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Assessing the positional accuracy and adequacy of the Nigerian GNSS reference network

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Abstract

The availability of continuously operating reference stations (CORS) has revolutionized the realization of geodetic datum with a shift from the conventional ground survey methods to modern positioning techniques. CORS are network of reference stations that continuously provide Global Navigation Satellite Systems (GNSS) data for accurate positioning. The Nigerian GNSS reference network (NIGNET) is a network of CORS that forms an integral part of Nigeria’s geodetic infrastructure and the geodetic reference frame of Africa. As a component of the African geodetic reference frame (AFREF), it has become necessary to evaluate the positional accuracy of the data obtained from NIGNET. This study utilised the GNSS analysis and positioning software (GAPS) to determine the three-dimensional coordinates of the NIGNET stations between 2011 and 2016. The accuracy of the coordinates was evaluated against an international GNSS service (IGS) station BJCO located in Cotonou, Benin Republic. In the analysis, NIGNET showed comparable results with (BJCO) based on the computed accuracy statistics such as the standard error of mean (SEM) - BJCO (SEMX = 0.33mm; SEMY = 0.91mm; SEMZ = 0.78mm) and NIGNET (SEMX = 0.59mm; SEMY = 0.91mm; SEMZ = 0.80mm). This result signifies a high level of accuracy for NIGNET and shows that BJCO did not significantly outperform it. In conclusion, the position accuracy of NIGNET meets the international standards. However, the network adequacy is quite deficient. This poses a great challenge to the mandate of AFREF. It is therefore recommended that the Nigerian government should step up the maintenance of NIGNET in order not to compromise this mandate.

Keywords: CORS, NIGNET, AFREF, Accuracy, GAPS

1. Introduction

Continuously operating reference stations (CORS), are composed of many permanent and stable reference stations that continuously provide global navigation satellite systems (GNSS) data for accurate positioning [1,2]. According to Iyiola et al. [3], the ability of GNSS receiver technology to incorporate data processing and transmission capabilities of base station computers resulted in CORS. Therefore, CORS network requires a reliable communication system to ensure real time computations, management and control. As a minimum requirement, each station requires a good quality receiver placed in a secure location, an antenna fixed to a stable monument, reliable communications and good power supply [2]. CORS networks are advantageous over the traditional systems because position correction can utilise multiple reference stations thus eliminating accuracy degradation with increasing range between reference stations and rover [3,4]. CORS are categorised into three or five classes depending on the purpose and the spacing between the stations and accordingly have been classified into either Tiers 1–3 or Tiers 1-5. More information on the classification can be found in Burns and Sarib [5], ICSM [6], LPI [7] and Rizos [8].

Data from a cooperatively operated global network of heterogeneous CORS is collected, archived, and freely distributed by the International GNSS Service (IGS). These datasets include GNSS orbit data, tracking data, and other receiver position information. The IGS requires that its participating stations have continuously stable measurements over a long period of time with little or no disruptions and changes in configuration [9]. However, due to the voluntary nature of the organisations that constitute the body, the IGS does not enforce stringent rules on the maintenance of the CORS network [10]. Nonetheless, participating organisations must agree to comply with the standards contained in the IGS Site Guidelines for participating CORS. In Nigeria, a network of CORS referred to as the Nigerian GNSS Reference Network (NIGNET) was started in 2008 by the Office of the Surveyor General of the Federation (OSGOF). Currently, NIGNET consists of sixteen stations and the network forms an integral part of the national geodetic infrastructure whilst contributing to the objectives of AFREF.

As an initiative of the United Nations Economic Commission for Africa (UNECA), AFREF has the objective of unifying and updating Africa's geodetic reference frame [11]. Upon full implementation, AFREF will comprise of a network of permanent continuously operating GNSS stations with its data being freely accessible to users anywhere in the continent. The densification of IGS networks toward the realisation of AFREF requires the establishment of a minimum of one GNSS CORS in every country within Africa [12]. According to Nwilo et al. [13], the implementation of NIGNET was initiated with the purpose of contributing to the AFREF project in line with the recommendation of the UNECA. NIGNET was linked to the International Terrestrial Reference Frame (ITRF) through continuous and simultaneous acquisition of GNSS data from nine IGS stations [14].

Due to the critical role played by NIGNET in the AFREF project, it is imperative to determine any displacement resulting from the shift in the position of the CORS. In the documentation of the results from the network adjustment of NIGNET, Nwilo et al. [13] reported that the network was successfully connected to the Nigerian Zero Order Geodetic Network and that its coordinates were referred to ITRF2008 with an accuracy of 1-10 mm. In a related effort using a post-processing technique, Iyiola et al. [3] compares the accuracy of the coordinates of fifteen passive ground control points in Osun State using the data from both NIGNET and IGS CORS for post-processing. Based on the consistency in the coordinates derived from NIGNET, and the negligible differences between NIGNET and IGS derived coordinates, the study concluded that NIGNET was a reliable network. Notwithstanding, it is evident from the scope of the work conducted that more needs to be done on the accuracy assessment to establish the reliability of NIGNET, particularly the temporal variability overtime.

More recently, Ayodele et al. [15] conducted a time-series analysis of the data from seven NIGNET stations over a period of four years (2011 – 2014). The selection and analysis of only seven stations over the period was based on stringent criteria of data availability and continuity. The aim was to understand the quality of the three-dimensional coordinates and any temporal variability. For a holistic understanding of NIGNET's performance, a combined assessment of the positional accuracy and adequacy is required for all the stations across the country. Therefore, this study aims to evaluate the positional accuracy and adequacy of all the stations in the NIGNET CORS in comparison with IGS and international standards in order to understand the usability of the network. The computation of the station coordinates was done using the GNSS Analysis and Positioning Software (GAPS) based on the principle of Precise Point Positioning (PPP). GAPS is a useful tool for determining parameters such as position, receiver clock errors, atmospheric delays and ambiguities. In comparison with other PPP services, GAPS offers some important and unique advantages. For example, it can accurately retrieve the mean multipath effect of a satellite arc, an important factor in position determination in contrast to other inaccurate multipath retrieval techniques [16]. GAPS offers two positioning services – an online positioning service and command line executable version, which can rapidly process large amounts of GNSS data [17]. A more detailed description of the software and PPP is presented in Leandro et al. [16] and Leandro et al. [18]. For validation purposes, the assessment also incorporates an IGS Station, which is believed to fulfil and comply with the guidelines defined by the IGS and standards for the acquisition of high-quality data.

2. Materials and methods

The methodology adopted in this study follows the main stages of data acquisition, processing and analysis procedure for the CORS data. Essentially, the RTKGET application program of RTKLIB was customised and used to download the RINEX files/data of the respective stations from the online network pages (NIGNET-http://mgn.nignet.net/; IGS-http://igs.org/network/). Data from two NIGNET stations (RECT located in Ile-Ife, and KANO located in Kano) were not available on the online portal during the 2011-2016 period under consideration. As a result, only datasets from 14 NIGNET stations and 2 IGS stations (CGGN and BJCO) were downloaded. Afterwards, the GAPS offline function was called via a custom code to read the downloaded RINEX files for processing.

During the processing with GAPS, the Cartesian (Earth Centered – Earth Fixed, ECEF) coordinates of the stations were determined and extracted at a sampling conformity of 30s interval and then averaged into daily coordinates. It was discovered that some of the RINEX files especially from RUST and FUTA had more of single frequency data. As such, some of the files were not successfully processed by GAPS. This is because GAPS requires information from dual frequencies in order to perform the ionospheric free combination to eliminate first order ionospheric delays. The data successfully processed from RUST was deemed sufficient for it to be retained in the analysis. However, after processing, it was further discovered that four NIGNET stations namely FUTA (Akure) in the South-West, HUKP (Katsina) in the North-West, FPNO (Owerri) in the South-East, and GEMB (Gembu) in the North-West, had excessively large data gaps which spanned over a year in some cases. Also, there was no data from the observation starting epoch of 2011 in the four stations. The two IGS stations for which data was downloaded are BJCO in Benin Republic and CGGN in Nigeria. CGGN is collocated with NIGNET's CGGT at Toro with both stations operating with the same antenna. Therefore, its accuracy metrics do not form part of the evaluation standards for NIGNET considered in this paper. After the exclusion of the stations with excessively large data gaps, the analysis proceeded with 10 NIGNET stations and 2 IGS stations.

Figure 1 shows the spatial distribution of the stations under study. In this study, a total number of 1875 data files were downloaded for station BJCO over a period of 6 years from 2011 to 2016. Year 2012 had the least number of observations for station BJCO with 248 observations while year 2014 had the highest number with 362 observations. During this same period, a total number of 12,447 data files were downloaded from the ten NIGNET stations. Within the NIGNET, MDGR had the least observations, 369 attributed to severe service disruptions while FUTY had the highest number of observations, with 1,799 data files.

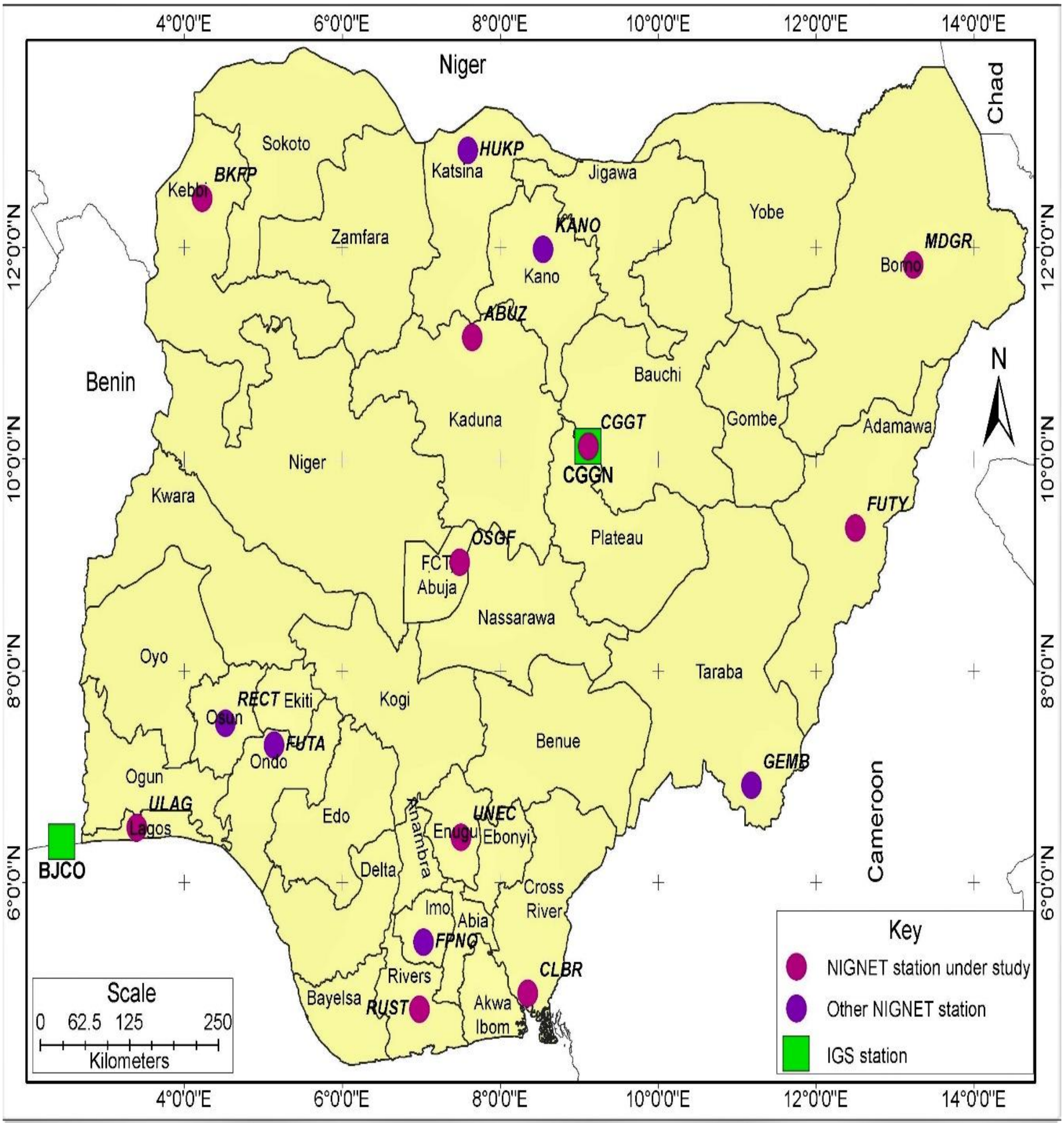

Figure 1 The distribution of the NIGNET CORS in Nigeria.

The determination of the coordinates of the stations using GAPS was followed by the data processing and analysis phase,which utilised R (a language for computing and statistical analysis). Using the Tukey's method, values greater than $Q3 + 1.5 * IQR$ and values less than $Q1 - 1.5 * IQR$, are referred to as the outliers, where $Q1$,$Q3$and IQR are the lower quartile, upper quartile, and inter-quartile range respectively [19]. This method of outlier detection was used to explore the distribution and other properties of the daily coordinates computed using GAPS. After the outlier elimination, the initial coordinates for each station were obtained by taking the average of the daily coordinates for the first months of observation while the daily coordinates after the first months were retained for further analysis. This approach of averaging the daily coordinates of the first months of observation to determine the initial coordinates of the stations is in line with the approach by Janssen [20]. The author recommends the use of coordinates determined during installation, after six months and eighteen months and every two years thereafter as reference marks for Tiers 1 and 2 CORS. The temporal stability and accuracy assessment for each station in line with the assessment guidelines was based on this set of initial coordinates. In the accuracy assessment, the mean coordinate differences, standard deviation (SD) and standard error of the mean (SEM) were computed across the stations. The coordinate differences were determined by subtracting the daily coordinates from the initial coordinates. The formula for SD is given as follows:

$$\text{SD } (\sigma) = \sqrt{\frac{\sum_{i=1}^{n}(c_i - \bar{c})^2}{n-1}} \qquad (1)$$

Where c_i= daily station coordinates, $\bar{c}$ = initial station coordinates, and n is the number of observations. The SEM is the standard deviation of the sampling distribution of the mean. It is given as follows:

$$\text{SEM } (\sigma_m) = \frac{\sigma}{n} \qquad (2)$$

Based on the IGS requirements, CORS should have long time series of continual stable measurements with little or no disruptions and configuration changes [21]. For CORS in the Tiers 1 and 2 categories, ICSM [6] recommends less than 8min/day and 9hr/year of data outage, while for CORS in the Tiers 3 category, data outage should be less than 15min/day and 44hr/year. In the analysis of the adequacy of NIGNET, the summary statistics of the data count from the NIGNET and IGS stations were compiled. The total number of observations per year was derived by summing the number of daily observations obtained throughout the year. These daily observations were obtained from the daily average of the initial coordinates of the downloaded data, which was at 30-second sampling interval. Also, the total number of the unprocessed data files across all the stations was calculated. These values were arrived at by subtracting the total number of the processed data files from the total number of the downloaded data files. The final coordinates of the network stations were computed from the coordinates overtime to obtain the most probable values. The next section presents the results obtained and the analysis.

3. Results and discussion

3.1 Evaluation of the initial station coordinates

The first step considered in the evaluation of the initial coordinates utilised boxplots to rapidly explore the data. Figure 2 presents the boxplots of the computed coordinate differences from the twelve stations for year 2011 in the three-dimensional coordinates. From the boxplots, it is to be noted that some of the stations such as OSGF and CGGT still present some outlying points after the first run, which is attributed to the limitation of the Tukey's method. A more robust approach using the Mahalanobis distance method was considered in another study [22].

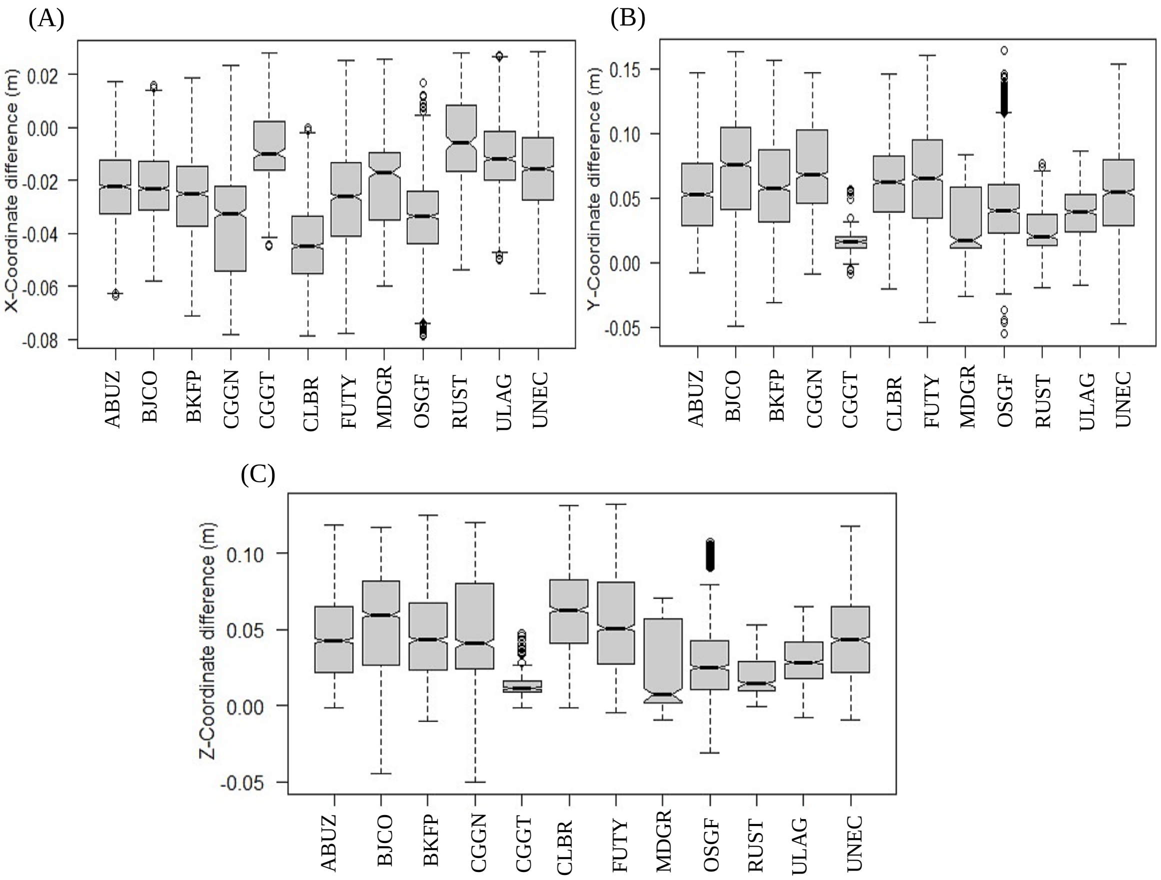

Figure 2 (A) Boxplots of coordinate differences at all stations for year 2011 in the x direction, (B) Boxplots of coordinate differences at all stations for year 2011 in the y direction and (C) Boxplots of coordinate differences at all stations for year 2011 in the z directions.

Following the exploratory analysis and determination of the initial coordinates of the stations, the standard deviation values (SDs) of the initial coordinates were computed. The IGS station, BJCO has SDs of 8.9 mm in the x-direction, 9.1 mm in the y-direction and 4.4 mm in z-direction. Generally, MDGR has the lowest SD value of 4.9 mm while CLBR has the highest SD value of 31.8 mm in the x-direction The assessment of the stations in the y-direction shows that ABUZ and BKFP have the least variability with an SD of 2.5 mm while OSGF has the highest variability with an SD value of 11.2 mm. The CLBR and BJCO are the stations with the minimum (SD = 1.4 mm) and maximum (SD = 4.4 mm) variability in the z-direction respectively. From the preliminary assessment, there is no clear relationship between the geographical location and the variability in coordinates. This is further alluded in the random distribution of the minimum and maximum values. Also, while there is sparse data for CLBR (only 3 points), the station shows a comparable performance with the other stations with more data points given the standard deviations of 31.8 mm, 5.6 mm and 1.4 mm in the x, y and z directions respectively. Therefore, CLBR was retained in the analysis.

Figure 3 presents the histograms of the coordinate differences at all the stations for year 2011 in the three directions. The coordinate differences of most stations in the x-direction follow a normal or near-normal distribution (that is, most points are in the middle with fewer farther from the central mean value). This is a good indication that the coordinate differences in the x-direction are fairly consistent across the full range of the observed data. However, stations CGGN, CGGT, CLBR, MDGR and RUST show some significant deviation from normality which points to some inconsistency in the coordinate differences in the observed data. In the y-direction, the coordinate differences of most stations also follow a normal distribution. This also indicates that the coordinate differences in the y-direction are consistent across the full range of the observed data. However, stations CGGN CGGT, MDGR, OSGF and RUST show some significant deviation from normality. Most of the coordinate differences in the z-direction are not normally distributed. With the exception of a few stations, the non-normality is evident in the observed data from ABUZ, BJCO, BKFP, CGGN, CGGT, FUTY, MDGR, and RUST, which are stations located mostly in the northern part of the country. Generally, the patterns observed portray a high degree of stability as well as directional consistency in the normally distributed stations and variability in the stations that are not normally distributed.

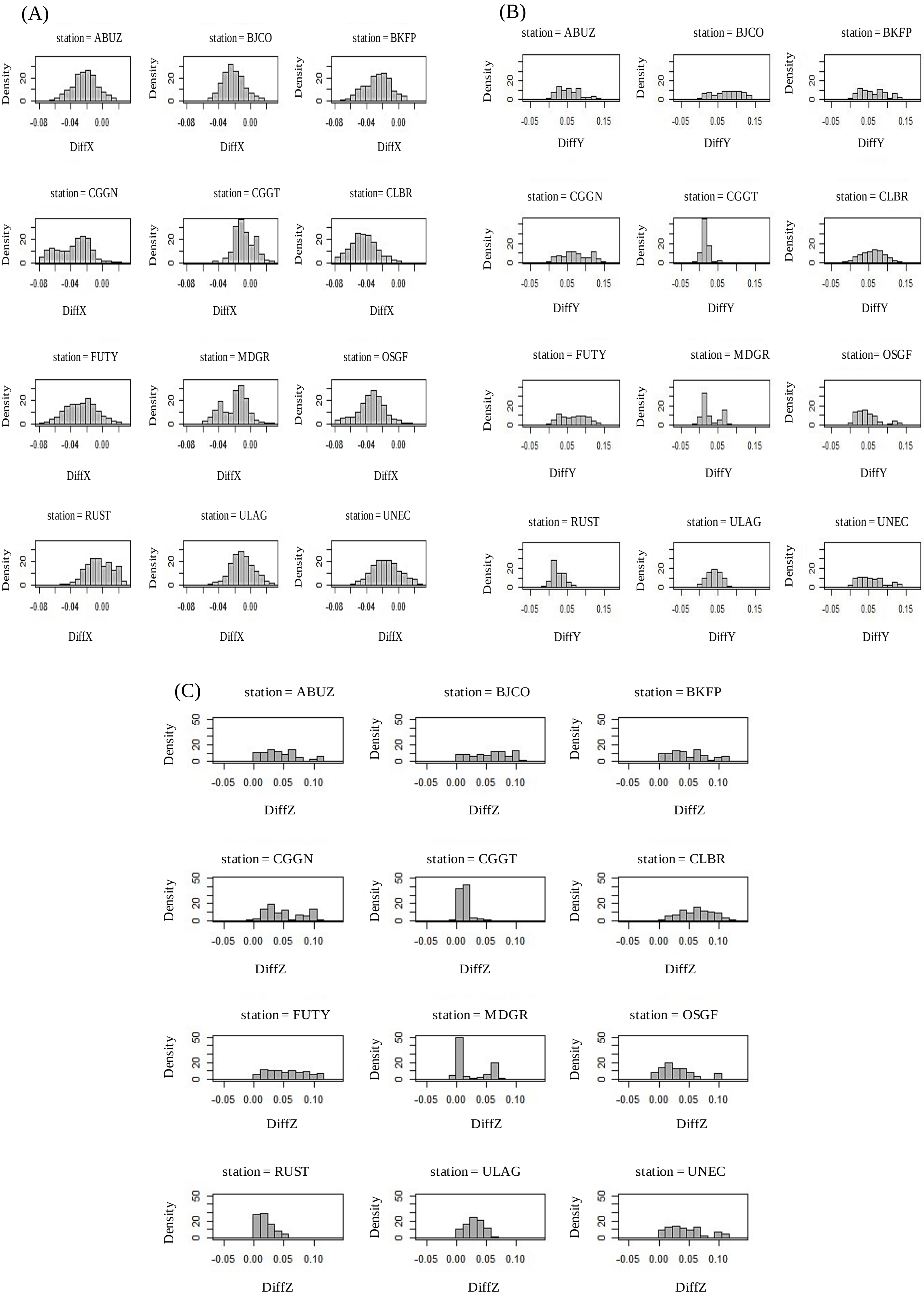

Figure 3 Histograms of the coordinate differences at all the stations for year 2011 in the x (A), y (B) and z (C) directions.

Figure 4 presents normal probability distribution plots of the coordinate differences at a station ABUZ in the three directions showing both temporal and directional variability. Similar patterns are also observed from the other stations in the network, which signify a level of consistency in trend. The symmetric or near-symmetric appearance of the normal distribution plots shows the coordinate differences have a general normal distribution and are well spread over the full range of the observed data. Also observed from the results are overlaps in the plots of 2011-2016 in the x-direction, which show a level of consistency in the coordinate differences in this direction. The incidence of overlaps reduced in the y-direction; indicating that the coordinate differences in this direction from 2011-2016 are spread out over different ranges and are thus, not as precise as the x-coordinate differences. The performance is worst in the z-direction as there are almost no overlaps in the plots. This shows little or no precision in the range of coordinate differences within the observed data in this direction over the years. In all the directions as well as in other stations, the degree of overlap reduces from 2011-2016 and this general trend shows a gradual degradation of accuracy over the years starting from 2011.

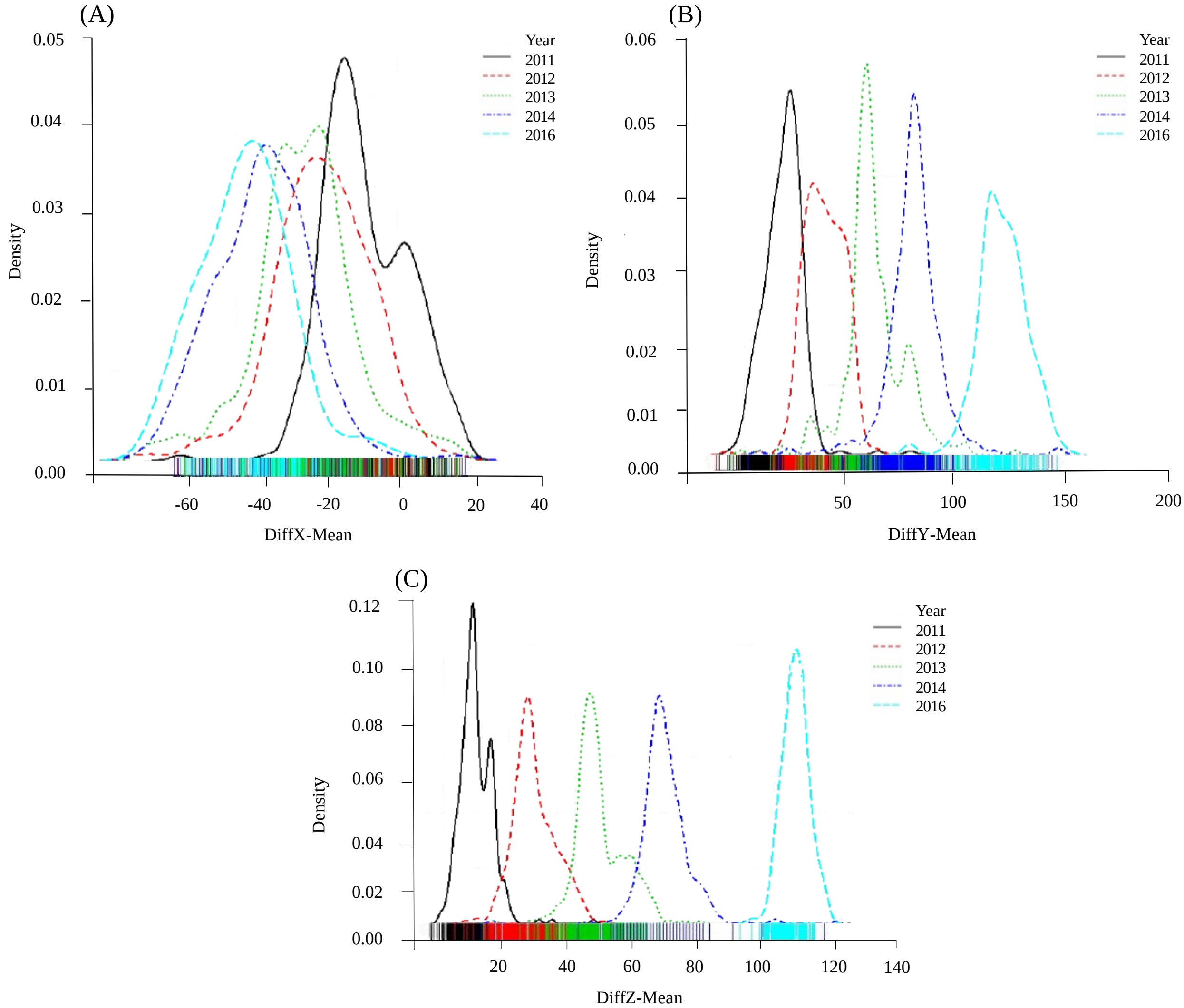

Figure 4 Normal density plot of coordinate differences at station ABUZ from 2011 – 2016 in the x (A), y (B) and z (C) directions.

3.2 Assessment of the daily coordinate differences

The daily differences vary from -79 mm to 28.5 mm in the x-direction; from -55.7 mm to 163 mm in the y-direction; and from -50.7 mm to 132.1 mm in the z-direction. Between 2011 and 2016, the minimum and maximum daily differences in the x-direction are seen at RUST (-4.4 mm) and at CLBR (-50.0 mm) respectively. In the y-direction, the lowest and highest daily differences are seen at CGGT (15.9 mm) and BJCO

(73.4 mm) respectively. In the z-direction, the lowest and highest daily differences are seen at CGGT (12.8 mm) and CLBR (62.8 mm) respectively. This metric presents the magnitude (the smaller the better) of the deviations of the data from the reference values, and as such presents a level of accuracy assessment in the data.

Figure 5 shows the daily differences between the computed initial coordinates and average yearly coordinates while Figure 6 shows the standard deviations of the daily differences between the computed initial coordinates and average yearly coordinates. For BJCO, the SD ranges from 1.5-26.7 mm in the x-direction, 16.7-73.2 mm in the y-direction, and 13.9-54.6 mm in the z-direction respectively. The maximum standard deviations observed in the x, y and z directions are 51.4 mm, 82.8 mm, and 73.5 mm respectively. Generally, for all the stations, the x-direction has the highest accuracy followed by the z-direction and the y-direction in that order.

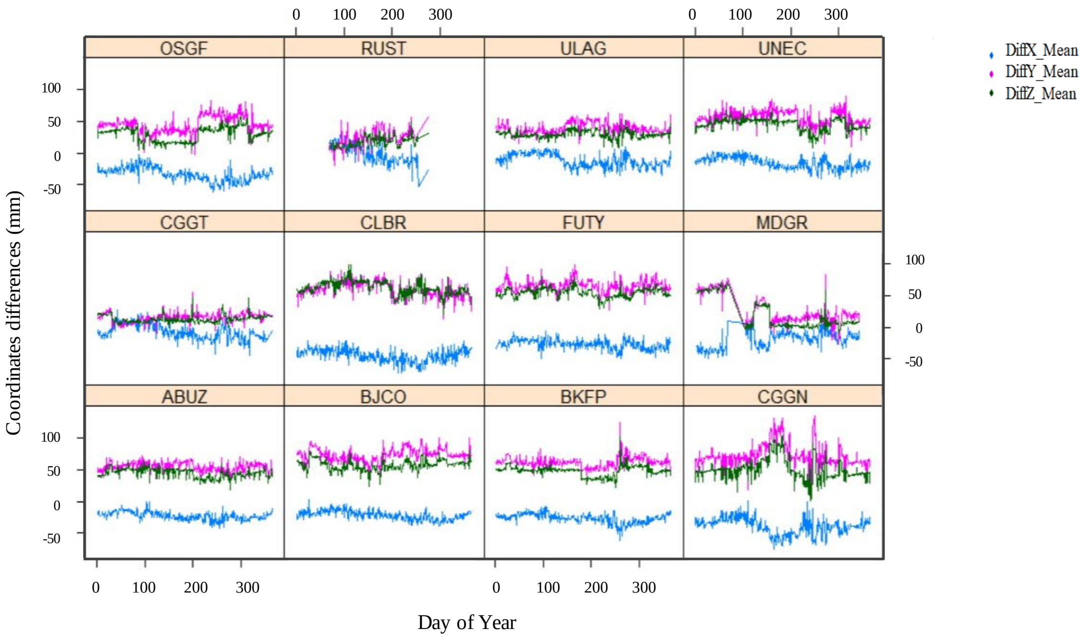

Figure 5 Daily differences between initial and average yearly coordinates.

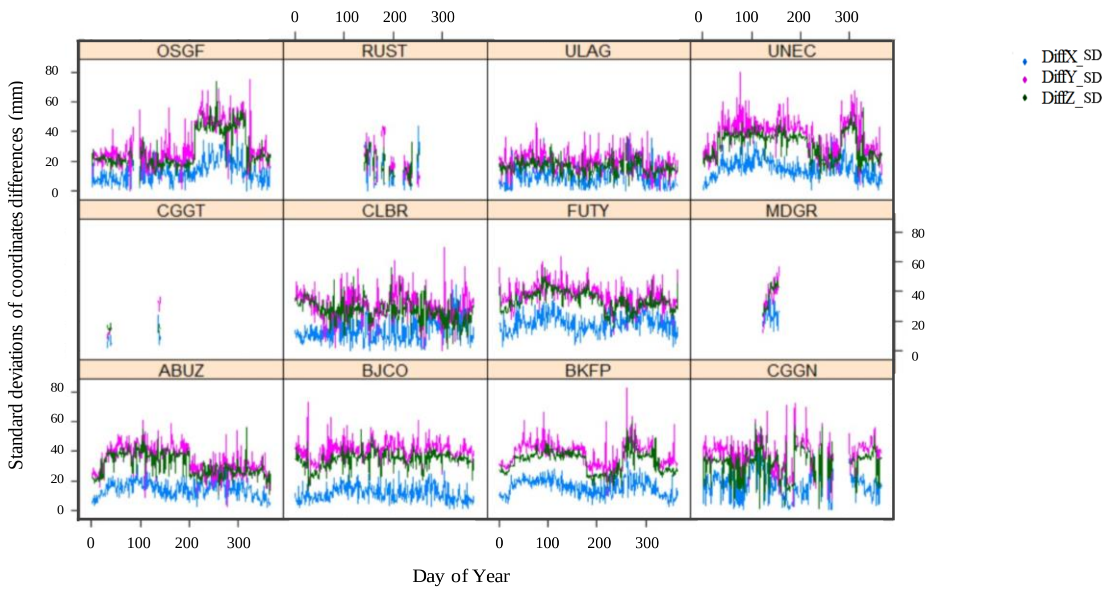

Figure 6 Standard deviations of daily differences between initial and average yearly coordinates.

Table 1 shows the mean, standard deviation and standard error of the mean (SEM) of the coordinate differences (that is, the difference between the computed initial coordinates and the average yearly coordinates). For the stations shown in Table 1, the SDs in the x, y and z-direction are denoted by SD_x, SD_y and SD_z respectively. There is a closer grouping of the coordinate differences in the y and z-directions. The trend suggests a negative correlation between the X and Y, and the X and Z coordinate differences, and positive correlation between the Y and Z coordinate differences. However, the randomness in the coordinate differences in the years of observations does not indicate the presence of systematic error. The absolute mean values of the coordinate differences in the x, y and z directions range from 4.37 mm (RUST) - 43.97 mm (CLBR); 15.86 mm (CGGT) - 73.40 mm (BJCO); and 12.76 mm (CGGT) - 62.75 mm (CLBR) respectively. The SDs of the coordinate differences range from 12.31 mm (CGGT) - 19.21 mm (FUTY) in the x-direction; 9.33 mm (CGGT) -37.72 mm (BJCO) in the y-direction; and 6.85 mm (CGGT) -32.19 mm (BJCO) in the z-direction respectively. BJCO presents high absolute mean coordinate differences in x, y and z corresponding to 21.91 mm, 73.4 mm and 56.7 mm respectively. It also records one of the highest standard deviations in its coordinate differences corresponding to 13.82 mm, in the x-direction, 37.72 mm, in the y-direction and 32.19 mm for x, y, and z in that order. These statistics show that the IGS Station, BJCO, did not perform significantly better than NIGNET. Further on the analysis, the standard error of the mean (SEM) for all the stations ranged from 0.33 mm (BJCO) - 1.07 mm (RUST) in the x-direction; 0.5 mm (CGGT) - 1.34 mm (MDGR) in the y-direction; and 0.37 mm (CGGT) - 1.44 mm (MDGR) in z-direction.

Table 1 Mean, SD and SEM of the coordinate differences from 2011 to 2016.

Stations	Coordinate Differences (mm)									N
	$\overline{x}$	SD_x	SEM_X	$\overline{y}$	SD_y	SEM_Y	$\overline{z}$	SD_z	SEM_Z	
ABUZ	-22.54	15.52	0.40	55.34	32.41	0.84	45.26	29.72	0.77	1506
BJCO	-21.91	13.82	0.33	73.40	37.72	0.91	56.70	32.19	0.78	1717
BKFP	-26.28	16.90	0.42	61.71	35.35	0.88	48.28	31.01	0.77	1613
CGGT	-7.51	12.31	0.66	15.86	9.33	0.50	12.76	6.85	0.37	350
CLBR	-43.97	16.11	0.46	60.43	29.14	0.82	62.75	26.04	0.74	1249
FUTY	-26.83	19.21	0.47	65.58	34.92	0.85	54.60	31.80	0.77	1694
MDGR	-20.47	16.07	0.88	28.21	24.52	1.34	21.91	26.30	1.44	334
OSGF	-34.76	16.84	0.50	45.93	32.04	0.96	30.50	28.15	0.84	1121
RUST	-4.37	16.47	1.07	25.05	17.48	1.14	19.00	12.75	0.83	235
ULAG	-10.52	14.53	0.49	38.18	18.92	0.64	29.20	14.51	0.49	870
UNEC	-15.33	17.58	0.46	57.54	36.61	0.97	46.36	30.90	0.82	1432

From Table 1, the average SEM of NIGNET is derived as follows:
SEM_X = 0.59 mm; SEM_Y = 0.91 mm; SEM_Z = 0.80 mm. These results show a reasonable level of absolute accuracy in the order of millimeter in the stations coordinates, which informed the computation of the final coordinates. Table 2 presents the computed final coordinates referred to as the most probable values over the period of observations for the stations. Accordingly, the values are adopted as the coordinates for the stations.

Table 2 The final coordinates of the stations.

Station	$X_f(m)$	$Y_f(m)$	$Z_f(m)$
ABUZ	6203471.286	833144.037	1225659.895
BJCO	6333054.569	271046.972	704608.807
BKFP	6211934.073	459427.186	1368163.329
CGGT	6201024.774	995293.102	1113828.282
CLBR	6287130.269	923039.891	546776.517
FUTY	6145031.670	1362144.453	1029444.514
MDGR	6080428.836	1418461.707	1299971.336
OSGF	6246436.518	820894.666	994298.441
RUST	6308854.678	772254.975	530373.458
ULAG	6326086.780	375614.285	719160.890
UNEC	6284282.977	827958.051	709034.948

Note: *f* denotes final

3.3 Analysis of the adequacy of the CORS data archive

Table 3 presents the NIGNET stations including the count of downloaded and processed daily observations. In 2011, only ABUZ, BKFP and CGGT had complete data all-year-round. Five stations (FUTY, OSGF, RUST, ULAG and UNEC) had observations downloaded for 361 days, 299 days, 304 days, 301 days and 362 days respectively. These five stations did not perform optimally at inception but had considerable number of observations compared with MDGR and CLBR which had 262 days and 36 days of observation respectively. In 2012, three stations (ABUZ, UNEC and BKFP) had the highest record of downloaded observations with no day missing. This was followed by ULAG with 364 days, and CLBR and OSGF which both recorded 363 days each. The improved performance of CLBR compared with its record in 2011 shows that it was resuscitated at the onset of 2012. FUTY logged data for 330 days in 2012 while MDGR was offline throughout the year. The least performance in 2012 was by RUST and CGGT with 132 and 39 days of observation respectively. In 2013, ULAG and UNEC retained a high level of efficiency by both logging data for 364 days. ABUZ which had recorded complete observations in the two previous years lost 10 days in 2013, BKFP lost 27 days, while RUST dropped to 52 days. FUTY recorded 361 observations which showed an improvement from the previous year. MDGR had a very abysmal record of only 11 observations while OSGF and CGGT logged 335 and 116 observations respectively. In 2013, six stations suffered a decline in the number of observations recorded from the previous year. The most alarming decline was at RUST which lost 80 days.

Table 3 Data count of the downloaded and processed daily observations.

Station	No. of Downloaded Observations (Days)						No. of Processed Observations (Days)					
	2011	2012	2013	2014	2015	*2016	2011	2012	2013	2014	2015	*2016
ABUZ	365	366	355	350	0	180	365	366	355	350	0	180
BKFP	365	366	339	365	46	221	365	366	339	365	46	220
CGGT	365	39	116	0	0	0	361	39	116	0	0	0
CLBR	36	363	340	355	284	190	36	292	340	355	277	187
FUTY	361	330	361	289	290	168	360	330	361	287	290	168
MDGR	262	0	11	96	0	0	262	0	11	96	0	0
OSGF	299	363	335	94	0	105	299	363	335	94	0	105
RUST	304	132	52	84	0	0	213	47	52	0	0	0
ULAG	301	364	364	349	0	0	301	364	295	1	0	0
UNEC	362	366	364	365	54	216	362	366	364	240	0	212
Total	3020	2689	2637	2347	674	1080	2924	2533	2568	1788	613	1072

Note: *01 January – 10 November 2016

In 2014, only BKFP and UNEC had complete days of observation all-year-round. The steady decline in ABUZ continued with a further loss of 5 days. CLBR improved with a record of 355 observations while ULAG reduced to 349 observations. FUTY suffered some lapses as its record reduced to 289 observations. MDGR OSGF and RUST recorded 96 days, 94 days and 84 days of observation respectively while CGGT was down with no observations throughout the year. In 2015, six stations were offline all-year-round. These stations include ABUZ, CGGT, MDGR, OSGF, RUST and ULAG. BKFP, UNEC, CLBR and FUTY recorded 46, 54, 284 and 290 observations respectively. In 2016, ABUZ and OSGF were brought back online, recording 180 and 105 observations respectively. CGGT, MDGR, RUST and ULAG remained inoperative and/or non-functional throughout the year. The quantity of data from BKFP improved tremendously from 46 observations in the previous year to 221 observations in 2016. CLBR, FUTY, OSGF and UNEC recorded 190, 168, 105 and 216 observations respectively.

In the period under study, ABUZ was operational for 5 years and was down in 2015. BKFP, CLBR, UNEC and FUTY were operational for the 6 years under consideration. CGGT was operational from 2011–2013 and down from 2014-2016. MDGR had poor performance through the period; its highest record was 262 observations in 2011. OSGF was online for 5 years while RUST was online from 2011-2014. ULAG was also operational for 4 years from 2011-2014. The total number of observations downloaded in the entire period are as follows - 3020 (2011), 2689 (2012), 2637 (2013), 2347 (2014), 674 (2015) and 1080 (01 January – 10 November 2016). Generally, there was a decline in the total number of downloaded observations with the highest records occurring at the inception period of NIGNET. The total number of observations processed are as follows - 2924 (2011), 2533 (2012), 2568 (2013), 1788 (2014), 613 (2015) and 1072 (01 January – 10 November 2016). It is expected that the stations have continuously stable measurements over a long period of time with little disruptions. However, this is not the case with NIGNET.

Some of the downloaded data files were single frequency data and as such were not successfully processed. Some of the reasons attributed to this fault include: failures of the receiver, power outages, poor station maintenance and data archiving. In addition, there might have been configuration issues in some of the downloaded files. Summarily, the highest percentage of the unprocessed observations was recorded in 2014 with 23.8%, followed by 2015 with 9.1%, 2012 with 5.3%, 2011 had 3.2% of the downloaded observations unprocessed, 2013 had 2.6% of the downloaded observations unprocessed and 2016 with the least percentage of unprocessed observations.

Finally, the adequacy of the network was evaluated based on the guidelines of the Intergovernmental Committee on Surveying and Mapping (ICSM), which states that data outage for Tiers 1 and 2 CORS should be less than 9 hr/year (<1day/year) and less than 44 hr/year (~2days/year) for Tier 3 CORS. Table 4 shows the percentage number of data outages recorded at the NIGNET stations based on the original downloaded data count of daily observations from 2011-2015. The analysis shows that none of the stations meets the standard for Tiers 1-3 CORS.

Table 4 Percentage number of data outages recorded at the NIGNET stations based on the original downloaded data count of daily observations from 2011-2015.

Station code	Percentage no. of data outages (days/year)					Tiers 1 and 2 standards	Tier 3 standard	Remark
	2011	2012	2013	2014	2015			
ABUZ	0.0	0.0	2.7	4.1	100.0	x	x	Not adequate for Tiers 1 – 3
BKFP	0.0	0.0	7.1	0.0	87.4	x	x	Not adequate for Tiers 1 – 3
CGGT	0.0	89.3	68.2	100.0	100.0	x	x	Not adequate for Tiers 1 – 3
CLBR	90.1	0.8	6.8	2.7	22.2	x	x	Not adequate for Tiers 1 – 3
FUTY	1.1	9.8	1.1	20.8	20.5	x	x	Not adequate for Tiers 1 – 3
MDGR	28.2	100.0	97.0	73.7	100.0	x	x	Not adequate for Tiers 1 – 3
OSGF	18.1	0.8	8.2	74.2	100.0	x	x	Not adequate for Tiers 1 – 3
RUST	16.7	63.9	85.8	77.0	100.0	x	x	Not adequate for Tiers 1 – 3
ULAG	17.5	0.5	0.3	4.4	100.0	x	x	Not adequate for Tiers 1 – 3
UNEC	0.8	0.0	0.3	0.0	85.2	x	x	Not adequate for Tiers 1 – 3

4. Conclusion

This study utilized Precise Point Positioning technique to determine the three-dimensional coordinates of the Nigerian CORS network. The assessment of the position accuracy of NIGNET carried out in this study is essential to determine its suitability to address geodetic problems that include defining a geodetic reference frame for Africa. This study has shown that while some of the NIGNET stations such as GEMB, FUTA, HUKP and FPNO are grossly deficient, the positional accuracy of the analyzed stations is comparable to the accuracy of the IGS station (BJCO) used as reference. Generally, this study found that in the three dimensions, the IGS stations do not show any significant difference in terms of the positional accuracy when compared with the NIGNET stations. One interesting result is the consistency observed in the trend of the three-dimensional coordinates across all the stations overtime. Therefore, it is inferred that the NIGNET stations are performing optimally in terms of the positional accuracy of the three-dimensional coordinates being transmitted, and as such can be utilised for relevant applications. However, it is essential that concerted efforts of stakeholders should be directed to sustaining and/or improving the current achievable accuracy whilst resuscitating the stations that are currently not transmitting any data. This is essential for both service delivery and continuity. Furthermore, it would ensure that benefits of the money invested in NIGNET are optimally accrued. Also, while this assessment is conducted in the Cartesian earth-centered-earth-fixed (ECEF) system, it is also necessary to understand the accuracy of the stations in the local topocentric system, ENU (East, North, Up). This will be considered in the future study to understand the velocity component of the network.

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6. Conflicts of interest

The authors declare no conflict of interest.

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