Realization of time-dependent geocentric datum transformation parameters for Nigeria

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Abstract

Geodetic reference frames were established decades ago by classical surveying techniques; however, due to biases caused by poor observation techniques and effects of plate tectonic, the origins are poorly defined and adopted. Due to plate tectonics, the relative position of points changes with time and therefore, datum such as MINNA requires redefinition at regular intervals to be in consonant with geodetic reference frame in use. Therefore, with the Continuously Operating Reference Stations (CORS) network in Nigeria, these biases can be mitigated and a more accurate datum transformation parameter between MINNA datum and ITRF can be developed and adopted. Therefore, this study presents the results of time-dependent datum transformation parameters proposed for Nigeria using 5-years GNSS data (from 2011 to 2015) obtained from the NigNet CORS. GAMIT GNSS scientific processing software was deployed in processing, while GLOBK was used for frame definition and datum transformation parameters development. Statistical assessments show the validity of the transformation parameters. The correlation value was found to be 1, root mean square error 0.00411, normalized mean absolute error $1.267\text{E}-10$ and reliability index 1.0.

Keywords Datum · Geocentric · Nigeria · Transformation parameters

1 Introduction

In recent years, the positional accuracy attainable from GNSS technology is at a millimetre level [10]. With this accuracy, coordinates change in a high pace over time due to plate tectonic motion and other geophysical phenomenon. Current and previous International Terrestrial Reference Frame (ITRF) realizations take into account tectonic plate motion and other deformation such as earthquakes. Therefore, coordinates of points with every new realization of ITRF change even at a later epoch of same realization.

The coordinates of geodetic datum are the fundamentals for positioning. However, GIS and surveying software as well as spatial data do not consider continuous changes in coordinates, meaning that national datum and coordinates are assumed fixed with time. Similarly, geodetic

networks are known to form the basis of investigating the shape, dimension and in many cases the gravity field of the earth [10, 26]. Therefore, positioning is a major stakeholder in modern day society in that it is of interest in navigation and guidance, datum realization, crustal deformation, plate tectonic studies, amongst others.

Geodetic datums are curved reference surfaces used to express position with adopted ellipsoid of revolution, size and shape [10, 29]. Generally, local geodetic datums whose ellipsoid does not coincide with the earth's centre of mass and geocentric datum whose ellipsoid coincides with the earth's centre of mass are the two fundamental categories of geodetic datum [10]. Geodetic datum can be static, dynamic and semi-dynamic [9, 25, 27]. Traditional geodetic datums are assumed static in nature. This is because they consider the constantly changing earth to

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be static which is very untrue because they are affected by geological and tectonic activities.

Dynamic datum, on the other hand, is a function of time. This means that coordinates vary with time. Example of a dynamic datum is the ITRF [2, 3]. Therefore, to take into account the changing earth, the ITRF is updated after every 5 years to accommodate advances in processing and data improvement. Implementation of a dynamic datum is a very difficult task at national a level. This has to be done monthly or weekly, thereby making the choice of the correct epoch for referencing observation extremely complex [13].

Semi-dynamic datum considers the constantly changing earth's motion, but coordinates are referred to a single reference epoch [9, 25, 27]. Coordinates in a semi-dynamic datum can be propagated from the pre-defined reference epoch to an epoch of interest. What needs update is the deformation model.

Rapid advances in space-geodetic technique such as GNSS, very-long-baseline interferometry (VLBI), Global Navigation Satellite System (GNSS), Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) and their found application in geodesy and geomatics have led to a significant improvement in modern positioning and allied applications. The tectonic motion of the NUBIA plate which might result in volcanism, earthquakes and earth tremors and other deformation sources such as subsidence and soil creep [10] and un-modelled measurement biases [6] affect geodetic infrastructure (e.g. NigNet), and therefore, decrease the accuracy of reference station coordinates, thereby leading to inconsistencies in legal traceability of coordinates of NigNet coordinates over time [11].

Since the MINNA datum for Nigeria was realized based on classical methods of surveying, it is known to be subjected to biases as a result of poor observations and techniques [8]. Also, Nigerian MINNA datum is faced with biases such as inaccuracies of the scale factor by compression of the Clarke 1880, poor definition of origin, geoidal height model absence and difficulty in datum parameters determination [30]. Therefore, with these inherent errors, there is the need to move away from the still-in-use MINNA datum and adopt a new datum that is geocentric in nature as done in countries like Australia (GDA2020), China (CTRF2000), Indonesia (DGN1995), Malaysia (GDM2000), New Zealand (NZGD2000), USA (NAD83), amongst others [7, 20]. Studies of [5, 8, 12, 18, 25] further justify the need for this study, in that coordinates of points anywhere in the world will change with time. Therefore, by integrating velocity, epoch and episodic deformation information, locations of points can be kept on track. Therefore, this study presents and proposes a new time-dependent geocentric datum transformation parameters for Nigeria by processing 5 years (2011–2015) of the 14 NigNet tracking stations (Fig. 1) [19] and 9 IGS stations (Fig. 2) [22] using GAMIT for producing

Fig. 1 Spatial distribution of NigNet tracking stations with the station at KANO excluded

Fig. 2 Spatial distribution of IGS stations adopted for the study

loose constrain estimate of position and covariance matrix and GLOBK for reference frame definition.

2 Need for transformation parameters and coordinate update in Nigeria

With series of earth tremor occurrences in Nigeria, epoch-by-epoch realization of ITRF is essential so that spatial data of global, local, national and regional origin can be integrated with ease. Over the years, the development of transformation parameters for Nigeria particularly, the classical transformation which involves 7-parameter similarity (Helmert) transformation, has been met with several

technical challenges such as inaccuracies of the scale factor by compression of the Clarke 1880, poor definition of origin, geoidal height model absence and difficulty in datum parameters determination as highlighted earlier. However, with the evolution of ITRF, the 7-parameter transformation has extended to 14-parameter transformation. The additional 7 parameters describe the transition of the initial 7 parameters with time [20]. Furthermore, depending on the need, surveys in Nigeria are reported in various coordinates that include Nigeria Transverse Mercator Projection (NTM), MINNA, World Geodetic System 1984 (WGS84) and ITRF. Ensuring the compatibility and uniformity of coordinates, [7] reported that the use of different coordinate system poses danger and a difficult task to achieve.

Therefore, the optimum way to achieve centimetre-level accuracy is to relate GNSS measurements to ITRF. Therefore, ITRF-based transformation parameters will go a long way towards realization of centimetre accuracy since deformation of the earth is taken into cognisance.

Most importantly, with modern space-geodetic techniques, such as the GNSS CORS network in Nigeria, the biases due to classical observational techniques and the phenomenon of plate tectonic motion can be mitigated and a more accurate geocentric datum transformation parameters between MINNA DATUM and the known ITRF can be developed and adopted. This study therefore aims at proposing *time-dependent* geocentric datum transformation parameters for Nigeria using 5-year (2011–2015) NigNet GNSS CORS data.

3 Materials and method

3.1 Test site description

In Nigeria, an initiative to establish a Continuously Operating Reference Stations (CORS) called NIGERian Reference GNSS NETWORK (NIGNET) (see Fig. 1) which is a network of

Continuous GNSS stations kicked off in 2008 by Office of the Surveyor General of the Federation (OSGoF). The initiative was aimed at contributing to the African Reference Frame (AFREF) and serve as a primary fiducial network that will define and materialize a new reference frame based on space-geodetic technique [19]. The study area is Nigeria located on the western part of Africa Plate between latitude 4° and 14°N and longitude 2° and 15°E. The details of the dataset used for this study are presented in Table 1. The spatial distribution of the NigNet and IGS stations used for the study is presented in Figs. 1 and 2, respectively.

3.2 GNSS data processing

GAMIT/GLOBK software release 10.6 was used for processing [14–16]. GAMIT/GLOBK is a comprehensive GNSS analysis package developed at Massachusetts Institute of Technology (MIT), the Harvard Smithsonian Center for Astrophysics (CFA) and the Scripps Institute of Oceanography (SIO) for estimating station coordinate and velocities, stochastic or functional representation of post-seismic deformations, atmospheric delays, satellite orbits and Earth orientation parameters [15, 32].

Depending on the task at hand, processing in GAMIT can be in single session or automatic batch processing (invoked when there is considerable large amount of data or multiple session of data and time is needed to be saved) using scripts for example *sh_gamit* in GAMIT or *sh_glred* in GLOBK. In the automatic batch processing, which was adopted in this study, the only preparation is assembling and preparation of control files like *sestbl*, *sittbl*, *station.info*, *session.info*, etc. Models applied to account for dynamic factors include Vienna Mapping Function (VMF1) for tropospheric mapping of dry and wet mapping function, FES2004 ocean tide loading model and IERS03 solid earth tide model.

The results obtained in automatic batch processing of GAMIT are generally loose constrain estimate of position

Table 1 Summary of dataset and sources adopted for the study

S/N	Dataset(s)	Source(s)	Purpose(s)
1	RINEX files associated with 14 selected NigNet tracking stations from 1 January 2011 to 31 December 2015 (1826 days)	www.nignet.net	Time series analysis, position and velocity estimate and strain computation
2	Nine international GNSS services (IGS) stations from 1 January 2011 to 31 December 2015 (1826 days)	ftp://cddis.gsfc.nasa.gov	Position, velocity and frame realization
3	SP3 precise ephemeris orbits	http://cddis.nasa.gov	For GAMIT/GLOBK processing
4	Ocean tide loading model (FES2004)	ftp://everest.mit.edu/pub/GRIDS	Correction for ocean tide loading
5	Dry and wet Mapping function (VMF1)	ftp://everest.mit.edu/pub/GRIDS	Incorporate and estimate tropospheric delay for both dry and wet mapping function
6	Atmospheric tidal loading (ATL) and non-tidal atmospheric loading (ATML)	ftp://everest.mit.edu/pub/GRIDS/	Correction for tidal and non-tidal atmospheric loading

and covariance matrix associated with a survey station. Table 2 depicts the processing parameters adopted for this study. The ASCII h-files containing loose-constrained weighted least squares estimate of sites coordinates and variance–covariance produced by GAMIT are converted to binary H-files readable by GLOBK to produce time series, velocity and reference frame definition.

3.3 Reference frame definition

Frame realization was carried out in GLOBK by adopting the International Terrestrial Reference Frame (ITRF) as global constraints. In this study, solutions from GAMIT were constrained to ITRF2008 [2] and ITRF2014 [3] while estimating seven Helmert parameters (3 translation, 3 rotation and 1 scale) and their respective rates for each solution from GAMIT analysis. The study constrained NigNet tracking stations to global stations consisting of 9 selected IGS (see, for example, Fig. 2) sites in ITRF2008 and ITRF2014 using GLOBK. The solutions from GLOBK include velocity solution, reference frame and Euler plate motion parameters, amongst others.

3.4 Coordinates transformation method

Transformation of GNSS coordinate time series from one reference frame to another can be realized with Helmert 14-parameter or 7-parameter transformation. The Helmert 14-parameter was adopted for this study. These include 3 translations (which affects position of coordinate origin), 3 rotations (which affects orientation of coordinate axes) and 1 scale (affects length of coordinate axes), and their rates (achievable with a velocity model). The Euclidian

similarity 14-parameter datum transformation model (Eqs. 1a–1c) which includes three rotations, $T_x(t)$, $T_y(t)$, $T_z(t)$, three translation ($R_x(t)R_y(t)R_z(t)$) and a scale factor $S_c(t)$ [6, 10, 31], was adopted and tested to transform station coordinates and respective velocities at epoch 2015.9685 (2015/12/20) from ITRF08 and ITRF14 to a proposed Geocentric Datum of Nigeria (GDN). Though, Euler plate motion parameters can also be used [26].

$$X(t)_{\text{GDN}} = T_x(t) + [1 + s(t)]X(t)_{\text{ITRF}_{yy}} + R_z(t)Y(t)_{\text{ITRF}_{yy}} - R_y(t)Z(t)_{\text{ITRF}_{yy}} \quad (1a)$$

$$Y(t)_{\text{GDN}} = T_y(t) - R_z(t)X(t)_{\text{ITRF}_{yy}} + [1 + s(t)]Y(t)_{\text{ITRF}_{yy}} + R_x(t)Z(t)_{\text{ITRF}_{yy}} \quad (1b)$$

$$Z(t)_{\text{GDN}} = T_z(t) + R_y(t)X(t)_{\text{ITRF}_{yy}} + [1 + s(t)]Z(t)_{\text{ITRF}_{yy}} - R_x(t)Y(t)_{\text{ITRF}_{yy}} \quad (1c)$$

The time-related variations are assumed to be linear; therefore, the quantities can be expressed by Eq. (2) [23, 24]. Equation (2) is inputted into Eq. (1) to finally get a 7-parameter transformation model.

$$\begin{aligned} T_x &= t_x(t_0) + \dot{t}_x(t - t_0) \\ T_y &= t_y(t_0) + \dot{t}_y(t - t_0) \\ T_z &= t_z(t_0) + \dot{t}_z(t - t_0) \\ S_c &= s_c(t_0) + \dot{s}_c(t - t_0) \\ R_x &= r_x(t_0) + \dot{r}_x(t - t_0) \\ R_y &= r_y(t_0) + \dot{r}_y(t - t_0) \\ R_z &= r_z(t_0) + \dot{r}_z(t - t_0) \end{aligned} \quad (2)$$

Table 2 Basic processing parameters [4]

Parameter(s)	Description
RINEX data	30 s sampling rate
Orbital data	IGS final/precise orbit
Ocean tide loading	FES2004
Ionospheric model	Double-difference ionospheric-free (IF) linear combination
Adjustment	Kalman filter
Tropospheric delay model	Saastamoinen model
Elevation cut-off	10°
Antenna model	ELEV
Earth tide model	IERS03
Choice of experiment	Baseline
Dry and wet mapping function	New Vienna Mapping Function (VMF1)
Atmospheric tidal loading (ATL) and non-tidal atmospheric loading (ATML)	Yes
Observations	30-s sampling interval
Satellite orbits/earth orientation parameters	IGS final orbits (SP3) and IGS final EOP products
Meteorological observation source	VMF1

where the 7 Helmert parameters $r_x(t_0)$, $r_y(t_0)$, $r_z(t_0)$ ($t_x(t_0)$, $t_y(t_0)$, $t_z(t_0)$ and $s_c(t_0)$) are rotations, translation and scale parameters in the position domain, respectively, at a reference epoch, which are constant. Their respective first time derivations in the rate domain are $\dot{t}_x$, $\dot{t}_y$, $\dot{t}_z$, $\dot{r}_x$, $\dot{r}_y$, $\dot{r}_z$ and $\dot{s}_c$. The Helmert parameters and their first time derivatives are obtained by invoking a generalized constraint in *glorg* module of GLOBK.

3.5 Test statistics for validating transformation parameters

The accuracy, precision and reliability of the newly obtained transformation parameters were evaluated using standard model performance indicators. The normalized mean absolute error (NMEA) [28], root mean square error (RMSE), reliability index (RI) [21] and correlation coefficient (r) are given in Eqs. (3)–(6) [17].

$$\text{NMAE} = \frac{\sum_{i=1}^n (|\text{residuals}_i|)}{n\bar{o}} \quad (3)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^n (\text{residuals}_i)^2}{n}} \quad (4)$$

$$\text{RI} = \sqrt[n]{\frac{\sum_{i=1}^n \left(\log \frac{o_i}{p_i} \right)^2}{n}} \quad (5)$$

$$r = \frac{\sum_{i=1}^n (p_i - \bar{p})(o_i - \bar{o})}{\left[\sum_{i=1}^n (p_i - \bar{p})^2 \sum_{i=1}^n (o_i - \bar{o})^2 \right]^{1/2}} \quad (6)$$

where n is the number of NigNet tracking stations used, residuals = $p_i - o_i$ and o_i and p_i are the i th computed and

Table 3 Summary of ITRF08 and ITRF14 to geocentric datum of Nigeria 2015 (GDN15) transformation parameters and their uncertainties at reference epoch 2015.9685

ITRFyy	t_x (mm)	t_y (mm)	t_z (mm)	s_c (ppb)	r_x (mas)	r_y (mas)	r_z (mas)
Rates	$\dot{t}_x$ (mm/year)	$\dot{t}_y$ (mm/year)	$\dot{t}_z$ (mm/year)	$\dot{s}_c$ (ppb/year)	$\dot{r}_x$ (mas/year)	$\dot{r}_y$ (mas/year)	$\dot{r}_z$ (mas/year)
ITRF08	2.10 ± 0.00	−4.96 ± 0.00	3.71 ± 0.00	−0.862 ± 0.302	6.3947 ± 0.1110	42.7931 ± 0.0410	−7.5334 ± 0.1910
Rates	−7.0 ± 0.0004	3.4 ± 0.0013	−0.89 ± 0.0009	0.528 ± 0.0863	−0.3467 ± 0.0301	0.1222 ± 0.0116	0.3385 ± 0.0507
ITRF14	1.23 ± 0.00	−2.02 ± 0.00	6.66 ± 0.00	−0.141 ± 0.157	6.5439 ± 0.0558	47.2092 ± 0.0211	−7.8789 ± 0.0979
Rates	−7.0 ± 0.00027	3.4 ± 0.00080	−0.89 ± 0.00056	0.322 ± 0.05184	−0.0304 ± 0.01786	−0.0944 ± 0.00701	−0.0844 ± 0.03023

mas milli-arc seconds, ppb parts per billion

Table 4 Geocentric (ECEF) coordinates of NigNet in ITRF08 and ITRF14 at epoch 2015.9685

ITRF08 at epoch 2015.9685				ITRF14 at epoch 2015.9685		
Station	X(m)	Y(m)	Z(m)	X(m)	Y(m)	Z(m)
MDGR	6,080,449.24413	1,418,433.59502	1,299,949.51341	6,080,449.24930	1,418,433.59434	1,299,949.51197
FUTY	6,145,058.44928	1,362,078.97999	1,029,390.00286	6,145,058.45130	1,362,078.97935	1,029,390.00254
GEMB	6,213,520.30484	1,228,500.48,824	763,261.05312	6,213,520.30668	1,228,500.48737	763,261.05293
CGGT	6,201,032.23378	995,277.36236	1,113,815.58849	6,201,032.23677	995,277.36246	1,113,815.58791
CLBR	6,287,174.18547	922,979.55290	546,713.85390	6,287,174.18627	922,979.55197	546,713.85325
ABUZ	6,203,493.78641	833,088.80383	1,225,614.72227	6,203,493.78850	833,088.80337	1,225,614.72216
HUKP	6,163,727.05738	821,421.99098	1,417,029.88278	6,163,727.05973	821,421.99077	1,417,029.88284
UNEC	6,284,298.27701	827,900.62128	708,988.67915	6,284,298.27866	827,900.62052	708,988.67908
OSGF	6,246,471.22824	820,848.83991	994,268.02177	6,246,471.22987	820,848.83931	994,268.02167
FPNO	6,301,965.77800	777,495.46754	600,049.71461	6,301,965.77942	777,495.46716	600,049.71555
RUST	6,308,859.02071	772,230.02159	530,354.55584	6,308,859.04088	772,230.02224	530,354.54541
FUTA	6,301,798.91397	566,460.90180	804,956.62950	6,301,798.91615	566,460.90087	804,956.62955
BKFP	6,211,960.31340	459,365.58393	1,368,115.13291	6,211,960.31551	459,365.58363	1,368,115.13312
ULAG	6,326,097.27163	375,576.21698	719,131.77913	6,326,097.27336	375,576.21624	719,131.77930

model estimated. Similarly, $\bar{o}$ and $\bar{p}$ are the mean computed and model estimates.

4 Results and analysis

4.1 Results

While estimating translation, rotation and scale (Helmert parameters) in GLOBK, a rigorous approach of frame definition was realized through a generalized constraints, where the study minimized the adjustments of coordinates of the frame-defining sites [15] as discussed earlier in Sect. 3.4. By minimizing the adjustment of coordinates of the frame-defining sites, all of the reference sites are free to adjust, thereby revealing bad data or coordinates solutions. Table 3 shows the summary of the time-dependent geocentric transformation parameters for Nigeria.

Similarly, Tables 4 and 5 are the coordinate solutions of the adopted NigNet stations in earth-centred earth-fixed (ECEF) and geodetic coordinate system, respectively. The residuals plots of the two coordinates systems in both reference frames are presented in Fig. 3a, b, with station RUST having the highest residual. The reason for this high residual is unknown in the present study. Probably, bad stabilization might be the cause, but the post-root mean square error (post-RMS) in ITRF14 for velocity and position system stabilization yielded 0.029 mm/year and 0.087 mm, respectively. In ITRF08, the post-root mean square error (post-RMS) for velocity and position system stabilization yielded 0.049 mm/year and 0.016 mm, respectively. [15] recommended value of 1–5 mm for position system

Fig. 3 Residual plot of coordinate of **a** (in ECEF, Table 4) solutions in ITRF08 and ITRF14; **b** (in geodetic, Table 5) solutions in ITRF08 and ITRF14

stabilization. Therefore, bad stabilization is written off as the cause.

4.2 Analysis

To this end, Tables 4 and 5 present the geocentric and geodetic coordinates of the NigNet GNSS stations at epoch 2015.9685, respectively. Furthermore, the time-dependent 14-parameter datum transformation relation

Table 5 Geodetic coordinates of NigNet in ITRF08 and ITRF14 at epoch 2015.9685

ITRF08 at epoch 2015.9685				ITRF14 at epoch 2015.9685			
Station	Lat(°)	Lon(°)	<i>h</i> (m)	Lat(°)	Lon(°)	<i>h</i> (m)	
MDGR	11.8380913021	13.1310026973	348.23460	11.8380912803	13.1310026805	348.23613	
FUTY	9.3497435023	12.4977988278	247.39244	9.3497434968	12.4977988182	247.39420	
GEMB	6.9172002414	11.1839415016	1795.64560	6.9172002378	11.1839414906	1795.64719	
CGGT	10.1230954562	9.1183128390	916.43041	10.1230954464	9.1183128355	916.43324	
CLBR	4.9503019072	8.3515696770	57.17408	4.9503019008	8.3515696676	57.17468	
ABUZ	11.1517407664	7.6486883103	705.06138	11.1517407619	7.6486883036	705.06334	
HUKP	12.9211546183	7.5909143745	559.61850	12.9211546142	7.5909143697	559.62076	
UNEC	6.4248068753	7.5049922697	254.39541	6.4248068731	7.5049922610	254.39693	
OSGF	9.0276667059	7.4863427013	532.64337	9.0276667028	7.4863426940	532.64487	
FPNO	5.4345731482	7.0332392250	88.31087	5.4345731555	7.0332392200	88.31232	
RUST	4.8018369060	6.9785222775	45.57414	4.8018367969	6.9785222612	45.59330	
FUTA	7.2986402623	5.1364422289	410.58464	7.2986402604	5.1364422188	410.58673	
BKFP	12.4685775715	4.2292431369	250.00403	12.4685775694	4.2292431328	250.00611	
ULAG	6.5173274203	3.3976244443	44.55984	6.5173274201	3.3976244367	44.56153	

Table 6 Transformed geocentric (ECEF) coordinates of NigNet in ITRF08 to epoch 2011.00 using that obtained from OSGoF

Stations	Coordinates from parameters to epoch 2011.00			Coordinates from OSGoF epoch 2011.00		
	X(m)	Y(m)	Z(m)	X(m)	Y(m)	Z(m)
MDGR	6,080,449.01428	1,418,433.39115	1,299,949.72885	6,080,449.31020	1,418,433.50620	1,299,949.42040
FUTY	6,145,058.26851	1,362,078.76812	1,029,390.22314	6,145,058.48550	1,362,078.88210	1,029,389.91230
GEMB	6,213,520.17239	1,228,500.26810	763,261.27930	6,213,520.30540	1,228,500.38660	763,260.95600
CGGT	6,201,032.02147	995,277.14949	1,113,815.81819	6,201,032.26630	995,277.24960	1,113,815.51850
CLBR	6,287,174.08361	922,979.32514	546,714.08852	6,287,174.16330	922,979.44880	546,713.76520
ABUZ	6,203,493.54500	833,088.59306	1,225,614.95558	6,203,493.81020	833,088.70460	1,225,614.62980
UNEC	6,284,298.13870	827,900.39694	708,988.91515	6,284,298.29670	827,900.51990	708,988.58530
OSGF	6,246,471.03300	820,848.62272	994,268.25665	6,246,471.24960	820,848.74400	994,267.92810
RUST	6,308,858.93534	772,229.79475	530,354.78307	6,308,859.04250	772,229.93130	530,354.45830
BKFP	6,211,960.02844	459,365.37528	1,368,115.37451	6,211,960.33600	459,365.48270	1,368,115.04300
ULAG	6,326,097.11517	375,575.99096	719,132.02554	6,326,097.29100	375,576.11170	719,131.68930

Table 7 Transformed geodetic coordinates of NigNet in ITRF08 to epoch 2011.00 using that obtained from OSGoF

	Coordinates from parameters to epoch 2011.00			Coordinates from OSGF epoch 2011.00		
	Lat(°)	Long(°)	h(m)	Lat(°)	Long(°)	h(m)
MDGR	11.8380913018	13.13100269731	348.232	11.8380903963	13.1310017662	348.256
FUTY	9.3497435186	12.49779883391	247.390	9.3497426732	12.4977978863	247.392
GEMB	6.9172002632	11.18394150575	1795.643	6.9171993891	11.1839405985	1795.615
CGGT	10.1230954707	9.11831284289	916.428	10.1230948094	9.1183117765	916.432
CLBR	4.9503019252	8.35156968042	57.171	4.9503011371	8.3515687778	57.130
ABUZ	11.1517407832	7.64868831494	705.059	11.1517399270	7.6486873808	705.054
UNEC	6.4248068890	7.50499227431	254.392	6.4248060252	7.5049913378	254.391
OSGF	9.0276667198	7.48634270492	532.641	9.0276658561	7.4863418111	532.637
RUST	4.8018368080	6.97852227960	45.590	4.8018360187	6.9785214459	45.577
BKFP	12.4685775920	4.22924313986	250.001	12.4685767469	4.2292421925	250.000
ULAG	6.5173274292	3.39762444805	44.559	6.5173265996	3.3976234836	44.563

as presented in Table 3 has been developed at epoch 2015.9685 (2015/12/20). First, to assess the accuracy and validity of the transformation parameters, coordinates of some of the stations at epoch 2015.9685 as obtained from GLOBK in this study were transformed to an epoch (2011.00) in which the Office of the Surveyor General of the Federation (OSGoF) last published their coordinates. Tables 6 and 7 present the ECEF and geodetic coordinates and from OSGoF and those obtained using the transformation parameters in Tables 3, 4 and 5, respectively.

4.3 Statistics for validating transformation parameters

The accuracy, precision and reliability of the transformation parameters in Table 3 were evaluated by comparing solution obtained from the transformation parameters in ITRF08

and from OSGF using the performance indicators discussed in Sect. 3.5. Figure 4 is the scatter plot in this regard.

The correlation value R , root mean square error (RMSE), normalized mean absolute error (NMAE) and reliability index (RI) are at the bottom right: (a) the plot in the X , (b) the plot in Y and (c) the plot in Z directions, respectively, of ECEF.

RMSE measures average square error. Zero values or near indicate close match. Therefore, the RMSE (0.00411 m) of the coordinates from the two data sources is an indication of close match. NMAE assesses the absolute deviation of computed coordinates from GLOBK and that of OSGF. Values of zero or near indicate close match and vice versa. The NMAE (1.267E–10 m) of the coordinates obtained from both sources showed a close match. The RI is an indication of how the two coordinate sources differ from each other; a near one value also indicates a close match. Therefore,

Fig. 4 a–c Scatter plot of the correlation between coordinates obtained from OSGF and that computed using the developed transformation parameters in Table 3

from the two coordinate sources, the two data sources showed close match. The correlation coefficient of the data sources also yielded 1.0, which is a perfect correlation.

Similarly, [1] stated that the origin and scale between ITRF2014 and ITRF2008 are less than 5 mm. Therefore, the transformation parameters for ITRF2014 as developed in this study are also valid since the difference is within 5 mm.

5 Conclusions and recommendations

In this study, time-dependent geocentric datum transformation parameters for Nigeria using the NigNet tracking stations have been developed. The accuracy, precision and reliability of the transformation parameters using the R^2 , RMSE, NMAE and RI statistics validate the transformation

parameters developed in this study. Also the origin and scale differences between ITRF2008 and ITRF2014 found to be within 5 mm also portray the reliability of the transformation parameters.

The significance of these results is fundamental in providing a variety of applications in areas such as geophysical hazard monitoring and assessment, sea-level monitoring, mining engineering, location based services, land boundary definition (international and local boundaries), environmental mapping, navigation, civil engineering and cadastral applications.

Based on the results of the study, the followings are hereby recommended:

1. The current trend by many countries is the realization of geocentric datum based on ITRF realization. Since the old MINNA datum is filled with many deficits, Nigeria should adopt the ITRF-based geocentric datum.
2. There should be awareness within the geospatial community on the need to move away from the old MINNA datum. This is a task vested on geospatial stakeholders such OSGoF.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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