International Journal of Academic Multidisciplinary Research (IJAMR)
ISSN: 2643-9670
Vol. 8 Issue 3 March - 2024, Pages: 146-154

Assessment of the Integrity of the GNSS-PPP Heights Data Acquired for the Monitoring of Earth's Dynamism in Benue Trough, Kogi State

Negedu, Achimugu Amos[1] and Ono, Mathew Nnonyelu[2]

[1]Bureau of Lands and Housing Development, Lokoja, Kogi State
[2]Department of Surveying and Geoinformatics, Nnamdi Azikiwe University, Awka, Anambra State

Email of corresponding Author: gumawelfare@gmail.com (+2348064468848)

Abstract: *There is need for assessment of the integrity of the heights generated using GNSS-PPP to enable users have confidence on their accuracy level. GNSS-PPP is dependent on some traditional corrections obtained from global reference stations scattered all over the world. Upon the actualization of these corrections, the receiver positions are greatly improved in terms of accuracy. GNSS observations were carried out on 11 observation points with the multi-frequency v30 Hi target instrument on the static mode. The observations were made at an epoch of 30 seconds for a period of one hour to one hour thirty minutes per station. On completing the satellite data observations, the acquired GNSS raw data were downloaded using a USB cable to the laptop. Subsequently, the GNSS raw data were converted to RINEX using the Hi-target Geomatics office software. The RINEX data converted were then, uploaded to Jason cloud Robukun online post processing solution (robukun.cat/Argonaut-paas-2/). That was where the data processing was carried out online. An online standard deviation calculator was deployed for quick computation and it was obtained from https://www.calculator.net/math/standard-deviation. This online calculator tool does the computation of confidence interval also. The geographical coordinates were uploaded individually and separated each with a comma and submitted. Same was done for the height data each. After sending, the results came back and displayed. The results of standard deviations of the various stations were in millimeters except for some points surrounded by canopy trees, mountains and buildings.*

Keywords: GNSS, PPP, RINEX, standard deviation, accuracy.

1.0 INTRODUCTION

Global Navigational Satellite System-Precise Point Positioning (GNSS-PPP) is a positioning technique that eradicates GNSS errors to deliver a much higher accurate positioning result using a single receiver (Guma *et al.*, 2023: Novatel, 2024). PPP is dependent on some traditional corrections obtained from global reference stations scattered all over the world. Upon the actualization of these corrections, the receiver positions are greatly improved in terms of accuracy. Just like the general Global Positioning System, the PPP technique delivers its corrections to the receiver which increases its positional accuracy. The PPP technique converges within 20 to 30 minutes and with this time, it attains full accuracy. The accuracy attained is a function of the quality of the corrections and their applicability in the receiver. With PPP an accuracy of to 2.5 cm (0.98 inch) is possible coupled with some progressive corrections and good instrumentation.

There are different types of GNSS observation and they include; the absolute observation and the relative (He *et al.*, 2021: Martinez *et al.*, 2021). The relative GNSS positioning is prone to errors from base or reference stations and no one knows the magnitude of errors it usually transfers (Gao, *et al.*, 2018: Kouba and Heroux, 2001). Kouba *et al*., (2017) explained that the absolute GNSS observation could either be Single point positioning (SPP) or the precise point positioning (PPP). The PPP has become so popular these days because using the technology has assisted Surveyors to have data that are less inaccurate because precise positioning has the capability of modeling and correcting the receiver clock errors, atmospheric and tropospheric errors as well (Guma *et al.*, 2023). The PPP technique also has been useful in the meteorological sector for it provides data for estimation of precipitated water vapour in the atmosphere via the use of the single receiver; the data obtained are always at high degree of accuracy for that, it makes its applicability in airborne mapping and other engineering works easy (Handoko, *et al.,* 2021).

Zumberge *et. al.*,(1998) mentioned that, one of the advantages of the PPP technique is that it involves just one GNSS receiver and so, observers are not obliged to reference to any ground local base station. With this regards, it eliminates the problem of concurrently observing both the rovers and base receivers (Petovello, 2018). The PPP technique has been regarded as a global positioning technique since the results are tied to a global reference frame. So on this regard, PPP provides its coordinates to users on higher degree of accuracy and precision. More so, the PPP has improved geometry and convergence time to about 20 to 30 minutes (Galala, 2018: An *et al*., 2020). Lastly the technology has dual frequency observation which helps in coming up with ionosphere-free linear combination of original observations thus doing away with the effects of ionosphere (Ovstedal, 2002).

In terms of ensuring reliability of data, the PPP technique analyzes the quality of any data through precision accountability since it is referenced to a global datum. In contrast to kinematic technique, the PPP has been providing high accuracy positioning with higher flexibility and low expenses (Guo, et al., 2018: Guma et al., 2023). It is very difficult to identify errors when using relative positioning technique because local errors could be distributed without knowing but, the only way to detect these errors is by applying PPP which is global based (Novatel, 2020). This study is to help provide confidence in the reliability of the results of PPP techniques. Just like Guma *et al*., (2023) pointed out, that the accuracy of GNSS-PPP is in millimeters and centimeters range so, experts should prefer its use to that of handheld receivers.

There is need to demonstrate the quality of PPP results statistically with respect to its usage in, around, and beyond the study areas. The high cost of GNSS receivers could affect positioning; and accurate positioning is responsible for proper planning and development (Ezeomedo, 2019). The cost of recalibrations and maintenance of these receivers have never been economically encouraging. Hence, this research aims at assessing the integrity of the GNSS-PPP coordinates with the objective of establishing GNSS-PPP heights accuracy.

1.1 Accuracy determination tool

Guma *et al.,* (2023) highlighted 2 statistical formulas for assessing the accuracy of every redundant observation and they are the confidence interval and the standard deviation. The authors discussed that, confidence interval gives the estimate of the precision of a sample size and it illustrates the quality observations. The confidence interval formula that was used was designated as;

$$CI = \bar{X} \pm t * \sigma\sqrt{n} \qquad 1$$

Where CI is the confidence interval, X is the mean of observation, t∗ is the critical value of the t distribution, σ is the standard deviation and √n is the square root of the population size when the formula was used on the sets of observations.

In describing the standard Deviation, the authors analyzed the accuracy and precision of observation data with the formula. It was pointed that as the standard deviation of any set of observation increases, the dispersion from the mean also increases. The formula that computes the standard deviation was displayed as;

$$\sigma = \sqrt{\frac{\sum(X-\mu)^2}{N}} \qquad 2$$

Where σ is the Standard deviation, $\sum(xi - \mu)2$is the sum of square of the differences between the mean and the individual values and N is the number of observation times. However, equation 2 is for the total population of the data.

Feldman (2023) explained that, when performing statistical analysis, it is almost impossible to bring all the acquired data together so, sample the data would be the next best point of usage.
Feldman (2023) explained that, a sample is a group of data selected from a larger data for the making of analysis about that larger data. Sample data are deployed when it is almost not practicable to study an entire data. As pertaining the advantage of using the sample data of any observation, it was gathered that it saves time and money, allows for more meaningful data, simplifies measurement over time, can improve accuracy.

The formula designated for standard deviation of the sample data is;

$$\sigma = \sqrt{\frac{\sum(X-\mu)^2}{N-1}} \qquad 3$$

2.0 GNSS-PPP Height accuracy

Chen (2023) wrote that, PPP compared with RTK technology, could achieve centimeter-level high-precision positioning both in Easting, Northing and height values. The PPP technique takes care of three kinds of error sources like orbit error, satellite clock error and ionospheric delay. Chen (2023) also summarized that the accuracy of the PPP depended on 4 factors which are; convergence time, the quality of correction data the satellites broadcast, the surrounding environment of receiver and finally, PPP Filter Algorithms. Abdallah and Schwieger (2014) conducted a comparison between the accuracy and the time of initialization PPP solutions with Differential GPS (DGPS) technique. The processing was estimated by means of GIPSY-OASIS software and CSRS-

PPP online services. PPP solutions were assessed with different periods of times of initialization. The OASIS software and CSRS-PPP online solution produced a RMSE of 10 cm from 10 minutes initialization time on the X, Y, Z coordinates. Again, Abdallah and Schwieger (2014) conducted a second observation process which lasted for 20 minutes, after the processing was performed with CSRS-PPP, a RMSE of 5 cm in horizontal coordinates were obtained and a less than 15 cm in height direction was obtained too during just 10 minutes convergence time.

Precise point positioning (PPP) is highly dependent on the precise ephemerides and satellite clock products that are used (Petovello, 2018). Mohammed, Moore, Hill and Bingley (2018) stated that for effective use of PPP, different ephemeris and clock products were used. The height accuracy was at millimetre level therefore, it had been established that the accuracy of the zenith component in every observation is system dependent and associated to the effectiveness of antenna phase.

Guma *et al.*, (2023) mentioned that, height is an important component especially in route design, deformation monitoring and terrain model analysis. The authors obtained their geoidal undulation values of EGM 2008 via GeoidEval utility online software. The root mean square (RMS) computed during the interpolation that came about the EGM 2008 geoid values were within the range of 1mm. After a field work where some redundant observations were made, the redundant observations for five stations had a standard deviation of 0.003m respectively. The results of the observations revealed that height accuracies at 95% confidence level are 0.0026m. Guma *et al.,* (2023) also concluded that, EGM 2008 geoid should be used only when working on short distances.

In trying to improve the GNSS PPP accuracy through WVR PWV augementation, Wang and Liu (2019) both the GPS and GLONAS observations were integrated and there was a root mean square of 1mm which showed an increase in their accuracy by 5% in the vertical component.

Teunissen, (2021) wrote that, the Precise point positioning (PPP) is a satellite modeling and positioning technique that uses pseudorange and carrier-phase observations, together with precise orbit and clock products, for single-receiver static observation. It is a great option to the well-known differential GNSS positioning. As PPP depends on accurate satellite position and clock data for post-processing. The increase in the navigation satellite systems couple with the availability of more satellites conveys a series of advances for PPP. Multi-frequency and developed the models for noise resolution has reduced the long PPP convergence periods. PPP has been adjudged very good for precise positioning, application for water vapor estimation, ionospheric estimation, time and velocity.

Rademakers *et al.,* (2016) stated that, autonomous vehicles need accurate positioning always and this accurate positioning is achievable when relating multiple positioning techniques with GNSS-PPP inclusive. This combination has always produced sub-meter position accuracy. The authors developed a low cost solution in Matlab called Single Frequency Precise Point Positioning (SF-PPP). This kind of PPP combination technique was validated with focus on open area. As for the open area a horizontal root mean square error (RMSe) of 0.5 m was achieved

Alkan *et al.,* (2020) was motivated to assess the accuracy performance of the real-time global GNSS PPP positioning service, i.e. Trimble CenterPoint RTX, and online PPP post-processing service, i.e. CSRS-PPP. The acquired raw GNSS data were uploaded to the CSRS-PPP online solution and the coordinates were returned calculated. It was shown that the 3D coordinates achieved were in centimeter-level.

Gurturk and Soycan (2022) explained that the precise point positioning (PPP) technique has become an alternative method to post-processing kinematic (PPK) technique in the assessment of GNSS data. In their study, GNSS data were acquired from two different flights and were processed with different software such as RTKLIB, gLAB, CSRS-PPP and GRAFNAV. The Three-dimensional (3D) positioning coordinate demonstrated accuracy between 0 and 6 cm for both kinematic PPP and PPK techniques.

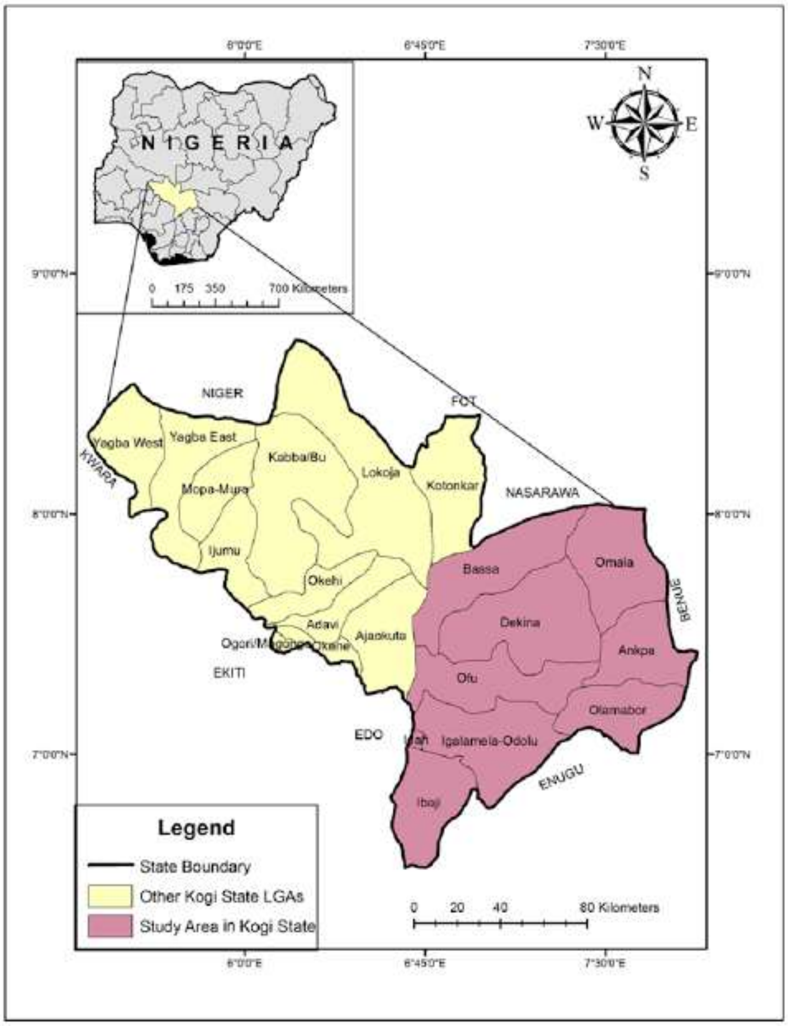
3.0 METHODOLOGY

3.1 Overview of Study area

The study Areas are eastern senatorial district of Kogi State. The area cover Latitudes 07 20’ and 08 00’N and longitudes 06 30’ and 07 45’E. The carefully chosen towns are Dekina L.G.A (Anyigba and Dekina), one station in Ofu L.G.A, one station in Ankpa L.G.A, one station in Omala L.G.A, three stations in Lokoja L.G.A. The geoid monuments were spread across the six Local Governments in all. Ekwedeh (2003) related that, the Vegetation spread in Kogi east are in a pattern of rainfall distribution, tropical wet and dry or savannah climate of AW classification. The rainy season is same for the whole State. It starts around April and lasts till October and the dry season usually starts from November and extends to March of the following year (Weather base, 2011). Kogi east as a whole do record an annual rainfall of between 1100 to 1300mm per annum and the climate condition of the area is usually affected by two main air masses such as the tropical maritime and the tropical continental (Ocholi, 2007).

Ukabiala (2019) intimated also that, the monthly temperature of the whole Kogi East varies between 17 and 36ºC. The highest temperature 36ºC has been occurring only during the dry season while the mean relative humidity is lowest during the dry season and highest during rainy season of the year. The entire region of Kogi east senatorial district has a mean annual temperature of 24^0C. 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 Kogi State and Kogi State showing Kogi east in colour red accent 2.



Source: https://www.researchgate.net/map-of-Kogi-east, Negedu and Ono (2024).

3.2 Data Acquisition

This study used both hardware and software instrument to achieve its aim. The Hardwares used for the GNSS data acquisition and processing include; Hi target V.30 dual frequency GNSS receiver and its accessories, Data logger, HP Laptop and internet facilities. Whereas the Softwares used included; Arc-GIS, Google map, microsoft word, Microsoft excel, Hi-target Geomatic offices software, Jason cloud robukun online software (robukun.cat/Argonaut-paas-2/) website and online Geoid Eval Calculator.

The instruments were tested for good functionality and all its components were in good working condition. The Hi-target V30 GNSS receiver calibration status was tested before use. Temporary adjustment which include setting up, centering and leveling up on a station with all necessary connections were performed on the Hi-target GNSS receiver. After the receiver was powered on, checks were made on the satellite tracking and observation ability of the receiver and it was in perfect condition.

This fieldwork only acquired primary data and they include the Northings, Eastings and Ellipsoidal heights of the various points earmarked for the observation on the study areas.

3.2.1 Acquisition of Primary data (GNSS Measurement)

GNSS observations were carried out on 11 observation points with the multi-frequency v30 Hi target instrument on the static mode. The observations were made at an epoch of 30 seconds for a period of one hour to one hour thirty minutes per station. On completing the satellite data observations, the acquired GNSS raw data were downloaded using a USB cable to the laptop. Subsequently, the GNSS raw data were converted to RINEX using the Hi-target Geomatics office software. The RINEX data converted were then, uploaded to Jason cloud Robukun online post processing solution (robukun.cat/Argonaut-paas-2/). That was where the data processing was carried out online.

4.0 Data processing

The standard deviation formula for sample data was used in this case to determine the accuracy of the data acquired. See equation 3. The reason for the equation 3 was to ascertain what Feldman (2023) wrote as improving the accuracy of the measurement.

4.1 Statistical analysis for accuracy of observation

In this study, the standard deviation tool was used to compute for the accuracy of the sample data of GNSS-PPP observations. Excerpt of the observation raw data of one of the stations named _LOKOJA is going to be used to determine the accuracy of the data. The same procedure applies to other stations as well. Redundant observation coordinates in the form of longitude, latitude and height of point _LOKOJA were the data used.

4.1.1 Analysis using standard deviation of sample population of the data

The best way to determine the accuracy of this observation is through the GNSS raw data for each point observed. The total number of redundant observation recorded by the GNSS receiver at point _LOKOJA is close to about 296 pages. But for the purpose of this analysis some sample were extracted and shown in table 4.1. The other points too, were of the same. They are about 296 pages and some more. Our main points of reference are latitude, longitude and height.

Fig 4.1: raw GNSS of _LOKOJA

GPSW,GPSSoW,	latitude(deg),	longitude(deg),	height(m)
2055,565661.0	7.801951121	6.741476863	84.708,
2055,565662.0	7.801946046	6.741478883	83.647,
2055,565663.0	7.801951499	6.741477228	83.659,
2055,565664.0	7.801950662	6.741477523	83.837,
2055,565665.0	7.801946992	6.741474391	82.921,
2055,565666.0	7.801948664	6.741477278	83.500,
2055,565667.0	7.801946725	6.741477331	83.096,
2055,565722.0	7.801948853	6.741480940	83.485
2055,565723.0	7.801951780	6.741485979	85.000

4.2 Standard deviation of _LOKOJA

The GNSS results for the _LOKOJA were collected and tabulated as seen in tables 4.1. The sample data mean was first obtained and then, the standard deviation followed suit. The mean was determined using the following formula;

$$\bar{X} = \frac{\sum x}{N} \qquad 1.$$

The standard deviations of the sample data was determined using;

$$\sigma = \sqrt{\frac{\sum(x_i) - \mu)^2}{N-1}} \qquad 2.$$

An online standard deviation calculator was deployed for quick computation and it was obtained from https://www.calculator.net/math/standard-deviation. This online calculator tool does the computation of confidence interval also. The geographical coordinates were uploaded individually and separated each with a comma and submitted. Same was done for the height data each. After sending, the results came back and displayed. For station _LOKOJA,

5.0 RESULT AND DISCUSSION

5.1 Results

International Journal of Academic Multidisciplinary Research (IJAMR)
ISSN: 2643-9670
Vol. 8 Issue 3 March - 2024, Pages: 146-154

The results of the standard deviation of the latitude, longitude and height are shown in table 4.2 to 4.12 as sdn (m), sde (m) and sdu (m) respectively.

Table 4.2: The standard deviation results for station _LOKOJA.

GPSW	GPSSoW	latitude(deg)	longitude(deg)	height(m)	sdn(m)	sde(m)	sdu(m)
2055	570225.0	7.80194534	6.74146159	84.798	0.015	0.019	0.095

The standard deviations of the latitude, longitude and height data for _LOKOJA were 0.015m, 0.019m and 0.095m respectively. It can abruptly be said in this case that the accuracy is in millimeter level. When these coordinates were converted to plane coordinate using Global Mapper software, the result becomes what is presented below with the various accuracies attached;

250929.71016E ± 0.015
863069.36438N ± 0.019
84.798m ± 0.095

Table 4.3: The standard deviation results for station A0LSG.

GPSW	GPSSoW	latitude(deg)	longitude(deg)	height(m)	sdn(m)	sde(m)	sdu(m)
2055	570225.0	7.80234125	6.74178296	86.476	0.063	0.217	0.162

The standard deviations of the latitude, longitude and height data for A0LSG were 0.063m, 0.217m and 0.162 m respectively. It can be inferred that the accuracy on the northing coordinate is in millimeter level while that of the easting and height are in centimeter. When these coordinates were converted to plane coordinate using Global Mapper software, the result becomes;
250965.40293E ±0.063
863112.97559N ±0.217
86.476m ±0.162

Table 4.4: The standard deviation results for station A05LSG.23o.

GPSW	GPSSoW	latitude(deg)	longitude(deg)	height(m)	sdn(m)	sde(m)	sdu(m)
2055	570225.0	7.74166956	6.74392586	69.010	0.035	0.099	0.116

The result as presented about A05LSG.23o shows some kind of good accuracy because there were no interferences anywhere around. The plane coordinates equivalents are presented below;

251166.07794E ±0.035
856399.38773N ±0.099
69.010m ±0.116

Table 4.5: The standard deviation results for station KL 4569.23o.

GPSW	GPSSoW	latitude(deg)	longitude(deg)	height(m)	sdn(m)	sde(m)	sdu(m)
2055	570225.0	7.77252278	6.74021760	84.954	0.012	0.014	0.077

The result as presented about KL 4569.23o shows some kind of good accuracy because there were no interferences anywhere around. The plane coordinates equivalents are presented below;

250775.05005E ±0.014
859814.96799N ±0.012
84.954m ±0.077

International Journal of Academic Multidisciplinary Research (IJAMR)
ISSN: 2643-9670
Vol. 8 Issue 3 March - 2024, Pages: 146-154

Table 4.6: The standard deviation results for station KL 4570.23o.

GPSW	GPSSoW	latitude(deg)	longitude(deg)	height(m)	sdn(m)	sde(m)	sdu(m)
2055	570225.0	7.77195204	6.74019437	83.735	0.018	0.024	0.120

The result as presented about KL 4570.23o shows some kind of good accuracy because there were no interferences anywhere around. The plane coordinates equivalents are presented below;

250772.14981E ±0.024
859751.83854N ±0.018
83.735m ±0.120

Table 4.7: The standard deviation results for station 9430320.23o.

GPSW	GPSSoW	latitude(deg)	longitude(deg)	height(m)	sdn(m)	sde(m)	sdu(m)
2055	570225.0	7.80213650	6.74168321	86.163	0.761	0.800	0.140

This station 9430320.23o is in the urban cryon of Lokoja so, multipath error has affected the accuracy of the results. However, the plane coordinates as presented may not show these ranges of accuracy. They are;
250954.27578E ±0.800
863090.38223N ±0.761
86.163m ±0.140

Table 4.8: The standard deviation results for station 9431580.19o.

GPSW	GPSSoW	latitude(deg)	longitude(deg)	height(m)	sdn(m)	sde(m)	sdu(m)
2055	570225.0	7.48217426	6.27870940	277.826	2.068	3.425	3.410

The standard deviation on this particular 9431580.19o is in meters. The reason for this is that the point is in surrounded by buildings and power lines which indicate that multipath error have occurred and likewise interferences from communication lines around. Their plane coordinates are;

199639.90867E ±3.425
827981.46831N ±2.068
277.826m ±3.410

Table 4.9: The standard deviation results for station A04LSGL.23o.

GPSW	GPSSoW	latitude(deg)	longitude(deg)	height(m)	sdn(m)	sde(m)	sdu(m)
2055	570225.0	7.77131182	6.74044066	80.799	0.015	0.012	0.043

This station A04LSGL.23o has accuracy in millimeter level and the results of standard deviation shows that, their accuracy is good. The plane coordinates too are presented below;

250798.94821E ±0.012

859680.86357N ±0.015

80.799m ±0.043

Table 4.10: The standard deviation results for station LKJ456S.22o.

GPSW	GPSSoW	latitude(deg)	longitude(deg)	height(m)	sdn(m)	sde(m)	sdu(m)
2055	570225.0	7.77252281	6.74021758	84.834	0.028	0.105	0.103

One of the points in Lokoja urban LKJ456S.22o. The standard deviations are in centimeter level in easting and height coordinate but, the northing is in millimeter.

250775.04786E ±0.103
859814.97132N ±0.028
84.834m ±0.103

Table 4.11: The standard deviation results for station LKJ4569.22o.

GPSW	GPSSoW	latitude(deg)	longitude(deg)	height(m)	sdn(m)	sde(m)	sdu(m)
2055	570225.0	7.77252356	6.74021923	84.802	0.177	0.581	0.553

This part of Lokoja urban has so many interferences that is why the accuracies just reflected same. The accuracies are in centimeter level. The plane coordinates are hereby presented;

250775.23037E ±0.581
859815.05333N ±0.177
84.802m ±0.553

Table 4.12: The standard deviation results for station ODENYI.22o.

GPSW	GPSSoW	latitude(deg)	longitude(deg)	height(m)	sdn(m)	sde(m)	sdu(m)
2055	570225.0	7.78176623	7.05117596	117.089	0.038	0.105	0.134

It was noticed that canopy trees and mountains made up this particular environment that have station ODENYI.22o. The plane coordinates are however presented below;
285088.32393E ±0.105

860666.91952N ±0.038

117.089m ±0.134

Summarily, the coordinates came in geographical however; the software Global Mapper was used to transform them to plane coordinates (Easting, Northing and Height).

6.0 CONCLUSION
The quality of PPP results statistically were assessed in this research work. One of the merits of this paper is to build confidence on the use of PPP or standalone receivers for geoid determination but, the study has established the accuracy of height data for such. This study however did justice to the accuracy determination of the heights and positions of points. With this PPP technique the cost of recalibrations and maintenance of more than receivers will no longer be there. The Surveyor would be rest assured that with one receiver, accuracy is sure. The aim of this paper has been achieved but further research that compare gravimetric method with the 2008 Geoid technique in orthometric height determination may still be explored in the nearest future. It is therefore recommended that this 2008 geoid model be used to distribute orthometric height in places that require earth monitoring, engineering precisions and deformation monitoring.

REFERENCES

Abdallah, A.T. and Schwieger, V. (2014). Accuracy assessment study of GNSS precise point positioning for kinematic positioning. Accessed from https://www.doi.org/10.13140/2.1.2725.6960 0n 8th of February, 2024.

Alkan, R.M., Erol, S., Ozulu, I.M. and Ilci, V. (2020). Accuracy comparison of post-processed PPP and real-time absolute positioning techniques. Geomatics, Natural Hazards and Risk 11 (1), 178-190, 2020. Accessed from htpps://www.tandfonline.com on 8th of February, 2024.

An, X., Meng, X and Jiang, W. (2020). Multi-constellation GNSS precise point positioning with multi-frequency raw observations and dual-frequency observations of ionospheric-free linear combination. Satellite Navigation 1, Article number: 7 (2020). Accessed from https://www.doi.org/10.1186/s43020-020-0009-x on 4th of February, 2024.

Chen, M. (2023). What is the PPP? Tersus GNSS. Accessed from https://www.tersus-gnss.com on 7th of February, 2024.

Ezeomedo, I.C. (2019). Role of land Surveyors and Geospatial Engineers in the built environment. Accessed from https://www.researchgate.net on 6th of January, 2024.

Gurturk, M. and Soycan, M. (2022). Accuracy assessment of kinematic PPP versus PPK for GNSS flights data processing. Survey Review 54 (382), 48-56, 2022.

Guo, J., Li., X, Li, Z., Hu, L., Yang, G., Zhao, C., Fairbairn, D., Watson, D. and Ge, M. (2018). Multi-GNSS precise point positioning for precision agriculture. Springer link, Volume 19, pages 895 – 911, 2018.

Guma, E.P., Bello, A.E., Usman A.A., Salihu A., Isah O.S., Raji S.O., Haruna, A.A., Yakubu, O. M., Negedu, A.A., Ibrahim, B.(2023). Verifying the limitation of GNSS-PPP derived orthometric heights in engineering design using non-rigorous approach. coou African Journal of Environmental Research Vol 4, No. 2, 2023. pp 113-129.Accessed from https://ajer.coou.edu.ng/index.php/journal, on the 11th of February, 2023

Guma, E.P, Raji S.O., Haruna, A.A, Ibiyemi, S., Usman, A.A. and Bello, E.A. (2023). Verifying the Consistency of Precise Point Positioning Controls for Cadastral Surveying. *FUDMA Journal of Sciences (FJS),* Vol. 7 No. 6, December, 2023, pp 200 – 208. Accessed from https://doi.org/10.33003/fjs-2023-0706-2117 on 3rd February, 2024.

Handoko, E.Y., Kurniawan, A., Maulida, P. and Cemara, N.A. (2021). Precipitable water vapor estimated using GPS precise point positioning. *IOP Conference series: Earth and Environmental science 824 (1), 012068, 2021.*

He, K., Weng, D., Ji, S., Wang, Z., Chen, W., Lu, Y. and Nie, Z. (2021). Improving the performance of Time-Relative GNSS Precise Positioning in Remote Areas. Accessed from https://www.mdpi.com on 4th of February, 2024.

Kouba, J., Lahaye, F. and Tetreault, P. (2017). Precise Point Positioning. Springer handbook of global navigation. Accessed from https://www.scholar.google.com on 4th of February, 2024.

Kouba, J. and Heroux, P., 2001. GPS Precise Point Positioning Using IGS Orbit Products, GPS Solutions, vol.5, no.2, pp. 12-28.

Leandro, F. and Santos, M., 2006. Wide area based precise point positioning. Proceedings of ION GNSS 2006, 26–29 September 2006. Fort Worth, Texas, pp. 2272–2278.

Martinez, M.J.J. and Abadia, M.F. (2021). An approach to improving GNSS positioning accuracy using several GNSS devices. Accessed from https://www.mdpi.com on the 4th of February, 2024.

Niell, A., 1996. Global mapping functions for the atmosphere delay at radio wavelengths. J Geophys Res, vol. 101, no. B2, pp. 3227–3246.

Novatel (2024). Precise Point Positioning: Autonomy and Positioning division. Accessed from https://www.novatel.com on 6th of February, 2024.

Ovstedal, O., (2002). Absolute Positioning with Single Frequency GPS Receivers, GPS Solutions, vol.5, no.4, pp. 33-44.

Teunissen, P.J.G. (2021). "GNSS Precise Point Positioning," in Position, Navigation, and Timing Technologies in the 21st Century: Integrated Satellite Navigation, Sensor Systems, and Civil Applications. *IEEE, 2021*, pp.503-528. Accessed from https://www. Doi.org/ 10.1002/9781119458449 on 6th of February, 2024.

Rademakers, E., Bakker, P., Tiberius, C., Janssen, K., Kleihorst, R. and Ghouti, N.E. (2016). Obtaining real-time sub-meter accuracy using a low cost GNSS device. 2016 European Navigation Conference (ENC), 1-8, 2016. Accessed from htpps://www. ieeexplore.ieee.org on the 8th of February, 2024.

Wang, J. and Liu, Z. (2019). Improving GNSS PPP accuracy through WVR PWV augmentation. Journal of Geodesy 93 (9), 1685-1705, 2019.

Zumberge, J., Heflin, M., Jefferson, C., Watkins, M. and Webb, F., 1998. Precise Point Positioning for the efficient and robust analysis of GPS data from large networks, J. Geophysical Research, vol.102, no. B3, pp. 5005-5017.