

An Assessment of CORS Measurements Uncertainty from Single- and Dual-Frequency GNSS Receivers

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ABSTRACT

The establishment, densification, and integrity assessment of survey control networks are critical components of geodetic infrastructure management. Often, such survey beacons are subjected to accuracy analysis, comparisons of parameters, and choice of receivers before being transferred. This study examines the performance of seven established second-order geodetic infrastructures within Bells University of Technology, Ota, using Trimble R10 with four sets of redundant observations per station from NS L10 – a first-order Nigerian geodetic station located at Arakanga Village, Odeda Local Government Area, Ogun State. To achieve this goal, four stations were selected thereafter for GNSS uncertainty measurements using single and dual frequency receivers with a minimum of two hours of occupation per station for three epochs per day: morning, afternoon, and night with reference to three Continuous Operating Reference Stations (CORS) (ACLA, Sacredion, and Quest). The results revealed that ACLA and Quest CORS, have 100% correlation with the established controls in Easting and Northing. The choice of receiver does not greatly influence the X and Y values of the receivers' position. In addition, for verification of Dual Frequency Trimble R10 data consistency, three sessions of observation were made at one hour, four hours, and eighteen hours on three other controls, and the results were compared. Furthermore, the results obtained corroborated the accuracy of parameters estimated from geodetic-grade receivers and do not differ significantly from each other when these are required for precise scientific applications. However, standard errors of $\pm 3\text{m}$ and $\pm 6\text{m}$ were respectively obtained for Sacredion CORS in this study. The outcome of this study will therefore aid stakeholders in the geomatics industry in the quest for adequate integrity checks of geodetic infrastructures.

Keywords: Geodetic infrastructure, Continuously Operating Reference Stations (CORS), GNSS receivers, Measurement uncertainty, Single- and dual-frequency

1.0 Introduction

Global Navigation Satellite System (GNSS) sources data from hundreds of certified International GNSS Service (IGS) reference stations throughout the globe for precise positioning services and have been used in military, and for civic and commercial purposes. Moreover, a record of phenomena such as tectonic deformation, earthquakes, groundwater depletion, and slow-moving landforms from static GNSS with extended observations offers a sustainable mitigation scheme globally. GNSS has made it possible for surveyors to create and establish control for a project from known and existing control that is kilometers away. Consequently, higher-order survey control markers are crucial to the integrity of the National Geospatial Reference System (NGRS).

Therefore, many nations have set up GNSS Continuously Operating Reference Stations (CORS) to aid in the reconception of their national datum in accordance with the International Terrestrial Reference Framework (ITRF). CORS are GNSS base stations that operate from permanent and stable locations and can function in any weather conditions. CORS can provide an immediate position with an accuracy of ± 20 mm, which is required by many industries (Ayodele *et al.*, 2017). Various CORS networks have been established in Nigeria (or are in the process of being established) to guarantee that the data and information provided to field users is trustworthy and fit-for-purpose, the quality of the data received by the control center must be regularly reviewed and verified. Data quality can be impaired by issues such as availability, cycle slippage, latency, multi-path, atmospheric impacts and interference. The quality of the end user's location is inextricably tied to the quality of the CORS data due to the nature of Network Real Time Kinematic (NRTK) positioning.

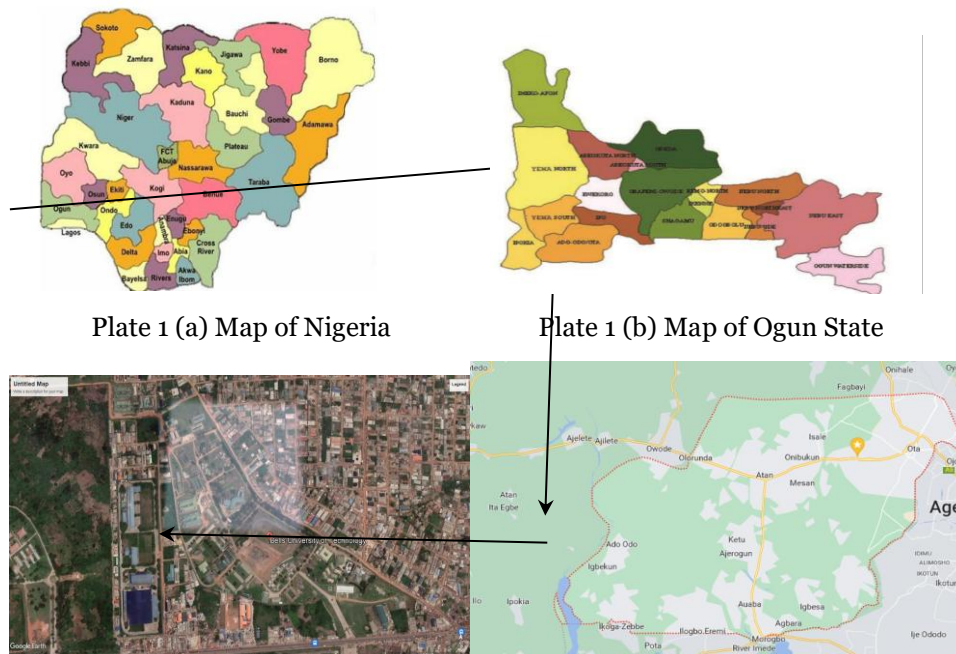
Consequently, Alkan *et al.*, (2020) used Trimble CenterPoint RTX real-time precise point positioning service and the Canadian Spatial Reference System-Precise Point Positioning (CSRS-PPP) online GNSS post-processing service to evaluate PPP and real-time absolute positioning. It was reported that PPP takes precedence over conventional positioning methods in terms of speed, accuracy and fieldwork flexibility. Dardanelli *et al.* (2021) evaluated static and NRTK coordinates using Virtual Reference Station (VRS), *Flächenkorrekturparameter* (FKP), National Marine Electronics Association (NMEA) and PPP solutions, via CSRS and RTKLIB. It is widely accepted that a static survey provides better accuracy, but it takes a long time to analyze the data once the survey is over. It was revealed that a prolonged period of observations more than one hour per station might be used to evaluate the congruence of alternative solutions. Kanellopoulos *et al.*, (2019) adopted both single frequency receiver and dual-frequency receivers. Single Base RTK and VRS were the two methods investigated. Errors related to atmospheric and site manufacturing conditions were excluded from the observations since the receiver and virtual stations were in close proximity and impacted equally. Virtual reference stations could only be used if at least three additional permanent reference stations of the same network were located within a 50 kilometer radius of each other. Therefore, it is possible to monitor deformation with single Base RTK and VRS. Isioye *et al.*, (2018) compared the performance of two constantly running GNSS receivers in Bauchi State. The study revealed that the choice of GNSS receiver might greatly alter parameters calculated from data logged as there was a slight variation in the observed Longitude, Latitude, Altitude (X, Y, Z) data from both receivers. Botsyo (2020) evaluated several instruments/receivers such as the Sokkia stratus single frequency, Ashtech Locus single frequency and Topcon hyper plus dual frequency GPS. The results for single-frequency GPS data as well as dual-frequency GPS observations demonstrate that changes in Northings are strikingly comparable, whereas changes in Eastings are marginally different compared to the Northings, the modifications in the Eastings are rather minor. Moreover, Tier 3 CORS are built by state government, organizations and commercial businesses in Nigeria to serve their satellite positioning needs. Previous studies opined that observational time/duration and choice of (GNSS) receiver plays a major role in the assessment of most probable value X, Y, Z derived from CORS (Ayodele *et al.*, 2020; Botsyo 2020; Wang *et al.*, 2019; Snay and Soler, 2011). Different methods (Static, RTK and Precise Point Positioning) and receivers were used to evaluate the performance of each receiver. Therefore, this study shall evaluate static GNSS measurements uncertainty from two receivers and three CORS (ACLA, Sacredion and Quest CORS) on

four selected controls within Bells University of Technology, Ota, Ogun State, Nigeria with a minimum of two hours occupation per station for three epochs per day: morning, afternoon, and night. In addition, one hour, four hours and eighteen hours GNSS observations on another three controls from L10 using Trimble R10 shall be adopted to validate the results.

2. 0 Materials and Methods

2.1 The Study Area

The study area is within Lagos State, Ogun State and Bells University of Technology Ota Ogun State. It is situated in Benja Village, along Ota Idiroko Road in Ado-Odo Local Government Area, Ogun State geographically located within latitude $6^{\circ}40'52''$ N and longitude $3^{\circ}10'04''$ E as shown in Plate 1(a, b, c, d).



© Google Earth Image

Plate 1(c): Google earth image of Bells University Plate 1(d): Map of Ado-Odo Ota

Plate 1(a, b, c, d) Study area showing map of Nigeria, Lagos State, Ogun State, Ado-Odo LGA Ota and Bells University.

2.2 Methods

Four stations were carefully selected from seven stations established from L10 using four units of Trimble R10 dual frequency GNSS with three hours observation per station, the network of these stations is shown in Figure 1. The instrument was set up on L10 as the base station. All necessary adjustment were carried out before the commencement of the observation. The coordinates of the seven stations are shown in Table 1.

Table 1: Co-ordinate of the seven controls established

Station ID	Easting (m)	Northing (m)	Ellipsoidal height (m)	Orthometric height (m)
BUTSo1SG	518876.552	739109.797	81.194	57.469
BUTSo2SG	519247.648	738814.947	83.969	60.257

Table 2: Result of the adjusted coordinates using Leica RX1200 receiver with reference to Sacredion CORS for day one, three epochs

DAY 1 MORNING			
Station ID	Easting (m)	Northing (m)	Ellipsoidal Height (m)
BUTSo4SG	518631.941	738946.297	77.131
BUTSo5SG	518526.835	739311.052	63.091
DAY 1 AFTERNOON			
BUTSo4SG	518631.935	738946.303	77.121
BUTSo5SG	518526.825	739311.043	63.100
DAY 1 NIGHT			
BUTSo4SG	518631.935	738946.303	77.121
BUTSo5SG	518526.825	739311.043	63.100

Table 3: Result of the adjusted coordinates using Leica RX1200 receiver with reference to Sacredion CORS for day two, three epochs

DAY 2 MORNING			
Station ID	Easting (m)	Northing (m)	Ellipsoidal Height (m)
BUTSo1SG	518873.398	739116.736	79.238
BUTSo7SG	518609.718	739508.958	55.591
DAY 2 AFTERNOON			
BUTSo1SG	518876.469	739109.692	35.858
BUTSo7SG	518612.786	739501.916	12.147
DAY 2 NIGHT			
BUTSo1SG	518873.554	739116.696	79.461
BUTSo7SG	518609.875	739508.917	55.747

Table 4: Result of the adjusted coordinates using Leica RX1200 receiver with reference to ACLA CORS for day one, three epochs

DAY 1 MORNING			
Station ID	Easting (m)	Northing (m)	Ellipsoidal Height (m)
BUTSo4SG	518635.024	738939.368	33.548
BUTSo5SG	518529.918	739304.126	19.507

STATION ID	D1 (OBS1[Sacredion]-GIVEN)			D2 (OBS2[ACLA]-GIVEN)			D3 (OBS1-OBS2)		
	X01-Xg	Y01-Yg	Z01-Zg	X02-Xg	Y02-Yg	Z02-Zg	X01-X02	Y01-Y02	Z01-Z02
BUTSo1SG	-3.154	6.939	-1.956	-0.151	0.029	-45.290	-3.003	6.910	43.334
BUTSo4SG	-3.171	6.922	-1.797	-0.089	-0.007	-45.380	-3.083	6.929	43.583
BUTSo5SG	-3.170	6.939	-1.828	-0.087	0.013	-45.412	-3.083	6.926	43.584
BUTSo7SG	-3.155	6.924	-1.747	-0.153	0.015	-45.171	-3.002	6.909	43.424

DAY 1 AFTERNOON			
BUTSo4SG	518634.520	738939.132	33.521
BUTSo5SG	518529.409	739303.892	19.491
DAY 1 NIGHT			
BUTSo4SG	518631.932	738946.306	77.127
BUTSo5SG	518526.823	739311.046	63.106

Table 5: Result of the adjusted coordinates using Leica RX1200 receiver with reference to ACLA CORS for day two, three epochs

DAY 2 MORNING			
Station ID	Easting (m)	Northing (m)	Ellipsoidal Height (m)
BUTSo1SG	518876.401	739109.826	35.904
BUTSo7SG	518612.720	739502.049	12.167
DAY 2 AFTERNOON			
BUTSo1SG	518876.469	739109.692	35.858
BUTSo7SG	518612.786	739501.916	12.147
DAY 2 NIGHT			
BUTSo1SG	518876.387	739109.818	35.938
BUTSo7SG	518612.705	739502.043	12.223

Table 6: Morning deviation from the mean of the adjusted coordinates from two CORS

Table 7: Afternoon deviation from the mean of the adjusted coordinates from ACLA CORS

STATION ID	D2 (OBS2[ACLA]-GIVEN)		
	Xo2-Xg	Yo2-Yg	Zo2-Zg
BUTSo1SG	-0.083	-0.105	-45.336
BUTSo4SG	-0.592	-0.243	-45.407
BUTSo5SG	-0.596	-0.221	-45.428
BUTSo7SG	-0.087	-0.118	-45.191

Table 8: Night deviation from the mean of the adjusted coordinates from Sacredion CORS

STATION ID	D1 (OBS1[Sacredion]-GIVEN)		
	Xo1-Xg	Yo1-Yg	Zo1-Zg
BUTSo1SG	-2.998	6.899	-1.7330
BUTSo4SG	-3.177	6.928	-1.808
BUTSo5SG	-3.180	6.930	-1.819
BUTSo7SG	-2.998	6.883	-1.591

Tables 6–8 show the deviation between the established value and the observed data from Sacredion CORS (D₁) and ACLA CORS (D₂). Unfortunately in Table 7 (afternoon) observed data from Sacredion CORS was not available between (12:35 - 16:47 pm). Similarly, in Table 8 ACLA CORS observed data was unavailable between (19:12 - 22:21 pm). Therefore, Table 6 was adopted for further analysis and statistical inference. From the tables, a misclosure of ± 3 m in the Easting and ± 6 m in the Northing were attributed to Sacredion CORS. These discrepancies were due to datum parameters inconsistency. While a misclosure of ± 15 cm in the Easting and ± 3 mm in the Northing were attributed to ACLA CORS. Moreover, it was observed that afternoon observations performed poorly when compared with morning and night observations respectively. This could be attributed to refractive index as opined by (Opaluwa *et. al.*, 2013). It was noticed that ACLA CORS yielded better results when compared with Sacredion CORS in Easting and Northing. However, the (height) value derived from ACLA CORS was not in accord with ellipsoidal height difference. For validation, a new CORS data was introduced to evaluate the results. Three stations were re-observed with SOUTH GNSS and referenced to Quest CORS. The result is shown in Table 9.

Table 9: Result of the adjusted coordinates using SOUTH GNSS receiver with reference to Quest CORS

Station ID	Easting (m)	Northing (m)	Ellipsoidal Height (m)
BUTSo1SG	518876.552	739109.797	81.194
BUTSo4SG	518635.112	738939.375	78.928
BUTSo5SG	518529.997	739304.071	65.132

Table 10: Deviation from the mean of the adjusted coordinates from two CORS: ACLA (D₂) and Quest CORS (D₄)

STATION ID	D2 (OBS2[ACLA]-GIVEN)			D4 (OBS4[Quest]-GIVEN)			D5 (OBS2-OBS4)		
	Xo1-Xg	Yo1-Yg	Zo1-Zg	Xo2-Xg	Yo2-Yg	Zo2-Zg	Xo1-Xo2	Yo1-Yo2	Zo1-Zo2
BUTSo1SG	-0.151	0.029	-45.290	0	0	0	-0.151	-0.029	45.290
BUTSo4SG	-0.089	-0.007	-45.380	-0.001	0	0	-0.088	0.007	45.380
BUTSo5SG	-0.087	0.013	-45.412	-0.008	-0.042	0.213	-0.079	-0.055	45.625

Table 10 shows a comparative analysis between ACLA and Quest CORS, their deviations from the given data ranges ± 15 cm in Easting and ± 55 mm in Northing. It is evident there is a correlation between Easting and Northing values observed from ACLA and Quest CORS coordinates when compared with established values. This corroborated the results observed from ACLA CORS and established coordinates. However, ellipsoidal height values were not used for analysis in this study. Furthermore, repeated measurements were taken at another sets of three stations between 23rd 24th September, 2022 in different observing sessions: one hour [1HR], four hours [4HRS] and eighteen hours [18HRS] using a Trimble R10 Dual Frequency GNSS and the results are shown in Table 11 and Figures 2 and 3.

Table 11: GNSS measurements from three observing sessions

Stn. Id.	1HR Repeated GNSS Observations			4HRS Repeated GNSS Observations			18HRS Repeated GNSS Observations		
L10	538163.273	796249.314	172.783	538163.273	796249.314	172.783	538163.273	796249.314	172.783
NISo01	547233.005	711196.292	3.332	547233.035	711196.272	3.288	547233.013	711196.260	3.344
NISo03	539372.557	731445.038	40.330	539372.554	731445.004	40.214	539372.535	731444.996	40.239
NISo04	539383.872	731357.212	39.432	539383.859	731357.179	39.288	539383.848	731357.173	39.315

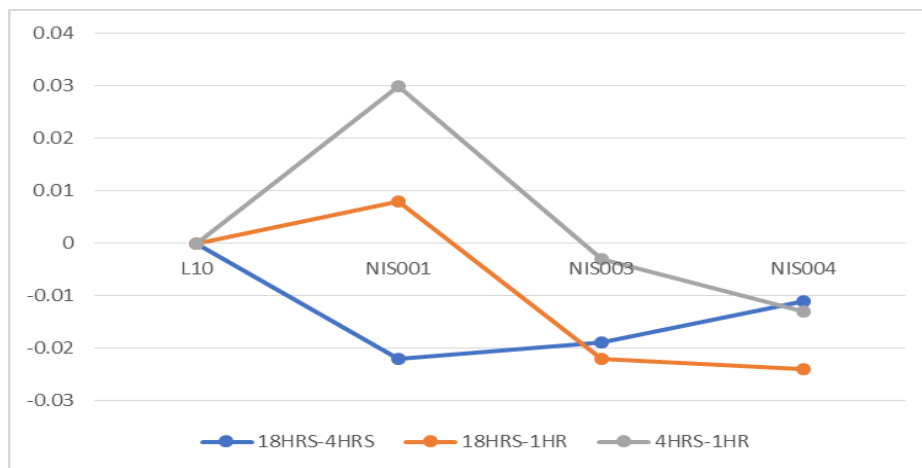


Figure 2: Discrepancies in the Easting from three observing sessions

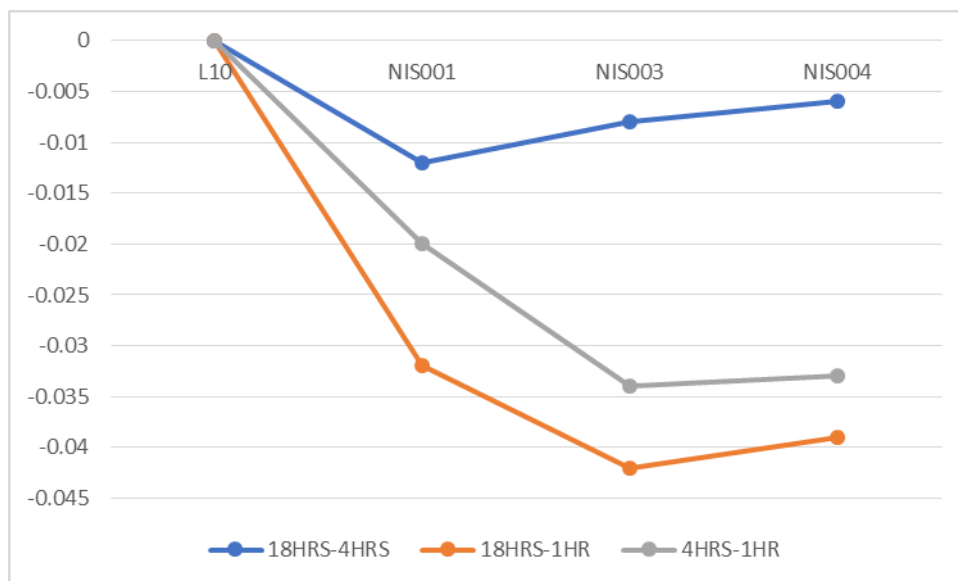


Figure 3: Discrepancies in the Northing from three observing sessions

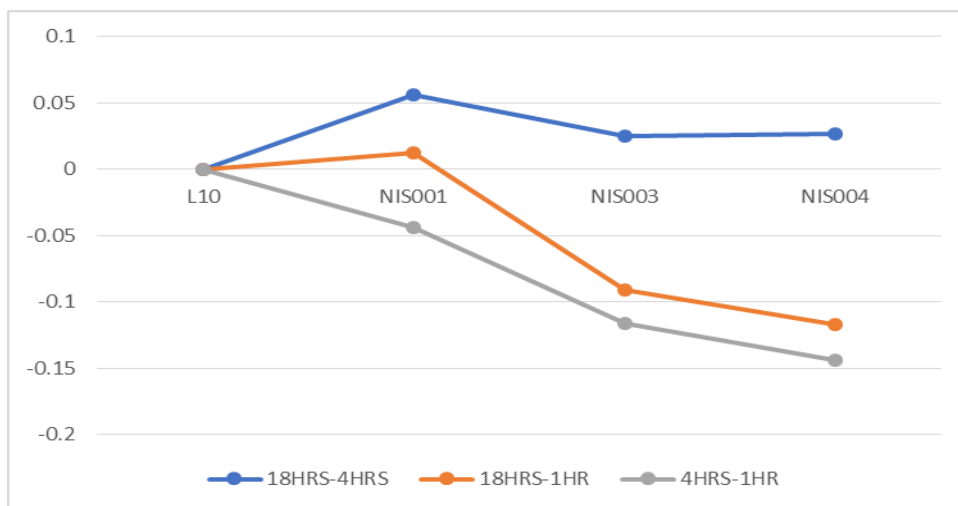


Figure 4: Discrepancies in the Height from three observing sessions

From the results in Table 11 and the graphical representation in Figures 2 3 and 4, it was observed that the resulting residuals are normally distributed in X and Z, while all residuals in Y are negative. Hence it could be concluded that the longer the occupation hours the better the residuals from observed points. The hypothesis test between Sacredion and ACLA CORS are as follows: **H₀**: $\mu_1 = \mu_2 = \mu_3$ i.e the means of the difference in coordinate observed from a receiver with reference to two CORS are equal (Null Hypothesis) **H₁**: $\mu_1 \neq \mu_2 \neq \mu_3$: i.e the means of the difference in coordinate observed from a receiver with reference to two CORS are not equal (Alternative Hypothesis); Reject F value if $F_{\text{computed}} > F_{\text{table}, 0.95}$ Otherwise accept the null hypothesis.

The F-computed values are 15.95 in Easting and 2.55 in Northing while the F table value is 9.28 at 0.05 level of significant. Therefore we accept the null hypothesis and reject the alternative hypothesis in Northing, while in Easting since the F_{computed} is greater than F_{table} , we reject the null hypothesis, which state that the means are not equal.

Similarly, F test was conducted to find the differences in the performance of two CORS (ACLA and Quest) at each station and are statistically significant at 95% confidence level **H₀** = The mean of coordinates observed from a receiver with reference to two CORS are equal (Null Hypothesis); **H₁** = The mean of coordinates observed from a receiver with reference to two CORS are not equal (Alternative Hypothesis)

The F_{computed} values are 1.000 in Easting and 0.999 in Northing while the F_{table} value is 19 at 0.05 level of significant. Therefore, we accept the null hypothesis and reject the alternative hypothesis since the critical value is more than computed value. Since the calculated value equals 1, this shows a strong relationship that the means are equal.

4.0 Conclusions

CORS data used were ACLA and Sacredion, while Quest CORS was used for validation. Since the differences in the measurements are within a tolerable value, they are therefore considered to be negligible. From the result obtained with ACLA CORS, inconsistencies in the ellipsoidal height difference between the ACLA CORS and existing height value of the stations were established. As a result of incomplete data (afternoon and night) sent for both ACLA and Sacredion CORS, only complete morning observations were used for computation, adjustment and statistical analysis in this study. The inconsistencies observed from Sacredion CORS could be attributed to calibration constant as well as datum challenges. However, this was removed for further analysis. The outcome of this study clearly demonstrates that coordinates collected and processed with static base stations and those obtained and processed utilizing COR Station technology are almost the same. The study recommend as follows: re-assessment with another sets of single frequency receivers is strongly recommended. Likewise, the use of static GNSS CORS for large scale township mapping is recommended. In addition, three-dimensional homogeneous datum harmonization of all States and private CORS in operation should be carried out through rigorous calibrations and validations exercise.

Data Availability

Adejare et. al. (2023) "Dataset of An assessment of CORS measurements uncertainty from single and dual frequencies GNSS receivers in Ota, Ogun state, Nigeria" (Mendeley Data)

Direct URL : <https://data.mendeley.com/datasets/hxcm5wbxt3>

DOI :

<http://dx.doi.org/doi:10.17632/hxcm5wbxt3.1>

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