Determination of Displacement In Obajana And Environs Using Precise Point Positioning

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Abstract: *The knowledge of displacement tends to explain the rate of dynamism in and around an area. Of course, displacement can be horizontal and vertical. The horizontal has to do with the Easting and Northing direction of any point whereas, the vertical displacement deals with the Height coordinate alone. This study aimed at determining the displacement of Obajana and environs using Precise Point Positioning. The study involved establishing of observation points at Obajana and few other towns. Observations were carried out with a Single Point Positioning (SPP) technique on static mode. The duration at which the receiver acquired satellite signal was averagely one hour. Raw GNSS data acquire were downloaded from the receiver and then, uploaded to online CSRS-PPP online solution. The results were processed into Eastings, Northings and Heights coordinates of the various observation points. The horizontal peak displacement formula was used to find the horizontal displacement between last phase of observation and the first phase of observation. For the vertical displacement, height differencing between last and first observation was computed. The results were in centimeter and millimeter range. The horizontal displacement were in centimeter and millimeter level and same for the vertical displacement was achieved. It is therefore recommended that, geoidal heights of all the major regions in Nigeria, be determined because reliance on global geoid may not provide accurate height information than regional geoidal undulations.*

Keywords: Horizontal displacement, vertical displacement, single point positioning, static mode, geoidal undulation, geoid**.**

I. INTRODUCTION

The knowledge of displacement tends to explain the rate of dynamism in and around an area (Grapethin *et al*, 2018). Of course, displacement can be horizontal and or vertical. The horizontal displacement has to do with shifts in the Easting and Northing direction of any point (Fang, Shi, Song, Wang and Liu, 2014**).** The vertical displacement is associated with the difference in heights at various epoch of observations and this can be known as ground subsidence too (Guma, 2015). This study will show the vertical displacement pattern of points after carrying out GNSS observations in and around the study area.

Displacement can be caused by different factors such as increased human activities according to Yasuko, *et al.,* (2014). Also, Grapethin *et al.,* (2018) wrote that extraterrestrial impacts, explosions, storm waves hitting the shore, tidal effects and rock or limestone mining and blasting are responsible for inducing movements on the earth's surface. These displacements if not monitored could erupt into hazards.

In 1999, Nigeria experienced its first earth tremor and because there was never any monitoring campaign prior to that time to detect its imminence, the occurrences came as surprise to the Nigerian Government and even the inhabitants of the areas concern. After the first earth tremor occurrence, some other places that have experienced it again in Nigeria are; Kwoi in Kaduna State, Mpape in Abuja, Ijebu-Ode in Ogun State, Shaki in Oyo State, Igbogene in Bayelsa State and Maitama in Abuja according to Nigeria National Space Research and Development Agency (NASDRA) (2018). In Mpape and Maitama alone, NASDRA (2018) credited the causes of these earth tremors to the excessive borehole drilling activities in and around these towns.

In the main study area of this research is located the largest Cement manufacturing factory in the whole of West African region. It is called Dangote Cement PLC. In Obajana incessant mining activities have been ongoing since 1992 when it was Obajana cement

Plc, the impact of mining activities needs to be monitored and controlled. There is need for monitoring of dynamism in order to have knowledge of the rate of displacements in the study area and environs.

The rest of the paper is organized as follows, section I contain the introduction of the study, section II contains the literature review of related works, section III contains the methodology adopted, while section IV contains the processing of data and section V contains the results and discussion and section VI contains the recommendations.

II. RELATED WORKS

Fang, Shi, Song, Wang and Liu (2014**)** used GPS to determine earthquake and tsunami early warning signal. Fang *et al*, (2014) determined the magnitude of these environmental hazards based on the GPS displacement waveform derived from real-time precise point positioning (RTPPP). Fang *et al*, (2014) analyzed a set of 1 Hz GPS data collected from some Network around the M_w 7.2 El Mayor-Cucapah earthquake of 2010 April 4th. They obtained the time-series of GPS stations coordinates in the global reference frame ITRF2008. In order to better analyze the accuracy of the horizontal and vertical components, they converted the coordinates from a global Cartesian system into a local coordinate system (east, north and vertical). The model used was the GPS displacement waveform which determines the horizontal peak displacement amplitude;

$$\text{Hpd} = \sqrt{E^2 + N^2} \quad 1.1$$

Here *E*, *N* are the east and north components of the displacement from the RTPPP results.

To determine the magnitude using GPS displacement waveforms;

$$M_o = \mu s A \quad 1.2$$

where μ is the shear modulus, *s* is the mean slip on the fault and *A* is the area of the fault plane. Then, the moment magnitude M_w is calculated from the seismic moment using;

$$M_w = \frac{2}{3}(\log M_o - 9.1) \quad 1.3$$

where M_0 is the moment measured in Nm. The moment magnitude is directly related to a physical property, *s* is the mean slip obtained from GPS data. The results after analysis by Fang *et al* (2018) reported that RTPPP achieved an accuracy of 1 cm in horizontal components and 2–3 cm in vertical components. These indicated that the displacement waves in horizontal components were capable of estimating the earthquake magnitude.

Kistler, Brockmann, Condamin, Schlatter and Wiget (2016), monitored rock movements in Gotthard region of Switzerland. This monitoring was done with GNSS observation and interferometric analysis. The ENVISAT satellites datasets from 1992 to 2010 was used. The GNSS measurements was carried out both on static and RTK real time. Each point was observed two times with two different GNSS receivers at different times in RTK mode. It was observed using the Swiss Positing Service swipos while selected points were well distributed all over the monitoring area. Cognizance were given to position and height data in a way that, the nearest continuously operating reference (COR) station that used used were 16, 39, 41 and 43 km away. The position displacement results obtained were in the range of 2 to 3 cm.
The work by Kistler *et al*, (2016) compared modelling displacements using GNSS-RTK and the time series analysis displacements from 1933 to 2015 using the interferomeric analysis. The GNSS measurements show slightly higher rates with 7 to 8 mm/year in comparison to the SAR rates with 5mm/year. The empiric accuracy of the GNSS displacement rates (confidence interval 95%) was between ± 1.6 and ± 2.5 mm/year for the epoch 2003 – 2015.

Casula, Dubbini and Galeandro (2007) measure Terra Nove Bay's crustal deformation. Casula *et al* (2007) noted that by incorporating many technical facilities and models, the quality of data from modern dual frequency receivers could be enhanced. So, GNSS technology was deployed for the purpose of improving GPS results through the modeling of outliers. In the processing of obtained GNSS data, the Gamit / Globk 10.2-3 GPS research software as used by Herring *et al*., (2006) was deployed. The whole procedure provided displacements and velocities closely comparable with their error ellipses of 1-2 mm/yr of noise and the vertical displacement was between 1-2 mm/yr.

Hohensinn, Haberling and Geiger (2020) wrote that, Global Navigation Satellite System (GNSS) receivers could provide displacements in few millimeters accuracy. Hohensinn *et al*, (2020) mentioned also that the GNSS receivers could be used for disciplines that monitor dynamic movements, like seismology or structural health monitoring.

Hohensinn *et al*, (2020) focused on the detection of small vibrations with amplitudes down to sub-millimeter level. The methodology used was compatible with time series analysis. The parametric time series models of the ARIMA (Autoregressive Integrated Moving Average) type was used to characterize the GNSS errors. A pre-filtering, centered on a calibrated model was deployed with a non-parametric spectral estimation methods like periodograms.

Hohensinn *et al*, (2020), tested for the presence of harmonic (sinusoids) movement in the data and was detected;

$$\chi_2^2 = \frac{\ell_n}{\sigma_y^2} \quad 1.4$$

By this, its amplitude and phase were estimated through the use of harmonic regression process. After the processing, it was shown that it is possible detect vibrations down to a level of tens of microns with few minutes of data being analyzed. Hohensinn et al, (2020), showed the potential of GNSS 100 Hz data to detect vibrations of tens of microns amplitude with a dataset length of hundred seconds.

Mustafa and Abdalla (2018) used satellite positioning measurements based on global navigation satellite systems (GNSS) to determine the horizontal displacements over old triangulation network. The method used was quite simple such that, it simply involved correcting of control points relative to the ones obtained with GNSS in a GNSS reference system.

Mustafa and Abdalla (2018) explained that the triangulation method was established by observations carried out based on angular measurements between the points using theodolites. The comparison with GNSS was considered to be more suitable than other conventional methods because with GNSS there is no distance inconsistencies unlike the triangulation measurements.

Mustafa and Abdalla (2018) evaluated the network baselines using the ratio-test criterion and root mean square (RMS). The cutoff ratio was set for values equal or greater than 1.5. RMS shows the high quality of the measurements over the entire network with maximum RMS of less than 2 cm. The average horizontal displacement in the control points is 8 mm to the East direction and 1.8 cm in the North direction. The final results show that there was average displacement of about 60 cm in the horizontal direction.

Subsidence is a vertical displacement because it has to do with downward movement of the surface of the earth. According to Guma (2015), subsidence is the downward movement of the ground as a result of underground material movement. It is most often caused by the removal of water, mineral resources out of the ground by pumping, fracking, oil, natural gas, or mining activities. Subsidence can also be caused by natural events such as earthquakes, soil compaction, glacial isostatic, erosion, sinkhole formation, and adding water to fine soils deposited by wind.

Leal (1989) observed that the simplest way to estimate subsidence is by differencing the last orthometric height and the first epoch orthometric height in GPS observation depending on the epoch interval.

$$h_2 - h_1 = V.dp \quad 1.5$$

Where,

h_1, orthometric height at the first epoch

h_2, orthometric height at the second epoch

Chang (2008) provided an absolute model that has been used to determine vertical deformation

$$\partial H_{12} = (h_2 - N) - H_1 \quad 1.6$$

Where dH_{12} is the vertical displacement value, h_2 is GPS height value, N is the geoidal undulation and H_1 is the orthometric height value.

III METHODOLOGY

Data Acquisition.

Observations for data acquisition were made on **Static** mode with Hi-Target single frequency receiver. The single receiver occupied each of the stations for one (1) hour. The time of the first phase of observation was February, 2020. Before observation at each station, temporary adjustment use to be carried out. This include; the setting up of the GPS receiver on the observation point. Centring with optical plummet to focus on the intersection that defines the middle of the ground point. Then, the foot screws attached with the tribrach were turned simultaneously to bring the spirit bubble to the centre of its run. After this, the height of instrument would be taken by measuring from the tip of the iron rod on the ground point to the Trunnion axis as identified on the receiver head. The data logger would be put on and the connection between the receiver and data logger would be made through their inbuilt Bluetooth system.

On the data logger, the “iHandy” app would be launched and navigate to “PROJECT” then, to “STATIC”. The point ID would be entered, the time lag for capturing was set at 5 seconds. The Antenna mask was left at 15^0 would be entered. Then after which observation would be "OK" to start acquiring satellite data. At every 5 seconds, the receiver beeps to indicate that, it was capturing data. At exactly 60 minutes, the data logger is stopped and automatically the received data from satellite are stored in the memory of the receiver. This procedure was repeated at all the observation points.

A total of 14 stations were observed in this campaign. At Obajana, there were 3 observation points with the following Prefixes; PHD 016, PHD 017 and PHD 018. The observation point PHD 017 is located close to the mining site of dangote cement factory in Obajana.

The first phase of the observations started on the 22nd February, 2020 and by 29th of February, 2020, all the first phase of observations were over. On the 22nd, KGY 021, PHD 010, PHD 006 and PHD 008 were observed. On the 23rd of February, 2020 PHD 007, PHD 001. The next one was observed on the 27th of February 2020 was PHD 011. On the 28th of February, LM 130, PHD 021, PHD 023 and PHD 024 were observed. The last points were the Obajana points which were observed on the 29th of February, 2020, and they are PHD 016, PHD 017 and PHD 018.

The second phase of observation that was used in the formula was carried out in February, 2021. All the stations were observed except station PHD 010 that was destroyed because of an ongoing construction work.

Post Processing of raw GNSS data and Results

The raw GNSS data observed were downloaded from the receiver and uploaded to Canadian Natural Resources Post-Processing online Solution (CSRS-PPP) and the results obtained are displayed in tabular form for the various intervals of observation.

Table 1.1: The PPP results for February, 2020

S/N	20-Feb			
	STN ID	**EASTING (m)**	**NORTHING (m)**	**ELLIP HGT**
1	PHD 001	**252506.448**	**872471.814**	**74.902**
2	PHD 006	**252670.394**	**868382.856**	**79.449**
3	PHD 007	**249303.245**	**862100.665**	**81.823**
4	PHD 008	**251812.304**	**864381.901**	**66.794**
5	PHD 010	**250094.703**	**868113.602**	**84.301**
6	PHD 011	**241153.682**	**843998.099**	**87.632**
7	PHD 016	**217416.604**	**881042.205**	**232.363**
8	PHD 017	**218015.872**	**883422.256**	**268.713**
9	PHD 018	**217698.872**	**882087.851**	**249.117**
10	PHD 021	**246109.945**	**864605.587**	**114.687**
11	PHD 023	**240464.990**	**863692.444**	**151.738**
12	PHD 024	**239193.685**	**864424.162**	**136.961**
13	KGY 021	**250995.696**	**867315.777**	**91.540**
14	LM 130	**245327.140**	**863497.840**	**91.337**

Table 1.2: PPP result for February, 2021 SPP Observations.

STN ID	EASTING	NORTHING	HEIGHT
KGY 021H	250995.734	867315.732	89.994
LM 130H	245327.140	863497.828	91.259
PHD 001H	252506.491	872471.823	74.842
PHD 006H	252670.505	868382.891	79.384
PHD 007H	249303.325	862100.626	81.883
PHD 008H	251812.334	864381.899	66.761

PHD 010H			
PHD 011H	241153.662	843998.130	87.725
PHD 016H	217416.606	881042.204	232.336
PHD 017H	218015.899	883422.248	268.714
PHD 018H	217698.895	882087.844	249.143
PHD 021H	246109.949	864605.568	114.703
PHD 023H	240464.918	863692.439	151.789
PHD 024H	239193.763	864424.186	137.136

Note: In the last table, PHD 010H was not observed because the observation point was removed by road construction truck.

IV PROCESSING OF DATA

Data Processing for Horizontal displacement

For the horizontal displacement in the Easting and Northing direction, the formula for peak displacement by Fang *et al*, (2014) was deployed;

$$H_p = \sqrt{\Delta E^2 + \Delta N^2} \qquad 1.7$$

The co-seismic displacement as estimated are between February, 2020 and February, 2021. The results are presented in table 1.3. The ΔE and ΔN are obtained from the differencing of February, 2020 and February, 2021 coordinates. Therefore, to determine the horizontal displacement that may have occurred between February 2020 and February 2021, we have;

For point PHD 001 between February 2020 and February 2021, we have;

ΔE = 0.043

ΔN =0.009

$D_p = \sqrt{0.043^2 + 0.009^2}$ = 0.043931m

The same procedure was carried out to determine the displacements for every other points.

Table 1.3: Horizontal Displacement results for all points.

STN ID	ΔE(m)	ΔN(m)	PEAK DISPLACEMENT(m) $D_p = \sqrt{\Delta E^2 + \Delta N^2}$
PHD 001	0.043	0.009	0.043931
PHD 006	0.111	0.035	0.116387
PHD 007	0.080	-0.039	0.089
PHD 008	0.03	-0.002	0.03
PHD 011	-0.02	0.031	0.03689
PHD 016	0.002	-0.001	0.002
PHD 017	0.027	-0.008	0.00563
PHD 018	0.023	-0.007	0.024
PHD 021	0.004	-0.019	0.003883
PHD 023	-0.072	-0.005	0.07217
PHD 024	0.078	0.024	0.081605
KGY 021	0.038	-0.045	0.0588982
LM 130	0.00	-0.012	0.012
**PHD 010	-0.099	-0.066	0.118983

Note: **PHD 010 have their vertical displacements and peak horizontal displacement estimated for 9 months interval because the point was destroyed as a result of construction work ongoing around the point area.

Data Processing for Vertical displacement

The Ellipsoidal heights were part of the data obtained from the CRSC-PPP online post processing results of points observed. The online Geoid Height Calculator was used to generate the geoidal undulations (N) and the orthometric heights (H). Table 1.4 and table 1.5 shows the various heights obtained for both phases of observation.

Table 1.4: Orthometric, Geoid and Ellipsoidal heights of February, 2021.

STN ID	Ellipsoidal Height (m)	Geoidal Undulation(m)	Orthometric Height (m)
PHD 001	74.842	23.274	51.568
PHD 006	79.384	23.220	56.164
PHD 007	81.883	23.135	58.748
PHD 008	66.761	23.164	43.597
PHD 011	87.725	22.948	64.777
PHD 016	232.336	23.295	209.041
PHD 017	268.714	23.289	245.425
PHD 018	249.143	23.293	225.85
PHD 021	114.703	23.167	91.536
PHD 023	151.789	23.164	128.625
PHD 024	137.136	23.172	113.964
KGY 021	89.994	23.203	66.791
LM 130	91.259	23.156	68.103
**PHD 010	82.627	23.211	59.416

** PHD 010 was observed for just 9 months because the point was destroyed during an ongoing construction exercise.

Table 1.5 contain heights obtained for February, 2020 observation. The heights were obtained from online Geoid Height Calculator.

Table 1.5: Heights for February, 2020.

STN ID	Ellipsoidal Height (m)	Geoidal Undulation(m)	Orthometric Height (m)
PHD 001	74.902	23.274	51.628
PHD 006	79.449	23.220	56.229
PHD 007	81.823	23.135	58.688
PHD 008	66.794	23.164	43.630
PHD 010	84.301	23.211	61.090
PHD 011	87.632	22.948	64.684
PHD 016	232.363	23.295	209.068
PHD 017	268.713	23.289	245.424
PHD 018	249.117	23.293	225.824
PHD 021	114.687	23.167	91.520
PHD 023	151.738	23.164	128.574
PHD 024	136.961	23.172	113.789
KGY 021	91.540	23.203	68.337
LM 130	91.337	23.156	68.181

This research used the formula deployed by Leal (1989) to obtain the vertical displacement;

$$h_2 - h_1 = V.dp \qquad 1.8$$

The vertical displacements for each point were computed for. The point PHD 001 was computed as thus;

$h_{2021} - h_{2020}$. where h_{2021} is the orthometric height for PHD 001 on February, 2021 and it is 51.568m. h_{2020} is the orthometric height obtained in February, 2020 which is 51.628m.

$$h_{2021} - h_{2020} = 51.568 - 51.628 = \mathbf{-0.06}\boldsymbol{m}$$

The same procedure was followed to determine the displacements on other observation points as can be seen in table 1.6.

Table 1.6: Vertical displacement results for each station point.

STN ID	h_2 orthometric Height (m) Feb, 2021	h_1Orthometric Height (m) feb, 2020	Vertical displacement= $h_2 - h_1$ (m)
PHD 001	51.568	51.628	-0.06
PHD 006	56.164	56.229	-0.065
PHD 007	58.748	58.688	0.06
PHD 008	43.597	43.630	-0.033
**PHD 010	*59.416*	61.090	-1.674
PHD 011	64.777	64.684	0.093
PHD 016	209.041	209.068	-0.027
PHD 017	245.425	245.424	0.001
PHD 018	225.850	225.824	0.026
PHD 021	91.536	91.520	0.016
PHD 023	128.625	128.574	0.051
PHD 024	113.964	113.789	0.175
KGY 021	66.791	68.337	-1.546
LM 130	68.103	68.181	-0.078

Note: **PHD 010 was observed for 9 months.

V. RESULT AND DISCUSSION

Discussion of Results

The horizontal displacement were in centimeter and millimeter level. From the horizontal displacement table, we could see that the displacement is more in the easting direction and less in the Northing direction. The overall displacement are in centimeter level for all the points observed.

More so, after simulating the vertical displacement formula, the values obtained were in centimeter range in the period of one year observations. The results after differencing the February, 2021 and February, 2020 for all the observation points were; -0.06m, -0.065m, 0.06m, 0.033m, -1.674m, 0.093m, -0.027m, 0.001m, 0.026m, 0.016m, 0.051m, 0.175m, -1.546m, -0.078m. This can only be estimates and not exact enough because a global geoid EGM 08 was used in the absence of a regional geoid.

VI. CONCLUSION AND Future scope

The displacements of the various points show that a lot happen in between one to two epoch of observations. The displacements as observed, showed some millimeter and centimeter level accuracy. Vertical displacements were determined but the results were in negative and positive values. This means that displacements and vibrations also affected the vertical movement of the points of observations.
In the nearest future, the geoid heights of all the regions of this country is advised to be determined because, reliance on global geoid may not provide accurate height information than the regional geoid.

Challenges encountered

The challenges that were faced in this research work can be summarized as security and pandemic. They are itemized below;

i. Initially the controls were labelled from PHD 001 to PHD 030 including the KGY 021 and LM 130 which are control points at strategic locations. Some of the points could no longer be accessed for observations because of the increased kidnapping cases in Kogi State. Kidnapping became so rampart that some of these observatory points have to be abandoned. The few that were observed especially in Obajana areas were accessed on Lokoja market days. It was discovered that on market days, the roads become too busy for kidnappers to operate and so, it became an advantage.

ii. During the peak of the COVID-19 Pandemic, there was this conspiracy theory of 5G network causing or accelerating the spread of the pandemic. So, in Adavi Local Government Area, there were records of harassments and threats to lives that our team was installing COVID-19 5G networks. Awareness from the crew members to the community was productive.

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