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An Assessment of the Reliability of the NIGNET Data

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ABSTRACT

The Nigerian Geodetic Reference Frame is defined by a number of Continuously Operating Reference Stations (CORS) that constitute the Nigerian GNSS Network (NIGNET). NIGNET is essential for planning and national development with the main goal of ensuring consistency in the geodetic framework both nationally and internationally. Currently, the strength of the network in terms of data reliability has not been adequately studied due to the fact that research into CORS in Nigeria is just evolving, which constitutes a limitation in its applications. Therefore, the aim of this research is to explore the reliability of the 3-dimensional coordinates of NIGNET to inform usability and adequacy for both scientific and practical applications. In particular, this study examines if the 3-dimensional coordinates of NIGNET are equally reliable in terms of positional accuracy. Accordingly, this study utilised GNSS data collected over a period of six years (2011 – 2016) from the network to compute the daily geocentric coordinates of the stations. Exploratory and statistical data analysis techniques were used to understand the magnitude of the errors and the accuracy level in the 3-dimensional coordinates. For this purpose, accuracy metrics such as standard deviation (σ), standard error (SE) and root mean square error (RMSE) were computed. While One-way ANOVA was conducted to explore the coordinate differences. The results obtained showed that SE and RMSE ranged from $13.00 - 56.50mm$ and $14.38 - 73.16mm$ respectively, which signifies high accuracy. Overall, while 88% of the network showed a high level of positional accuracy, the reliability has been compromised due to excessive gaps in the data archiving. Therefore, due attention must be given to NIGNET to achieve its purpose in the provision of accurate information for various geospatial applications. Also, any efforts directed at understanding the practical implications of NIGNET must be well-embraced for the realization of its set objectives.

Keywords: Geodetic Infrastructure, Reliability, NIGNET, CORS, Data Analysis

1.0. Introduction

Advancements in positioning have made Global Navigation Satellite Systems (GNSS) a critical component of the modern day geodetic infrastructure and services. In 2008, the Office of the Surveyor General of the Federation started the establishment of the Nigerian GNSS Reference Network (NIGNET). NIGNET consists of a network of Continuously Operating Reference Stations (CORS). Currently, NIGNET is formed by sixteen (16) CORS covering the entire country. CORS are a network of stations using GNSS operating continuously from permanent and stable locations for accurate positioning (Fajemirokun, 2009; Schwieger *et al.*, 2009). CORS provide geodetic controls of comparable accuracy to the classical geodetic network and is a better alternative given the improvements in surveying and mapping technologies. CORS are categorised into different classes according to purpose and the spacing between stations. For example, Burns and Sarib (2010) and the Intergovernmental Committee on Survey and Mapping, ICSM (2014) classified CORS into Tiers 1–3 while LPI (2012) classified CORS into Tiers 1–5. The use of CORS can give an instant position to an accuracy of ±20 mm required by many industries (UNSW, 2017).

For NIGNET, its main goal is to ensure consistency in the local (Nigerian Geodetic Reference Frame) with the International Terrestrial Reference Frame (ITRF). NIGNET serves as the fiducial network that defines the country's spatial reference framework as well as contributing to the African Geodetic Reference Frame (AFREF) using the techniques of modern space geodesy. The establishment of NIGNET is essential given that the national geodetic network of any country is a pivotal infrastructure that provides the foundation for all geo-related activities and services. Such services include land management, urban development, physical planning, construction, mineral exploration, and transportation (land, air and water). NIGNET also provides the base for a coherent multipurpose Land Information System and its subsequent maintenance. This is particularly useful in a country's economic development by delineating and monitoring changes in property, environment, and biodiversity. It is also vital in the smooth implementation of the national land policy (Jatau *et al.*, 2010). In order to ensure consistency, the linking of NIGNET to the ITRF was made by acquiring Global Positioning System (GPS) data from nine International GNSS Service (IGS) stations (OSGOF, 2012). The IGS stations served as the reference points while the data used were acquired at the same time with the data from NIGNET.

Given the critical role played by NIGNET in defining the geocentric datum for Nigeria, it is important to account for any displacement arising from the shift in position of the CORS. Recently, Ayodele *et al.* (2017) analysed data from seven NIGNET stations covering 2011 to 2014 in order to monitor temporal variations and to understand the quality of the three-dimensional coordinates. The results showed an acceptable level in the data quality and accuracy of NIGNET with the highest and lowest variabilities in the initial coordinates occurring in the x and z directions respectively. The authors also noted some infrastructural problems plaguing NIGNET such as faulty receivers, irregular power supply, and disruptions in internet connectivity. The observations in the network led to the assessment of the accuracy in the three-dimensional coordinates of ten operational NIGNET stations from 2011-2016 using a known IGS station (BJCO) as reference. While the results from the study showed an acceptable level of accuracy, the reliability of the network remains unclear. Consequently, in this study, the reliability of the network was explored using both exploratory and quantitative analysis techniques such as the Mahalanobis distance method of outlier detection and filtering, standard deviation (S.D), standard error (S.E), mean absolute deviation (MAD) and root mean square error (RMSE) for accuracy metrics Also, analysis of variance (ANOVA) was used to test for any significant variation in the 3-dimensional coordinate to understand whether the X, Y, and Z-coordinates are of different levels of reliability-. To conclude the reliability assessment, an evaluation of the sufficiency and adequacy of the NIGNET data was conducted using the data count of the daily observations in line with the IGS and ICSM guidelines for the acquisition of high quality CORS data.

2.0. Materials and Methods

Figure 1 presents the map of Nigeria showing the distribution of the NIGNET COR Stations used in this study. The downloaded files contained data from fourteen (14) NIGNET stations that were available on the online portal and two IGS stations (CGGN and BJCO). Following this, a custom MATLAB script was written to call the offline function of the GNSS Analysis and Positioning Software (GAPS) to read the RINEX files from the folder they were placed. GAPS is a Precise Point Positioning (PPP) application developed at the University of New Brunswick, Canada. Further details about GAPS and how it functions can be found in Leandro *et al.* (2010) and Urquhart *et al.* (2014). During the processing, the geocentric coordinates of the stations were computed and extracted at a sampling interval of 30 seconds and then averaged into daily coordinates. A full description of the methodology for the processing of the station coordinates using GAPS can be found in Ayodele *et al.* (2017). Table 1 presents the summary of BJCO (the reference station) showing the geodetic coordinates and years of observations considered. From the table, the least number of yearly observations recorded was in year 2012 (248) while the highest number of observations was recorded in year 2014 (362). For the 6-year period from 2011–2016 under study, a total number of 1,875 available data files were acquired for BJCO. Four NIGNET stations with excessively large data gaps were excluded leaving a final selection of ten NIGNET stations. The excluded stations include HUKP (Katsina), FPNO (Owerri), FUTA (Akure) and GEMB (Gembu). MDGR had severe service disruptions during this period making it the station with the least number of observations (369 data files) while FUTY had the highest number of observations (1799 data files).

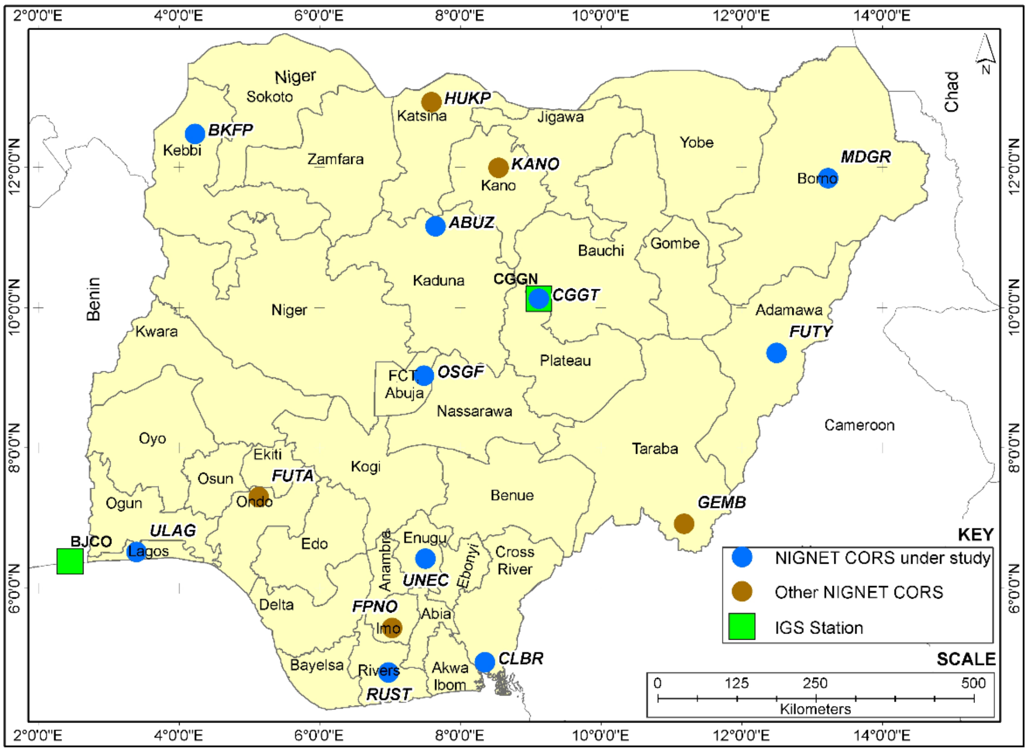

Figure 1: Map of Nigeria showing the distribution of the COR stations

Table 1: The description and the count of the downloaded daily data BJCO IGS station

Station code	Latitude (degree)	Longitude (degree)	Ellipsoidal height (m)	Location	No. of Yearly Downloaded Observations (days)					
					2011	2012	2013	2014	2015	*2016
BJCO	6.38	2.45	30.7	Benin Republic	299	248	332	362	346	288

*1 Jan – 10 Nov, 2016

Following the determination of the coordinates of the stations using GAPS, a final set of daily coordinates for the first months of observation were averaged to derive the initial coordinates for each station. The next stage of the data processing and analysis utilised *R* (a language for computing and statistical analysis) to compute the Mahalanobis Distances. The data points beyond the Mahalanobis distance cut-off value were filtered out as outliers. To obtain a detailed picture of the magnitude of the errors and the accuracy level in the three-dimensional coordinates, the following accuracy metrics were computed: standard deviation – S.D (σ), standard error - S.E ($\sigma/\sqrt{N}$), mean absolute deviation (MAD) and root mean square error (RMSE). Correlation analysis was also performed to check for the correlation between the coordinate differences in the three directions. The MAD and RMSE have been widely used by researchers to measure model performance and are calculated for the data as follows (Chai and Draxler, 2014):

$$MAD = \frac{1}{n}\sum_{i=1}^{n}|e_i| \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} e_i^2} \quad (2)$$

Next, using the Statistical Package for the Social Sciences (SPSS) version 16.0, an ANOVA test was conducted to explore the differences in the filtered X, Y and Z- coordinate differences. The null hypothesis (H_0) is that there is no significant difference in the means of the X, Y and Z coordinate differences or that the 3-dimensional coordinates are equally reliable. The converse forms the alternative hypothesis (H_1). H_0 is rejected if the *p-value* is less than the significance level of 0.05. If H_0 is rejected, meaning there is a significant difference among the groups, then a Tukey post-hoc analysis will be conducted in order to determine which specific groups differed from each other. Finally, to evaluate the sufficiency and adequacy of the NIGNET data, the data count of daily observations from the NIGNET portal was compared with that of an IGS station (BJCO) which is believed to comply with the IGS and ICSM guidelines for the acquisition of high quality CORS data. One of the IGS requirements is the need to have long time series of continual stable measurements with as few disruptions and configuration changes as possible (IGS, 2017). For Tiers 1 and 2, less than 8 min/day and 9 hr/year of data outage is recommended, while for Tier 3 CORS, data outage should be less than 15 min/day and 44 hr/year (ICSM, 2014). ICSM (2014) also recommended a survey uncertainty of better than 20mm. These recommendations formed the basis for the assessment of the adequacy of the network data.

3.0. Results

3.1. Exploratory data analysis

Using the Mahalanobis distance method, the variability in the daily coordinates was analysed to screen out the outliers. Figure 2 shows a sample plot of X-coordinate differences against the Mahalanobis distance. All coordinate points beyond the cutoff distance of 2.795 were filtered off as outliers. This manifests in the density plot of the squared Mahalanobis distance shown in Figure 3. The good quality observations are concentrated towards the left portion of the plot. Further right, moving away from the square of the cut-off value, the outliers start to thin out over greater distances. Figure 4 shows a Q-Q plot of the squared Mahalanobis distance against the quantiles of chi-square of 2 degrees of freedom while Figure 5 presents a boxplot of the coordinate differences at all stations in the x-direction.

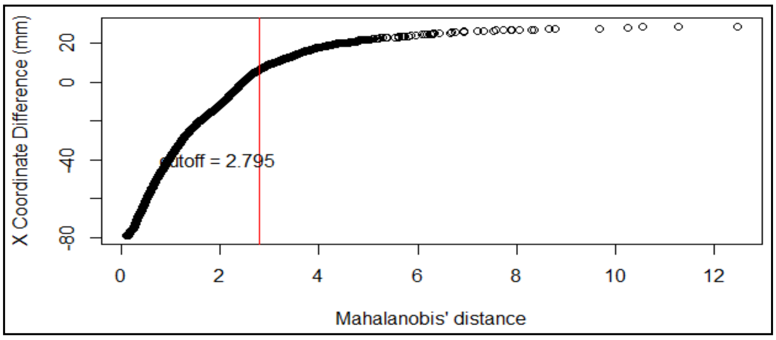

Figure 2: Plot of *x*-coordinate differences against the Mahalanobis distance

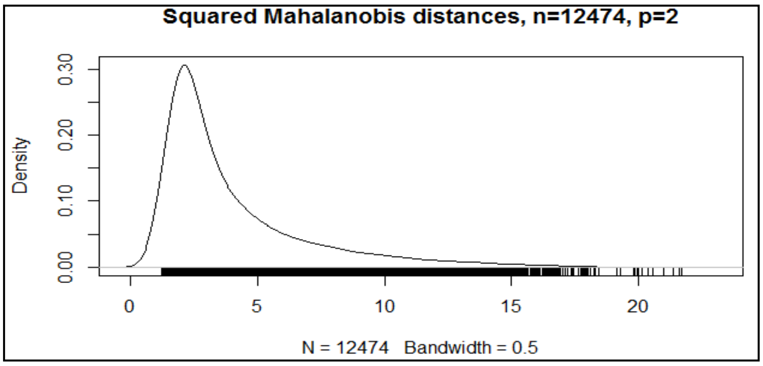

Figure 3: Density plot of squared Mahalanobis distance

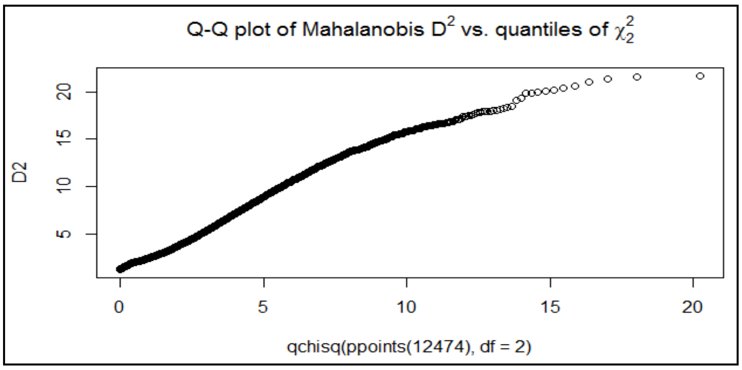

Figure 4: Q-Q plot of the squared Mahalanobis distance against the quantiles of chi-square of 2 degrees of freedom

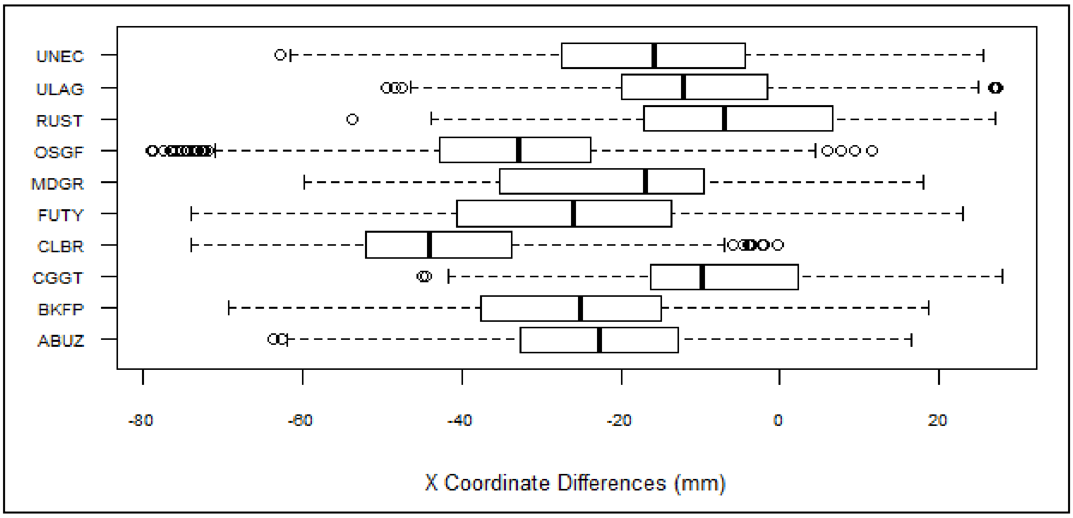

Figure 5: Boxplots of coordinate differences at all stations in the *x*-direction

3.2. Quantitative data analysis

3.2.1. Analysis of the initial station coordinates

Table 2 shows the mean and standard deviations of the initial station coordinates. The SDs in the x, y and z-directions are denoted by SDX_i, SDY_i and SDZ respectively. The results for the IGS station show that BJCO has SDs of 8.9 mm, 9.1 mm and 4.4 mm in the x, y and z directions respectively. In a general assessment of all the eleven IGS and NIGNET stations to understand the level of variability in the initial coordinates, MDGR has the lowest SD (4.9mm) while CLBR has the highest SD (31.6mm) in the x-direction. This signifies the stations with the minimum and maximum variability in the x-coordinates. In the y-direction, ABUZ and BKFP are the least variable stations with an SD of 2.5 mm while OSGF presents the highest variability (SD = 11.2 mm). In the z-direction, CLBR and BJCO are the stations with the minimum and maximum variability in coordinates with SDs of 1.4 mm and 4.4 mm. From the initial assessment, there is no clear indication of whether geographical location is responsible for the variability in coordinates. This is evidenced in the randomness observed in the distribution of the locations of the minimum and maximum values.

Table 2: Mean and standard deviations (SDs) of the computed initial coordinates

Station	$\overline{X}_i(m)$	$\overline{Y}_i(m)$	$\overline{Z}_i(m)$	$SD_{X_i}(m)$	$SD_{Y_i}(m)$	$SD_{Z_i}(m)$	N
ABUZ	6203493.826	833088.697	1225614.635	0.007	0.003	0.002	28
BJCO	6333076.479	270973.572	704552.107	0.009	0.009	0.004	16
BKFP	6211960.353	459365.476	1368115.049	0.006	0.003	0.002	29
CGGT	6201032.284	995277.242	1113815.522	0.007	0.003	0.003	29
CLBR	6287174.239	922979.461	546713.767	0.032	0.006	0.001	3
FUTY	6145058.500	1362078.873	1029389.914	0.008	0.004	0.003	30
MDGR	6080449.306	1418433.497	1299949.426	0.005	0.003	0.002	15
OSGF	6246471.278	820848.736	994267.941	0.010	0.011	0.003	21
RUST	6308859.048	772229.925	530354.458	0.012	0.004	0.004	14
ULAG	6326097.300	375576.105	719131.690	0.008	0.004	0.003	30
UNEC	6284298.307	827900.511	708988.588	0.011	0.003	0.002	28

3.2.2. Analysis of the daily station coordinates

Table 3 presents the mean absolute deviation (MAD) and root mean square error (RMSE) in the daily station coordinates from 2011-2016. In the table, the MAD describes the average distance of each daily coordinate from the mean (initial) station coordinates shown in Table 2. Similarly, the magnitude of the RMSE provides a good measure of the level of spread of the residuals in the data. CGGT has the lowest variability in the three directions ($MAD_X = 12.20mm$, $RMSE_X = 14.38mm$; $MAD_Y = 16.14mm$, $RMSE_Y = 18.44mm$; $MAD_Z = 12.72mm$, $RMSE_Z = 14.42mm$. This observation is as expected and it is not unconnected with the fact that CGGT is located in a solid location compared to the other stations. Similarly, CLBR which is located in the coastal zone has the highest variability in x and z-directions as expected ($MAD_X = 42.77mm$, $RMSE_X = 44.96mm$), and CLBR ($MAD_Z = 62.23mm$, $RMSE_Z = 67.02mm$), while FUTY ($MAD_Y = 64.87mm$, $RMSE_Y = 73.16mm$) has the highest variability y-directions.

Table 3: Summary of MAD and RMSE of the daily station coordinates from 2011-2016

Station	MAD_X (mm)	MAD_Y (mm)	MAD_Z (mm)	$RMSE_X$ (mm)	$RMSE_Y$ (mm)	$RMSE_Z$ (mm)
ABUZ	23.4859	55.1011	44.6664	27.1957	63.6742	53.4848
BKFP	26.8498	61.5280	48.2706	30.9037	70.7931	57.4000
CGGT	12.2014	16.1382	12.7178	14.3844	18.4408	14.4192
CLBR	42.7717	62.0155	62.2251	44.9635	67.9041	67.0195
FUTY	27.7770	64.8650	53.7864	32.3625	73.1647	62.3040
MDGR	21.5268	29.0277	21.9808	26.0540	37.5886	34.0503
OSGF	33.8218	45.8082	31.3158	37.1361	55.1622	41.5294
RUST	13.8697	25.2174	18.8248	16.7598	29.7339	22.6099
ULAG	14.6185	38.3836	28.9511	17.6079	42.5873	32.2187
UNEC	19.1426	57.3797	45.7222	23.0469	67.2318	55.1066

For a quick visualisation of the relationships in the coordinate differences, Figure 6 presents a correlation plots in the 3-dimensions across all the stations. The random spread of the points in the XY and XZ scatter plots shows there is negative correlation between the X and Y coordinate differences. There is also a negative correlation between the X and Z coordinate differences. However, the YZ plot shows a tight grouping of the coordinate differences in the y and z-directions. This shows that there is a high correlation between the Y and Z coordinate differences.

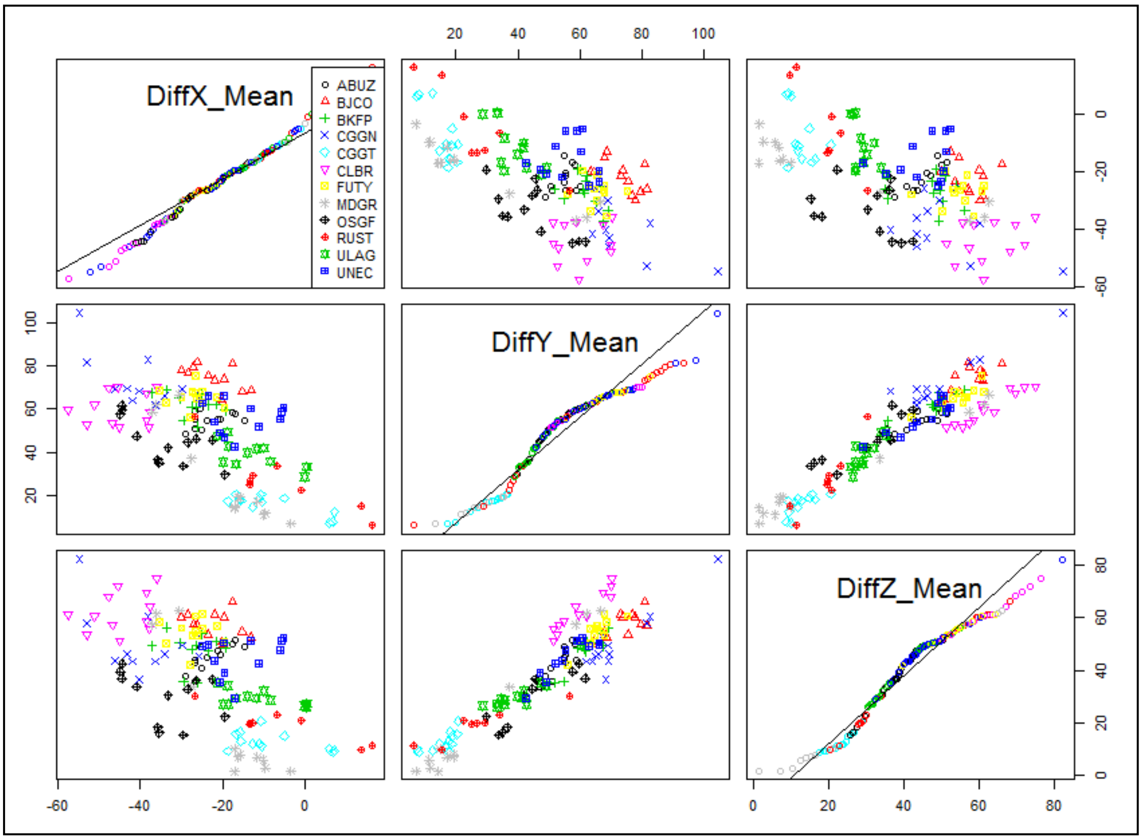

Figure 6: Correlation plot of the mean coordinate differences across all stations

3.2.3. Accuracy analysis of the yearly coordinate differences

After the outlier filtering using the Mahalanobis method, the descriptive statistics of the daily coordinate differences from 2011-2016 were calculated and are presented in Tables 4-6. For the coordinate differences in the x-direction, year 2015 has the least S.D of 12.839 mm while the highest S.D of 14.997 mm occurred in year 2013. For the y-direction, the least S.D was observed in the year 2011 (9.125 mm) while the highest S.D was observed in year 2013 (13.200 mm). The lowest and highest S.Ds in the Z-coordinate differences occurred in years 2016 (5.038 mm) and 2013 (8.629 mm). Figure 7 presents a plot of the mean coordinate differences across all the stations from 2011-2016. From the figure, the result shows a strong relationship between the *Y* and *Z* coordinate differences as the dispersion of their differences from the initial coordinates follows the same trend and direction while the *X* coordinate differences are moving in the opposite direction.

Table 4: Descriptive statistics of the mean X-coordinate differences from 2011-2016

Year	N	Mean (mm)	S.D (mm)	S.E (mm)	95% Confidence Interval for Mean (mm)		Min (mm)	Max (mm)
					Lower Bound	Upper Bound		
2011	2438	-8.585	13.539	27.400	-9.122	-8.047	-55.80	28.00
2012	2258	-20.283	14.487	30.500	-20.881	-19.685	-60.10	20.80
2013	2082	-24.231	14.997	32.900	-24.876	-23.587	-68.90	23.70
2014	1592	-36.332	13.653	34.200	-37.003	-35.661	-74.00	10.10
2015	535	-44.213	12.839	55.500	-45.304	-43.123	-74.00	-3.50
2016	924	-43.818	13.000	42.800	-44.658	-42.979	-78.90	-11.20

Table 5: Descriptive statistics of the mean Y-coordinate differences from 2011-2016

Year	N	Mean (mm)	S.D (mm)	S.E (mm)	95% Confidence Interval for Mean (mm)		Min (mm)	Max (mm)
					Lower Bound	Upper Bound		
2011	2438	16.893	9.125	18.500	16.531	17.256	-26.20	83.30
2012	2258	35.650	10.620	22.300	35.212	36.089	-10.10	79.20
2013	2082	58.548	13.200	28.900	57.981	59.116	9.00	108.80
2014	1592	76.284	12.336	30.900	75.678	76.891	35.80	151.20
2015	535	94.210	13.059	56.500	93.100	95.319	45.60	132.10
2016	924	117.985	10.880	35.800	117.283	118.687	84.00	147.00

Table 6: Descriptive statistics of the mean Z-coordinate differences from 2011-2016

Year	N	Mean (mm)	S.D (mm)	S.E (mm)	95% Confidence Interval for Mean (mm)		Min (mm)	Max (mm)
					Lower Bound	Upper Bound		
2011	2438	9.494	6.421	13.000	9.239	9.749	-10.60	69.50
2012	2258	26.855	7.564	15.900	26.542	27.167	0.50	54.30
2013	2082	46.125	8.629	18.900	45.755	46.496	21.50	90.40
2014	1592	65.750	6.689	16.800	65.421	66.079	43.70	112.40
2015	535	85.972	7.044	30.500	85.374	86.570	65.60	106.30
2016	924	104.269	5.038	16.600	103.943	104.594	88.00	122.30

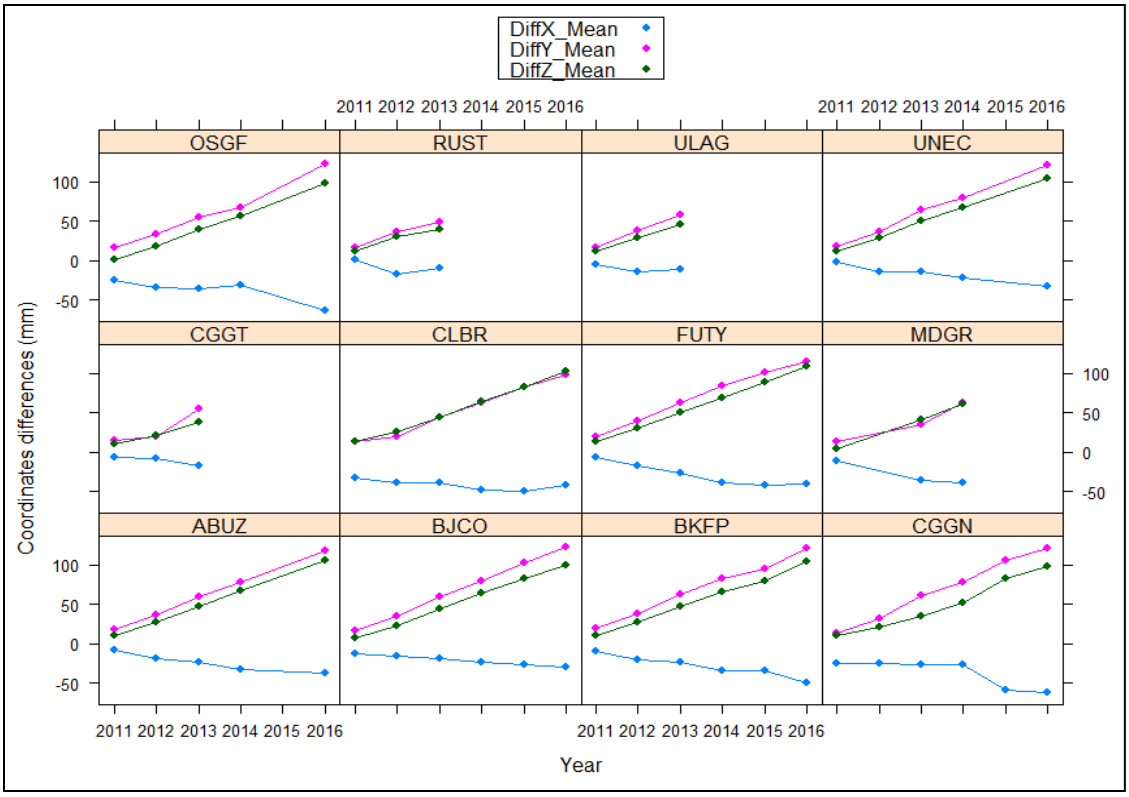

Figure 7: Mean coordinate differences across all stations from 2011 - 2016

In Figure 7, it is evident that the trend of dispersion of the X-coordinate differences is significantly different from the Y and Z coordinate differences. Having established this fact, the next section presents an ANOVA test to analyse the periodic (yearly) variations in the X, Y and Z coordinate differences.

3.2.4. Analysis of variance in station coordinates

The results of the ANOVA test in Table 7 shows that there is a significant difference between the X, Y and Z coordinate differences. The results of the ANOVA test suggest a rejection of the null hypothesis. Therefore, a Tukey Post-hoc test was conducted to further explore the differences in the epochs under comparison within the 2011-2016 period. The results of the Tukey Post-Hoc test presented in Tables 8-10 shows that there is a significant difference in the mean X-coordinate differences across all the epochs under study in the 2011-2016 period except for 2015 and 2016. That is, the mean X-coordinate differences for 2015 and 2016 are equally reliable. For the mean Y-coordinate differences and the mean Z-coordinate differences, there is a statistically significant difference between all the epochs under study in the 2011-2016 period.

The mean difference of the yearly comparisons shown in Table 8 yield the same value when viewed in both directions, the only difference being a change of sign from positive to negative or vice versa. For example, the mean difference for 2011-2012 is +11.698; for 2012-2011, it is -11.698. Consequently, the abridged versions of the post-hoc table are presented in Tables 8-10.

Table 7: Results of ANOVA test

		Sum of Squares	df	Mean Square	F	Sig.
DiffX_Mean	Between Groups	1433173.256	5	286634.651	1460.00	.000
	Within Groups	1928973.462	9823	196.373		
	Total	3362146.717	9828			
DiffY_Mean	Between Groups	9594701.173	5	1918940.235	14930.00	.000
	Within Groups	1262478.106	9823	128.523		
	Total	10860000.000	9828			
DiffZ_Mean	Between Groups	8624702.076	5	1724940.415	33510.00	.000
	Within Groups	505669.629	9823	51.478		
	Total	9130371.705	9828			

Table 8: Multiple comparisons of the mean X-coordinate differences with the Tukey Post-Hoc test

(I) Year	(J) Year	Mean Difference, I-J (mm)	S.E (mm)	Sig.	95% Confidence Interval	
					Lower Bound (mm)	Upper Bound (mm)
2011	2012	11.698	0.409	0.000	10.532	12.865
	2013	15.646	0.418	0.000	14.455	16.838
	2014	27.747	0.452	0.000	26.46	29.034
	2015	35.628	0.669	0.000	33.721	37.535
	2016	35.234	0.541	0.000	33.691	36.777
2012	2013	3.948	0.426	0.000	2.734	5.162
	2014	16.049	0.459	0.000	14.742	17.356
	2015	23.93	0.674	0.000	22.009	25.85
	2016	23.535	0.547	0.000	21.975	25.095
2013	2014	12.101	0.467	0.000	10.771	13.431
	2015	19.982	0.679	0.000	18.046	21.918
	2016	19.587	0.554	0.000	18.008	21.166
2014	2015	7.881	0.7	0.000	5.885	9.877
	2016	7.486	0.58	0.000	5.834	9.138
2015	2016	-0.395	0.761	0.995	-2.565	1.775

Dependent Variable - DiffX_Mean

Table 9: Multiple comparisons of the mean Y-coordinate differences with the Tukey Post-Hoc test

(I) Year	(J) Year	Mean Difference, I-J (mm)	S.E (mm)	Sig.	95% Confidence Interval	
					Lower Bound (mm)	Upper Bound (mm)
2011	2012	-18.757	0.331	0.000	-19.701	-17.814
	2013	-41.655	0.338	0.000	-42.619	-40.691
	2014	-59.391	0.365	0.000	-60.432	-58.350
	2015	-77.316	0.541	0.000	-78.859	-75.774
	2016	-101.092	0.438	0.000	-102.340	-99.843
2012	2013	-22.898	0.344	0.000	-23.880	-21.916
	2014	-40.634	0.371	0.000	-41.691	-39.576
	2015	-58.559	0.545	0.000	-60.113	-57.005
	2016	-82.334	0.443	0.000	-83.596	-81.073
2013	2014	-17.736	0.377	0.000	-18.812	-16.660
	2015	-35.661	0.550	0.000	-37.228	-34.095
	2016	-59.437	0.448	0.000	-60.714	-58.159
2014	2015	-17.925	0.567	0.000	-19.540	-16.310
	2016	-41.701	0.469	0.000	-43.037	-40.364
2015	2016	-23.775	0.616	0.000	-25.531	-22.020

Dependent Variable - DiffY_Mean

Table 10: Multiple comparisons of the mean Z-coordinate differences with the Tukey Post-Hoc test

(I) Year	(J) Year	Mean Difference, I-J (mm)	S.E (mm)	Sig.	95% Confidence Interval	
					Lower Bound (mm)	Upper Bound (mm)
2011	2012	-17.361	0.210	0.000	-17.958	-16.764
	2013	-36.632	0.214	0.000	-37.242	-36.022
	2014	-56.256	0.231	0.000	-56.915	-55.597
	2015	-76.479	0.343	0.000	-77.455	-75.502
	2016	-94.775	0.277	0.000	-95.565	-93.985
2012	2013	-19.271	0.218	0.000	-19.892	-18.649
	2014	-38.896	0.235	0.000	-39.565	-38.226
	2015	-59.118	0.345	0.000	-60.101	-58.134
	2016	-77.414	0.280	0.000	-78.213	-76.615
2013	2014	-19.625	0.239	0.000	-20.306	-18.944
	2015	-39.847	0.348	0.000	-40.838	-38.855
	2016	-58.143	0.284	0.000	-58.952	-57.335
2014	2015	-20.222	0.359	0.000	-21.244	-19.200
	2016	-38.519	0.297	0.000	-39.364	-37.673
2015	2016	-18.296	0.390	0.000	-19.407	-17.185

Dependent Variable - DiffZ_Mean

3.3. Sufficiency and adequacy of the station coordinates

Going further on the performance evaluation, the stations are expected to have a long time series of continuous stable measurements with as few disruptions as possible. Table 11 shows the NIGNET stations and the data count of daily observations available on the NIGNET server. In the period under study, the following stations had no data available on the NIGNET server – ABUZ (2015), CGGT (2014-2016), MDGR (2012; 2015-2016), OSGF (2015), RUST (2015-2016) and UNEC (2015-2016). It is observed that the data completeness has degraded overtime since the inception of NIGNET. The most severe cases of incomplete data occur in 2015 and 2016. Apparently, some components of the NIGNET infrastructure have been degrading with time and OSGOF has not been able to meet up with the maintenance demands.

Table 11: The selected NIGNET stations and the data count of daily observations

Station code	Latitude (degree)	Longitude (degree)	Ellipsoidal height (m)	Location	No. of Observations (Days)					
					2011	2012	2013	2014	2015	*2016
ABUZ	11.15	7.65	706.1	Zaria	365	366	355	350	0	180
BKFP	12.47	4.23	251.0	Birnin Kebbi	365	366	339	365	46	221
CGGT	10.12	9.12	917.4	Toro	365	39	116	0	0	0
CLBR	4.95	8.35	61.5	Calabar	36	363	340	355	284	190
FUTY	9.35	12.50	248.4	Yola	361	330	361	289	290	168
MDGR	11.84	13.23	351.8	Maiduguri	262	0	11	96	0	0
OSGF	9.03	7.49	533.6	Abuja	299	363	335	94	0	105
RUST	4.80	6.98	46.6	Port Harcourt	304	132	52	84	0	0
ULAG	6.52	3.40	45.5	Lagos	301	364	364	349	0	0
UNEC	6.42	7.50	255.4	Enugu	362	366	364	365	54	216
Total					3.2	5.8	2.6	23.8	3020	2689

*1 Jan – 10 Nov, 2016

There were also cases of unprocessed observations. These unprocessed observations were due to the fact that some of the RINEX files downloaded from the NIGNET portal contained only single frequency data. The reason for this issue with the RINEX files might be attributed to receiver malfunctions, poor station maintenance or issues with data collection and handling. It is also possible that there were configuration issues in some of the RINEX files created by OSGOF. Within the period under study, the total number of NIGNET data files successfully processed ranged from 76.2% in 2014 to 99.3% in 2016. However, virtually all the data files from BJCO were successfully processed with the least being 97.2% in 2012 as presented in Table 1. The most severe cases of unprocessed data in NIGNET occurred in 2012 and 2014 at RUST – 319 unprocessed files (64.4%) and 366 unprocessed files (100%) respectively; at ULAG in 2014 – 364 unprocessed files (99.7%) and at UNEC in 2015 – 365 unprocessed files (100%). Other significant cases occurred at CLBR – 2012 (19.6%), RUST – 2011 (29.9%), ULAG – 2013 (19.0%) and UNEC – 2014 (34.2%). Despite the observed disruptions in the data from BJCO, the IGS data are still more consistent and well distributed over the period under consideration. At no point was BJCO offline all year round as in the case of some NIGNET stations. This points to the fact that the IGS stations are well monitored and better maintained than NIGNET. Summarily, the analysis conducted revealed a gross deficiency in data archiving and a consequent inadequacy of the network data to meet with the various geodetic needs. This is particularly evident in 2015 with maximum of 77% and 81% data recording in only two stations (CLBR and FUTY). The condition is worse in 2016 as only one station (BKFP) recorded up to 60% data.

4.0 Conclusion

This study examined the reliability of the GNSS data collected over a period of six years (2011 – 2016) from the Nigerian CORS network (NIGNET). Both exploratory and statistical data analysis techniques were used in the study to arrive at a concrete conclusion. The results obtained showed that while more than 80% of the network data is highly accurate in terms of positional accuracy and stability, the adequacy is highly deficient. This constitutes a serious challenge considering the requirements to meet various geodetic and geospatial needs. The current results revealed a 100% sub-standard in data recording and archiving in 2015 and 2016 when compared with the IGS standard. The trend observed in the data showed a deteriorating state that if nothing is done to address it, then not only is its objectives cannot be realised but also its sustainability is not guaranteed. To avoid this, the relevant stakeholders are enjoined to work together to salvage the network from failure.

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