and levelling benchmarks were obtained from the office of the Surveyor General of the Federation, Makurdi zonal office. The data processing were conducted using multiple regression analysis method. The regression parameters a0, x1 and x2 were obtained as 1166.721268, -0.00085137265 and -0.00089422771399 respectively. From the analysis, the standard error of estimates S$\varkappa$1 and S$\varkappa$2 associated with x1 and x2 were obtained as 0.0001291688765 and 0.0001351270512 respectively.

Idowu and Abubakar (2012) predicted the orthometric heights for unknown stations in a study area using least squares collocation technique. Data used for the study are the rectangular coordinates and orthometric heights of 30 stations. The stages of approach adopted includes the use of classical least squares technique to predict orthometric heights at the observation stations, the use of optimization technique to determine the optimal values of covariance parameters needed for the evaluation of covariance function and the use of least squares collocation technique for the prediction of orthometric heights at the observation stations and outside observation stations. Analyzing the results obtained, it was observed that the least squares collocation technique used for the prediction did not have significant error. After comparison was made to ascertain the accuracy of result, the difference between the observed and the predicted orthometric heights of the same station was discovered to be within the acceptable error level.

Research direction

The GNSS-PPP technique was adopted to determine the ellipsoidal height which according to Ghilani and Wolf (2008) has solved the age-long problem of insufficient gravity data and the less accurate astrogeodetic approach for orthometric height determination. The geoid-ellipsoid separation values were obtained from EGM 2008 values. The reason for EGM 2008 is because; the RMS error in the interpolated height is 1 mm (Karney, 2022). With this accuracy, the use of GNSS derived heights can be adjudged the best approach to determining the orthometric height of points.

MATERIALS AND METHODS

Overview of Study area

Kogi East is a part of the linear north east – south west trending basin, 800km long and 90 km wide on the average in eastern Nigeria (Ogungbesan and Akaegbobi, 2011). It is considered to have originated as an aulacogen on the Precambrian shield as a result of the separation of the African and American plates in early cretaceous times (King,1950; Olade,1975). However, in this research, the study Area is limited to the Eastern part of Kogi State which is located between Latitude 07 20' and 08 00'N and longitude 06 30' and 07 45'E. The selected local governments are Dekina L.G.A, Ofu L.G.A, Ankpa L.G.A, Bassa L.G.A and Omala L.G.A. In summary, a total of 6 benchmark stations were located and marked cutting across 5 L.G.As in Kogi station as part of Benue trough in the State. The benchmarks were spread across the six Local Government of Kogi State forming part of Kogi East.

Vegetation distribution in the area follows a pattern that is similar to that of rainfall distribution (Ekwedeh, 2003). The study area has a tropical wet and dry or savannah climate (classification: AW). The rainy season usually lasts from April to October and the dry season from November to March (Weather base, 2011). The zone has an annual rainfall ranging from 1100 to 1300mm per annum. The climate of the area is thus affected by two main air masses; the tropical maritime and the tropical continental (Ocholi, 2007).

According to (Ukabiala, 2019), the monthly temperature of the environment varies between 17 and 36^{o}C. The highest temperature 36^{o}C has been recorded during the dry season while the mean relative humidity is lowest during the dry season and highest during rainy season of the year. The region has a mean annual temperature of 24^{0}C.

The mean relative humidity is lowest during the rainy season of the years, given 15 and 67% respectively thrives best in a warm climate. The mean monthly humidity values are slightly high for the wet season months (June – October) with the highest value occurring within the month of June and September. This is when the influence of the moisture laden south westerlies is greatest.

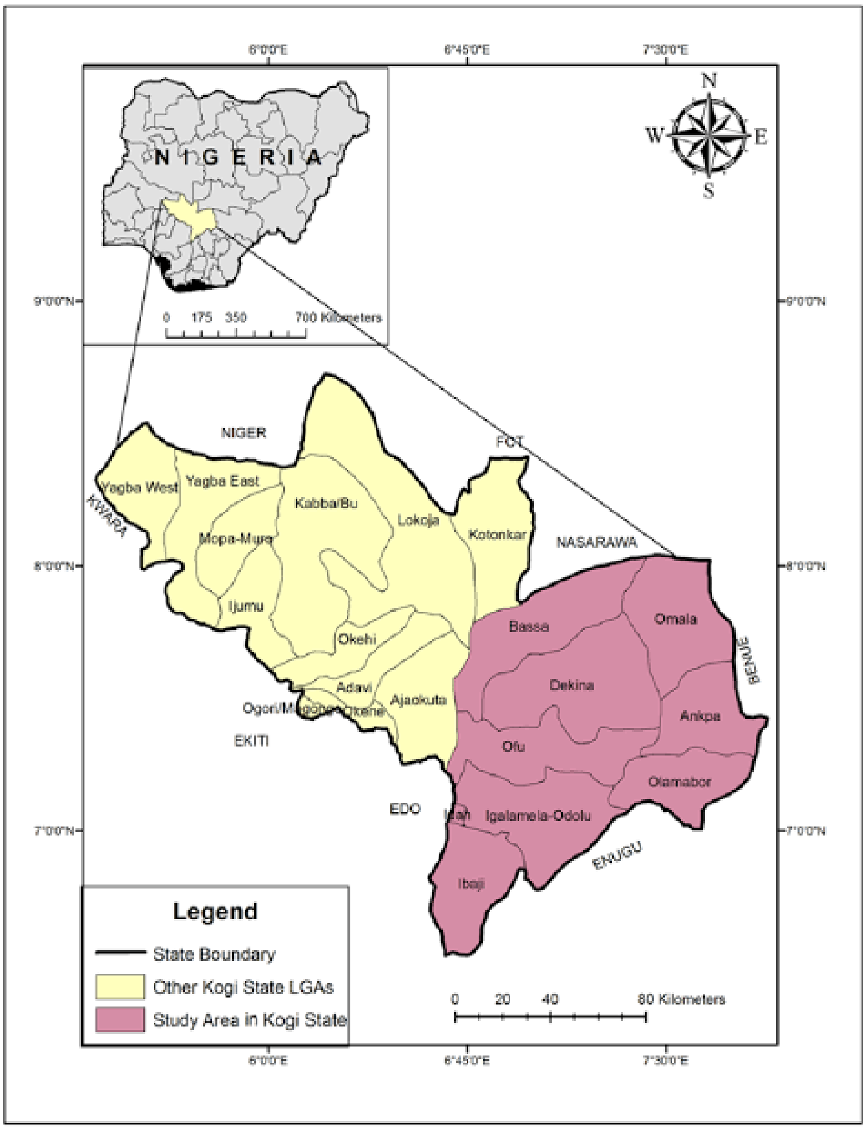

Figure 2: Map of Nigeria showing the study areas in colour red
Source: https://www.researchgate.net/map-of-Kogi-east.

Data Acquisition

The instruments used for this study are divided into hardware and software. The Hardwares include; Hi target V.30 dual frequency GNSS receiver and its accessories, Data logger, Computer hardware and software and Computer – HP Laptop and internet facilities. Softwares include; Arc GIS, Google map, microsoft word, Microsoft excel, Hi target Geomatic offices, CSRS – PPP website, Geoid Eval Calculator

The instruments were checked and all its components were in order. The batteries were fully charged before and during the observations. The Hi-target V30 GNSS receiver calibration status was checked before use. An integrity test which include setting up, centering and leveling up on a station with all necessary connections were conducted on the Hi-target GNSS receiver. Checks were also made on the satellite tracking and observation.

Two types of data were required for this study; the primary data and the secondary data. The primary data required are the Northings, Eastings and Ellipsoidal height of the various points identified on the study area. These were obtained from GNSS receiver during field observations.

Acquisition of Primary data (GNSS Measurement)

GNSS observations were conducted on 6 station monument. The dual frequency v30 Hi target instrument was used in the static mode to make observations on all the established points. Observations were made at an epoch rate of 30 seconds for a period of one hour to one hour thirty minutes (session) per station. The following field precautions were taken into consideration during the observation; the antenna height was made to be higher than the observer, no observation was made or taken to less than four satellites, the observation session for one hour was consistently maintained and all GNSS observations were restrained from areas under canopy.

On completing the satellite observation, the obtained GNSS data were downloaded into laptop from the receiver through the use of downloading cable. Thereafter the Hi-target Geomatic office software was used to convert the files to PPP RINEX format which is the compatible files.

The RINEX were uploaded to CSRS-PPP online post processing solution through CRSR-PPP WEBSITE (webapp.geoid.nrcange.ca). The processing was done through CSRS-PPP removing all the ambiguities associated with GNSS observation and the result obtained back through email address.

Acquisition of Secondary data (Geoid values)

The secondary data were the EGM 2008 as obtained from Geoid eval platform in https://www.geographiclib.sourceforge.ion/cgi-bin/GeoidEval. Geoid Eval platform makes provision for the geographical coordinates to be inputed before the geoidal-ellipsoidal separation values can be provided. Geoid Eval computes the height of the geoid above the WGS 84 ellipsoid using interpolation in a grid of values for the earth gravity models. The curvilinear coordinates (latitude and longitude) of each of the observed positions were imputed into geoid Eval environment online and then submit. The software however computes the corresponding geoid heights automatically and result displayed on the screen.

RESULTS AND DISCUSSIONS

Primary data

The Primary data as obtained by GNSS measurement come in Easting, Northing and Height. The height is usually ellipsoidal reference. The Canadian Spatial Reference System-PPP platform was used for the processing of the data. The raw GNSS data was downloaded into the computer which was later converted to RINEX file using Hi-Target Geomatics office software 2.2 version. These RINEX file were uploaded to the CSRS-PPP online Post processing platform and after this, the result was sent back through the internet. The results are in Table 1.

Table 1: The GNSS results for all the observed stations

STATION	NORTHING	EASTING	HEIGHT
BMO 1 IT	821057.569	250346.754	98.146
BMO 2 AY	827002.588	297636.090	399.935
BMO 3 BJ	869965.725	335665.997	128.219
BMO 4 AI	836332.355	346913.019	404.274
BMO 5 DK	849325.807	285097.922	190.796
BMO 6 OD	860666.912	285088.297	117.097

Computation of Geoid Heights (Geoid Undulation)

The earth gravitational model 2008 (EGM 2008) Geoid heights ((N^{EGM08})) was used to achieve the aim of this study. Geoid Eval computes the height of the geoid above the WGS 84 ellipsoid using interpolation in a grid of values for the earth gravity models. The curvilinear coordinates (latitude and longitude) of each of the observed Benchmark positions were imputed into geoid eval calculator online and then submit. The software however does the computation and the corresponding geoid heights obtained automatically and result displayed on the screen. Table 2 shows the details of Geoid heights extraction.

Table 2: The curvilinear coordinates and their corresponding geoidal heights

Station ID	Latitude	Longitude	Geoid Heights
BM 01 IT	07º 25' 19.87844	06º 44' 17.57624	23.0424
BM 02 AY	07º 28' 40.48633	07º 09' 58.37609	22.9579
BM 03 BJ	07º 52' 3.75685	07º 30' 33.81999	22.8830
BM 04 AI	07º 33' 50.08832	07º 36' 44.57624	22.4127
BM 05 DK	07º 40' 45.25013	07º 03' 6.24007	23.3250
BM 06 OD	07º 46' 54.35818	07º 03' 4.23259	23.3382

Computation of Orthometric Heights

In line with the aim of the study, equation 1, was referred to and used. The orthometric height, H as displayed in the equation 1 was however used to compute the orthometric height. Ellipsoidal height (H) was obtained from online post processed CSRS-PPP GNSS observation. In the case of Geoid Undulation EGM 2008, Geoid Eval utility online calculator was used to compute the geoid height (N). The curvilinear coordinates of Latitude and Longitude of the established and observed Benchmaks was submitted into Geoid Eval calculator which does the computation and produced the geoidal height which was however imputed into the relation to obtained orthometric height. The process was repeated for all the stations, the result of the computed orthometric were shown in Table 3;

Table 3: The ellipsoidal, geoid and orthometric heights ($H - h = N$)

STATION	ELLPSOIDAL HEIGHT	GEOID HEIGHT (EGM 2008)	ORTHOMETRIC HEIGHT
BM OI IT	98.146	23.0424	75.1036
BM O2 AY	399.935	22.9579	376.9771
BM O3 BJ	128.219	22-8830	105.336
BM O4 AI	404.274	22.4127	381.8613
BM O5 DK	190.796	23.3250	167.471
BM O6 OD	117.097	23.3382	93.7588

The combined result as presented in Table 4, shows the northing and easting of each of the observation station, the geographical coordinates as well and the ellipsoidal and finally, the orthometric heights.

Table 4: The final result

Station ID	Northing	Easting	Latitude	Longitude	Ellipsoidal Height	ORTHOMETRIC HEIGHT
BM O1 TT	821057.569	250346.754	07º 25' 19.878"	06º 44' 17.5762	98.146	75.1036
BM 02 AY	827002.588	297636.090	07º 28' 40.486"	07º 09' 58.3760	399.935	376.9771
BM 03 BJ	869965.725	335665.997	07º 52' 3.7568"	07º 30' 33.8199	128.219	105.336
BM 04 AI	836332.355	346913.019	07º 33' 50.088"	07º 36' 44.5762	404.274	381.8613
BM 05 DK	8493u25.807	285097.922	07º 40' 45.250"	07º 03' 6.24007	190.796	167.471
BM 06 OD	860666.912	285088.297	07º 46' 54.358"	07º 03' 4.23259	117.097	93.7588

The results in Table 4 are so reliable in the sense that, the platforms that produce them have been adjudged highly accurate. The platforms dealt with the effect of random errors on measured quantities and all the errors associated with GNSS processing. The ellipsoidal heights were obtained from GNSS observation and processed through CSRS-PPP online post processing of benchmark positions established. In the PPP analysis, parameters such as the receiver clock error, ionospheric delays code biases, code multipath and the total neutral atmospheric delay of the observation were determined, for the determination of the permanent station coordinates using the PPP technique. However, precise orbit and clock solutions were used to enable absolute positioning of a single receiver.
The CSRS-PPP processed and analyzed, the error ellipse, estimated A priori and sigma 95% result in centimeter and millimeters accuracy respectively. This conclude the precise and integrity of the positional observations, orthometric heights computed from geoid undulation computed from online Geoid Eval utility calculator and processed ellipsoidal height was computed to 1mm accuracy. The precise accuracy of the curvilinear coordinates and geoid undulation as computed through geoid eval utility produced the precise result of the computed orthometric heights. The Ellipsoidal height was obtained from CSRS-PPP online post processing of benchmark station observed. The online Geoid height calculator was used to generate geoid undulations (N) and the orthometric height (H). Table 4 shows the various heights obtained.
Since geoid Eval online processing generates result in the RMS accuracy of 1mm (Karnel, 2022) and the positional accuracy of CSRS-PPP is adjudged to be within 3cm (Guma *et al.* 2023), the final results as obtained can be deduced to be accurate also. However, this is a research in progress because the authors will wish to compare the gravimetric method of geoid determination with this EGM 2008 when embarking on a further research.

CONCLUSION

The necessity to determine the reference plane which is the mean sea level (geoid) was achieved. The GNSS-PPP was used to obtain the ellipsoidal height and the geographical coordinates of these points were used to obtain the geoid-ellipsoid separation values for each station observed. The accuracy statements of the various platforms (PPP and Geoid Eval) showed high and acceptable accuracies. Just as stated in the preceding section, this study is still in progress as the gravimetric method is going to be explored for comparison. The values obtained can be used for monitoring of open cast coal mining and other mining activities going on in the study areas. It is therefore recommended that; Orthometric heights be distributed around the state in general as this will help in making accurate height observations as well as reporting accurate results; supports should be provided to experts to facilitate this kind of research that monitor the earth dynamisms at all levels.

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