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Comparison of the Positions Computed from DGPS/GNSS Observations Using the New/Unified and Various Old Transformation Parameters in Nigeria

Eteje Sylvester Okiemute[1], Oduyebo Olujimi Fatai[2] and Olulade Sunday Adekunle[3]
Ph.D Candidate[1, 2], Lecturer[3]
Department of Surveying and Geoinformatics[1, 2, 3]
Nnamdi Azikiwe University, Awka, Anambra State, Nigeria[1, 2], Federal School of Surveying, Oyo, Oyo State, Nigeria[3]

Abstract:
The accurate computation of positions of points from DGPS/GNSS observations acquired on the WGS84 ellipsoid in each country requires the application of transformation parameters. This is because, positions are determined with respect to the local datum/ellipsoid adopted for geodetic computation in each country. Prior to the derivation of the new/unified transformation parameters which were recently published by the Office of the Surveyor-General of the Federation, OSGOF, various sets of transformation parameters were determined by different multinational oil companies for use in Nigeria. Since the positions of reasonable number of points had been computed using these old sets of transformation parameters before the new/unified ones were derived and promulgated, there is need to verify which of the positions computed with the old sets of transformation parameters agree with the positions computed with the new/unified ones. Consequently, this paper compares the positions computed from DGPS/GNSS observations using the various, old sets and the unified transformation parameters. GNSS observations of four different points were processed with Compass post processing software using the various, old sets and the unified transformation parameters to obtain the positions of the points. The coordinates of each point obtained from the processing of the observations using the old sets of transformation parameters were compared with those obtained using the unified ones. The comparison results show that the positions computed using three different (SPDC, AGIP and DMA) sets of transformation parameters agree with those computed using the unified ones.

Keywords: Processing, DGPS/GNSS Observations, New/Unified and Old Transformation Parameters, Positions

INTRODUCTION

The Navigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System (GPS) is a worldwide radio-navigation system created by the U. S. Department of Defense (DOD) to provide navigation, location, and timing information for military operations (Vail et al, 2015). The system consists of 24 satellites in space. These satellites are equipped with four atomic clocks each to provide accurate timing. They transmit two radio frequencies on two separate L-bands (L1 = 1575.42 MHz and L2=1227.60 MHz). The L1 signal consists of a Coarse/Acquisition (C/A) and a Precision (P) code. The L2 signal contains only the P-code. Only the C/A code of the L1 signal, known as the Standard Positioning Service (SPS), is available for civilian use. The L1 and L2 signals are available for military and other authorized users and provide a Precise Positioning Service (PPS) (Eteje et al, 2018)**.** The GPS system consists of three basic elements: the space segment, control segment, and user segment. The space segment consists of the constellation of up to 24 active NAVSTAR satellites in six orbital tracks. The satellites are not in geo-synchronous orbit and are in constant motion relative to a ground user. The control segment consists of several ground stations that serve as uplinks to the satellites and that make adjustments to satellite orbits and clocks when necessary. The user segment consists of the GPS receiver which will typically consist of an antenna, multi-channel receiver, and processing unit (Vail et al, 2015 and Eteje et al, 2018). The DGPS/GNSS acquires observations on the WGS84 ellipsoid. But the acquired observations are processed to determined positions on the local datum as well as the local ellipsoid adopted for geodetic computations in various countries. In the determination of positions on the local datum from DGPS/GNSS observations obtained on the WGS84 datum/ellipsoid, the seven datum transformation parameters are applied.

Prior to the determination of the new set of transformation parameters recently published by the Office of the Surveyor-General of the Federation, OSGOF, various transformation parameters had been derived and used by various multinational oil companies including academic scholars for the processing of DGPS/GNSS observations in Nigeria. These transformation parameters were determined by various groups as well as scholars for these companies. The use of various sets of transformation parameters in the country was as a result of no unified set of transformation parameters. Uzodinma and Ehigiator-Irughe (2013) gave the names of various multinational oil companies that derived their own transformation parameters for use in Nigeria as: KARIALA Consulting of Port-Harcourt (KARIALA), Shell Petroleum Developing Company (SPDC), Consolidated Oil Company (CONOIL), AGIP, CHEVRON, NORTEC, ELF and EXXON-MOBIL Oil Companies. The Defense Mapping Agency (DMA) of the United States of

America and other academic scholars such as Fajemirokun, Ezeigbo and Agajelu as given by Uzodinma and Ehigiator-Irughe (2013) also derived their individual set of transformation parameters. Some of the previously used transformation parameters were seven while the others were considered three parameters. The ones considered three parameters consist of only three translation parameters. The rotation parameters and the scale factor were all zero. For instance, those derived by the Defense Mapping Agency (DMA) of the United States of America, CHEVRON, EXXON-MOBIL and ELF.

Today, a new set of transformation parameters have been derived by academic scholars and signed into use as well published by the Office of the Surveyor-General of the Federation, OSGOF. Using the positions determined with the new as well as the unified set of transformation parameters as baselines for comparison of the same positions determined using these old sets of transformation parameters, those positions which were previously computed using the old sets of transformation parameters that agree with the positions computed with the new as well as the unified transformation parameters can be determined.

This paper presents the comparison of the positions previously computed from DGPS/GNSS observations using the various, old sets of transformation parameters with the coordinates computed using the new transformation parameters with a view of determining which of these computed positions using the old sets of transformation parameters agree with the ones computed using the new transformation parameters.

The Nigeria Geodetic Datum

The Nigeria Minna datum is a geodetic datum that is suitable for use in Nigeria-onshore and offshore. Minna datum references the Clarke 1880 (RGS) ellipsoid (Semi-major axis, a = 6378249.145m; Flattening, f = 1/293.465) and the Greenwich prime meridian. The datum origin is fundamental point: Minna base station L40. Latitude: 9°38'08.87"N, longitude: 6°30'58.76"E (of Greenwich). It is a geodetic datum for topographic mapping. It was defined by information from NIMA (Eteje et al, 2018). Uzodinma et al (2013) gave the orthometric height, *H* of station L40 as: 281.13m.

Conversion between Geodetic and Cartesian Rectangular Coordinates

Geodetic coordinates can be converted to rectangular Cartesian coordinates by (Heiskanen and Moritz, 1967, and Ziggah et al, 2017):

$$\begin{aligned} X &= (N+h)\cos\varphi\cos\lambda \\ Y &= (N+h)\cos\varphi\sin\lambda \\ Z &= \left[N(1-e^2)+h\right]\sin\varphi \end{aligned} \qquad (1)$$

Where, φ, λ and h are respectively the geodetic latitude, geodetic longitude and ellipsoidal height while X, Y, Z are the Cartesian coordinates to be estimated. *h* is ellipsoidal height (orthometric height, H + geoidal height, N). *N* in equation (1) is the radius of curvature in the prime vertical given by Ono (2009) as:

$$N = \frac{a}{(1-(2f-f^2)\sin^2\varphi)^{1/2}} \qquad (2)$$

Where, *a* is the semi-major axis while *f* is flattening given as (Eteje et al, 2018):

$$f = \frac{a-b}{a} \qquad (3)$$

b = semi-minor axis

On the other hand, rectangular Cartesian coordinates can be converted to geographic coordinates using the following (Janssen, 2009):

$$\varphi = \tan^{-1}\left[\frac{Z}{\sqrt{X^2+Y^2}}\left(1-e^2\left(\frac{N}{N+h}\right)\right)^{-1}\right] \qquad (4)$$

$$\lambda = \tan^{-1}\left[\frac{Y}{X}\right] \qquad (5)$$

$$h = \sqrt{X^2+Y^2}.\sec\varphi - N \qquad (6)$$

Where, e^2 = eccentricity squared = $2f-f^2$, N = radius of curvature as given in equation (2).

Transformation between WGS84 and Minna Datums

The processing of DGPS/GNSS observations which are always acquired on the WGS84 ellipsoid to obtain positions on the Minna datum/Clarke1880 ellipsoid requires datum transformation. This is because GPS/GNSS uses the WGS84 ellipsoid while the end datum is a local one with different ellipsoid which best fit the region of application, for instance, Minna datum. The accurate transformation of positions on the WGS84 ellipsoid to Minna Datum, Clarke 1880 ellipsoid requires the application of the seven datum transformation parameters. The application of the seven datum transformation parameters, requires their combination with the Cartesian coordinates, X, Y and Z (Eteje et al, 2018). These parameters consist of an origin shift in three dimension, (T_X, T_Y, T_Z), a rotation about each coordinate axis (R_X, R_Y, R_Z) and a change in scale (ΔS) (Ono, 2009). The model (Bursa-Wolf model) required for the transformation of positions from WGS84 ellipsoid to Minna datum is given as (Wolf, 1963, Bursa, 1966, Featherstone and Vanicek, 1999, Hakan et al, 2002 and Ono, 2009):

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{Minna} = \begin{pmatrix} T_X \\ T_Y \\ T_Z \end{pmatrix} + (1+\Delta S)\begin{pmatrix} 1 & R_Z & -R_Y \\ -R_Z & 1 & R_X \\ R_Y & -R_X & 1 \end{pmatrix}\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{WGS84} \qquad (7)$$

The transformation between the WGS84 and Minna datums consists of the following steps:

1. Conversion of the geographic coordinates (latitude, φ, longitude, λ and ellipsoidal height, h) on the WGS84 ellipsoid to Cartesian coordinates, X, Y, Z on the WGS84 datum.
2. Conversion of the Cartesian coordinates, X, Y, Z on the WGS84 datum to Cartesian coordinates on the Minna datum. This is where the seven datum transformation parameters are applied.
3. Conversion of the Cartesian coordinates on the Minna datum to geographic coordinates on the Minna datum/Clarke 1880 ellipsoid.
4. If the coordinates of points are required in the plane rectangular Nigeria Traverse Mercator, NTM and Universal Traverse Mercator, UTM, the geographic coordinates are converted to either NTM, UTM or both.

Equations (1) to (7) are used to develop programs which the post processing software normally apply during DGPS/GNSS observations processing.

The new/unified set of transformation parameters that enables positions determined in Nigeria to be accurately transformed between the WGS84 and Minna datums are given by the Office of the Surveyor-General of the Federation, OSGOF, Okeke (2014) and Okeke et al (2017) as:

Transformation Parameters from WGS 84 to Minna Datum

T_x = 93.809786m ± 0.375857310m
T_y = 89.748672m ± 0.375857310m
T_z = -118.83766m ± 0.375857310m
R_x = 0.000010827829 ± 0.0000010311322
R_y = 0.0000018504213 ± 0.0000015709539
R_z = 0.0000021194542 ± 0.0000013005997
S = 0.99999393 ± 0.0000010048219

Transformation Parameters from Minna Datum to WGS 84

T_x = -93.809786m ± 0.375857310m
T_y = -89.748672m ± 0.375857310m
T_z =118.83766m ± 0.375857310m
R_x = -0.000010827829 ± 0.0000010311322
R_y = -0.0000018504213 ± 0.0000015709539
R_z =-0.0000021194542 ± 0.0000013005997
S= 1.0000061 ± 0.0000010048219

The transformation parameters previously derived for transformation between WGS84 and Minna datums by various multination oil companies and some academic scholars as given by Uzodinma and Ehigiator-Irughe (2013) are respectively shown in tables 1 and 2.

Table 1: Some Transformation Parameters Used in the Petroleum Industry in Nigeria (WGS84 to Minna Datum)

PARAMETER	**SPDC**	**CHEVRON**	**EXXON- MOBIL**	**AGIP**	**DMA**	**NORTEC**	**KARIALA**	**ELF**
T_X	+111.916m±2.3m	+92.968m	+94.031m	+111.916m	92m±3m	+93.200m	+113.936m±1.21m	88.98m
T_Y	+88.852m±2.3m	+89.582m	+83.317m	+87.852m	93m±6m	93.310m	+88.918m±1.21m	83.23m
T_Z	-114.499m±2.3m	-116.39m	-116.708m	-114.499m	-122m±5m	-121.156m	-113.701m±1.21m	-133.55m
Rx	-1.87527”±0.33”			-1.87527”		-1.93”	+1.881”±0.55”	
Ry	-0.20214”±1.61”			-0.20214”		-0.41”	0.204”±0.10”	
Rz	-0.21935”±0.19”			-0.21935”		+0.14”	+0.222”±0.11”	
Scale(ppm)	-0.03245±0.20			-0.03245		-21.2688	-0.017±0.17	

Source: Fubara, (2011), and Uzodinma and Ehigiator-Irughe (2013)

Table 2: Other Datum Transformation Parameters Derived by Some Academic Scholars for use in Nigeria (WGS84 to Minna)

PARAMETER	**FAJEMIROKUN**	**EZEIGBO**	**AGAJELU**
T_X	-160.4m±0.1m	-92.9m±1.6m	-90.1m±1.8m
T_Y	-67.4m±0.0m	-116.0m±2.3m	-107.7m±1.8m
T_Z	144.0m±0m	116.4m±2.4m	116.9m±1.8m
R_X	00. 4”±3.0”	00. 33”±1.1”	00. 08”±0.8”
R_Y	1.20”±4.6”	04.20” ±1.7”	-00.35”±1.3”
R_Z	01.70”±3.7”	01.70”±1.5”	-01.73”±0.8”
Scale(ppm)	1 ± 1.4	20± 6	3.43±1.3

Source: Ezeigbo, (2004), and Uzodinma and Ehigiator-Irughe (2013)

METHODOLOGY

The methodology adopted in this study is divided into data acquisition, data processing, and results presentation and analysis. Figure 1 shows the flow chart of the adopted methodology.

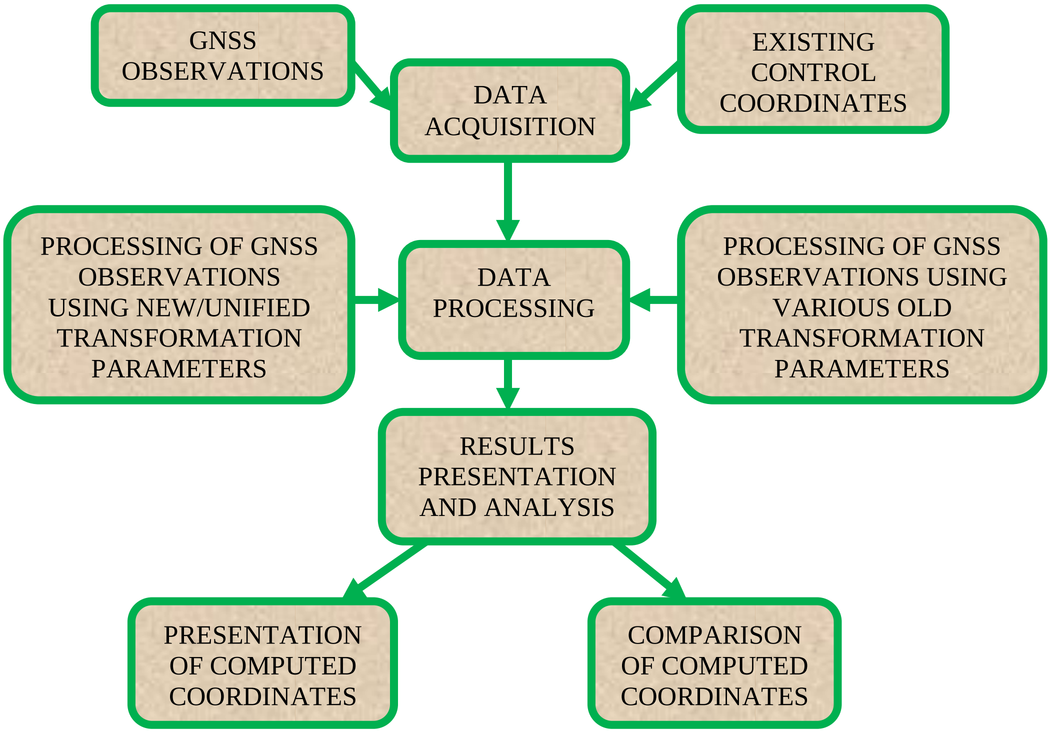

Fig. 1: Adopted Methodology Flow Chart

Data Acquisition

The data used in this study were GNSS observation data acquired using CHC900 GNSS dual frequency receivers. A total of four new stations (GPSESO1, GPSESO2, GPSESO3 and GPSESO4) were observed with respect to a control station (ASPXW42A). The observations were carried out with three GNSS receivers, two rover receivers and a base receiver. The observations were carried out in two different loops. In the first loop, the base receiver was set at the control station while the two rover receivers were occupying the two new points, GPSESO1 and GPSESO2 simultaneously (see Figure 2).

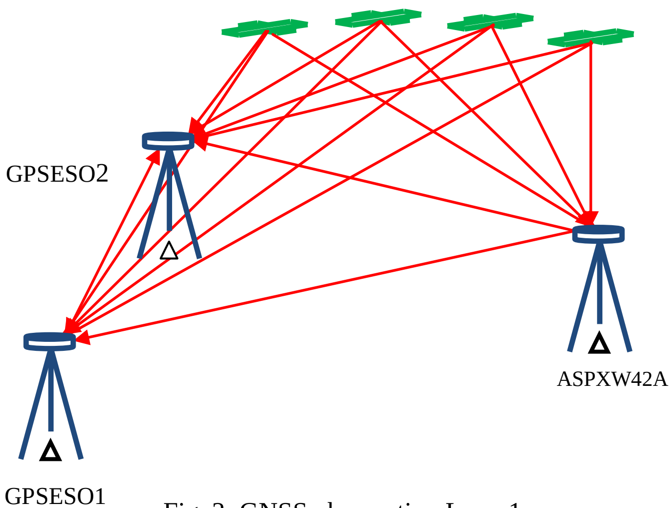

Fig. 2: GNSS observation Loop 1

In the second loop, while the base receiver still at the control station acquiring observations, the two rover receivers were moved to simultaneously occupy stations GPSESO3 and GPSESO4 (see Figure 3). Each of the four new points was occupied by the rover receiver for not less than 60 minutes during the observation.

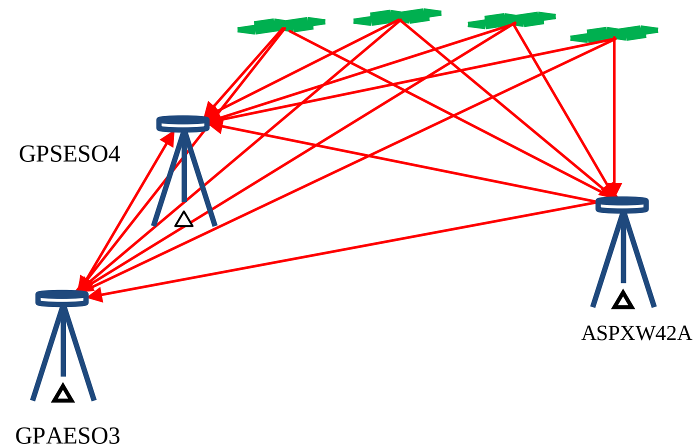

Fig. 3: GNSS observation Loop 2

Data Processing

The GNSS observations were processed using Compass post processing software. At first, the observations were processed using the new/unified set of transformation parameters as baseline positions of the points (see Figure 4). During the processing of the observations using the new transformation parameters, the scale factor was subtracted from 1 before use. This was because the processing output using the published scale factor, 0.99999393 was outrageous. Subsequently the various, old sets of transformation parameters were used one after the other to process the observations. The processing of the observations using the old sets of transformation parameters enabled the positions of the points to be determined using the old sets of transformation parameters. The positions of the points were computed in the NTM using the Nigeria west belt parameters.

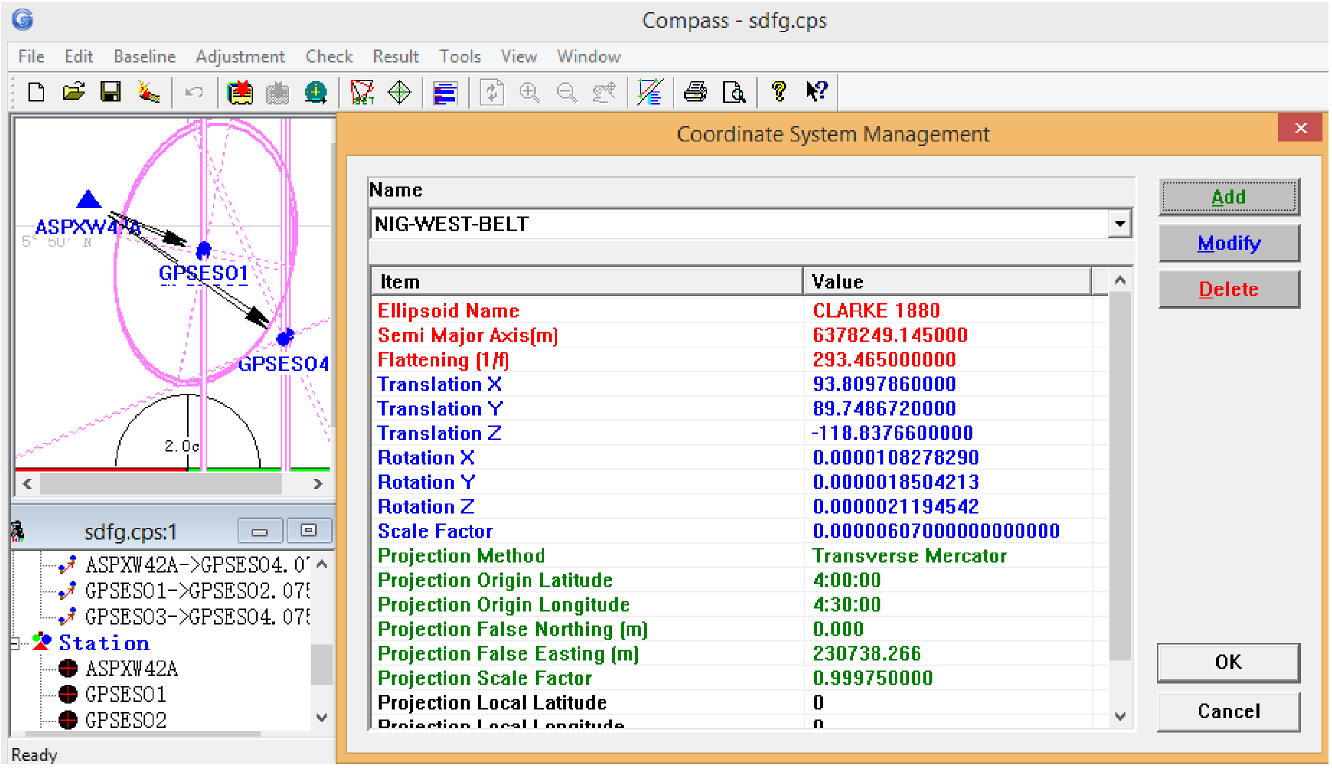

Fig. 4: Processing of GNSS Observations Using the New/Unified Transformation Parameters

Results Presentation and Analysis

Tables 3 presents the coordinates and heights of the points computed using the new/unified and the various, old sets of transformation parameters. This was done to enable the comparison between the positions obtained using the new/unified transformation parameters with those computed using the old sets of transformation parameters. From table 3, it can be seen that the positions processed with the transformation parameters derived by NORTEC were not presented. This was because the post processing software was unable to process the observations using the transformation parameters derived by NORTEC as the scale factor (-21.2688) was too large. Consequently, the entire processing was regarded as outlier and rejected.

Table 3: Coordinates of the Points Computed Using the Unified and the Old Sets of Transformation Parameters

OIL COMPANY/ RESEARCHER	GPSASE1			GPSASE2			GPSASE3			STAGPS4		
	NORTHING (m)	EASTING (m)	HEIGHT (m)	NORTHING (m)	EASTING (m)	HEIGHT (m)	NORTHING (m)	EASTING (m)	HEIGHT (m)	NORTHING (m)	EASTING (m)	HEIGHT (m)
NEW/UNIFIED	202146.0686	391672.1513	14.8752	201981.5251	391615.7296	14.1407	199786.1466	393932.7917	15.5729	199669.5063	393846.6803	15.0316
SPDC	202146.0686	391672.1513	14.8752	201981.5251	391615.7296	14.1407	199786.1466	393932.7917	15.5729	199669.5063	393846.6803	15.0316
CHEVRON	202187.9999	391567.2985	14.3628	202028.8311	391512.7071	13.6072	199905.1653	393754.5906	15.1354	199792.335	393671.273	14.5785
EXXON-MOBIL	202188.0000	391567.2982	14.3598	202028.8313	391512.7069	13.6042	199905.1656	393754.5901	15.1303	199792.3353	393671.2725	14.5735
AGIP	202146.0686	391672.1514	14.8747	201981.5251	391615.7296	14.1402	199786.1466	393932.7918	15.5721	199669.5063	393846.6804	15.0308
DMA	202146.0686	391672.1514	14.8747	201981.5251	391615.7296	14.1402	199786.1466	393932.7918	15.5721	199669.5063	393846.6804	15.0308
NORTEC			-290.9023			-304.164			-246.5272			-256.3546
KARIALA	202166.3827	391621.3602	14.6304	202004.443	391565.8251	13.8858	199843.8065	393846.4704	15.3631	199729.012	393761.7123	14.8143
ELF	202187.9985	391567.3014	14.3632	202028.8295	391512.71	13.6081	199905.1615	393754.5955	15.1398	199792.3311	393671.2778	14.5832
FAJEMIROKUN	202810.9459	390003.9472	-1.5903	202731.626	389976.6489	-3.0004	201673.3331	391097.6355	1.3099	201617.1055	391055.974	0.2689
EZEIGBO	203371.0084	388589.3471	-302.4917	203363.477	388586.7471	-316.228	203262.9936	388693.5078	-256.4629	203257.6548	388689.54	-266.6416
AGAJELU	203150.9025	389146.3156	-39.9763	203115.1582	389133.9909	-42.9635	202638.2561	389640.0791	-31.4837	202612.918	389621.27	-33.6952

Tables 4 and figures 5 and 6 also present the coordinate and height differences between the positions obtained using the new/unified transformation parameters and those computed using the old sets of transformation parameters. This was done to enable the differences in northings, eastings and ellipsoidal heights of the observed points using the new and the old sets of transformation parameters be determined. It can be seen from table 4 that the differences in northings, eastings and ellipsoidal heights of the points computed using the transformation parameters derived by SPDC, AGIP and DMA are all zero (0.000m) except the differences in ellipsoidal heights of AGIP and DMA which are 0.001m, within millimeter standard. It can also be seen from table 4 that the differences in northings, eastings and ellipsoidal heights of the points computed with transformation parameters derived by CHEVRON, EXXON-MOBIL, AGIP, DMA, KARIALA, ELF, Fajemirokun, Ezeigbo and Agajelu respectively range from: (-41.931 to -122.829)mN, (103.023 to 178.201)mE and (0.438 to 0.534)m; (-47.306 to 122.829)mN, (103.023 to 178.202)mE and (0.443 to 0.537)m; (-20.314 to -59.506)mN, (49.905 to 86.321)mE and (0.210 to 0.255)m; (-47.304 to -122.825)mN, (103.020 to 178.196)mE and (0.433 to 0.533)m; (-664.877 to -1947.599)mN, (1639.081 to 2835.156)mE and (14.263 to 17.141)m; (-1224.940 to -3588.148)mN, (3028.983 to 5239.284)mE and (272.036 to 330.368)m; and (-1004.834 to --2943.412)mN, (2481.739 to 4292.713)mE and (47.057 to 57.104)m. The smaller the differences in northings, eastings and heights, the better the agreement. Also, the smaller the bars of the histograms, the better the agreement. It can again be seen from table 4 and figures 5 and 6 that there are no differences in northings and eastings of SPDC, AGIP and DMA as the computed differences in northings and eastings are all zero. The difference in ellipsoidal heights of SPDC is zero and those of AGIP and DMA are 1mm. This implies that the positions and ellipsoidal heights previously computed by SPDC, AGIP and DMA using their derived transformation parameters agree with those computed with the new/unified transformation parameters. It also shows that the positions were accurately determined.

Table 4: Coordinates and Height Differences

OIL COMPANY/ RESEARCHER	GPSASE1			GPSASE2			GPSASE3			STAGPS4		
	ΔN (m)	ΔE (m)	Δh (m)	ΔN (m)	ΔE (m)	Δh (m)	ΔN (m)	ΔE (m)	Δh (m)	ΔN (m)	ΔE (m)	Δh (m)
SPDC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CHEVRON	-41.931	104.853	0.512	-47.306	103.023	0.534	-119.019	178.201	0.438	-122.829	175.407	0.453
EXXON- MOBIL	-41.931	104.853	0.515	-47.306	103.023	0.537	-119.019	178.202	0.443	-122.829	175.408	0.458
AGIP	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.001
DMA	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.001
NORTEC			305.778			318.305			262.100			271.386
KARIALA	-20.314	50.791	0.245	-22.918	49.905	0.255	-57.660	86.321	0.210	-59.506	84.968	0.217
ELF	-41.930	104.850	0.512	-47.304	103.020	0.533	-119.015	178.196	0.433	-122.825	175.403	0.448
FAJEMIROKUN	-664.877	1668.204	16.466	-750.101	1639.081	17.141	-1887.186	2835.156	14.263	-1947.599	2790.706	14.763
EZEIGBO	-1224.940	3082.804	317.367	-1381.952	3028.983	330.368	-3476.847	5239.284	272.036	-3588.148	5157.140	281.673
AGAJELU	-1004.834	2525.836	54.852	-1133.633	2481.739	57.104	-2852.109	4292.713	47.057	-2943.412	4225.410	48.727

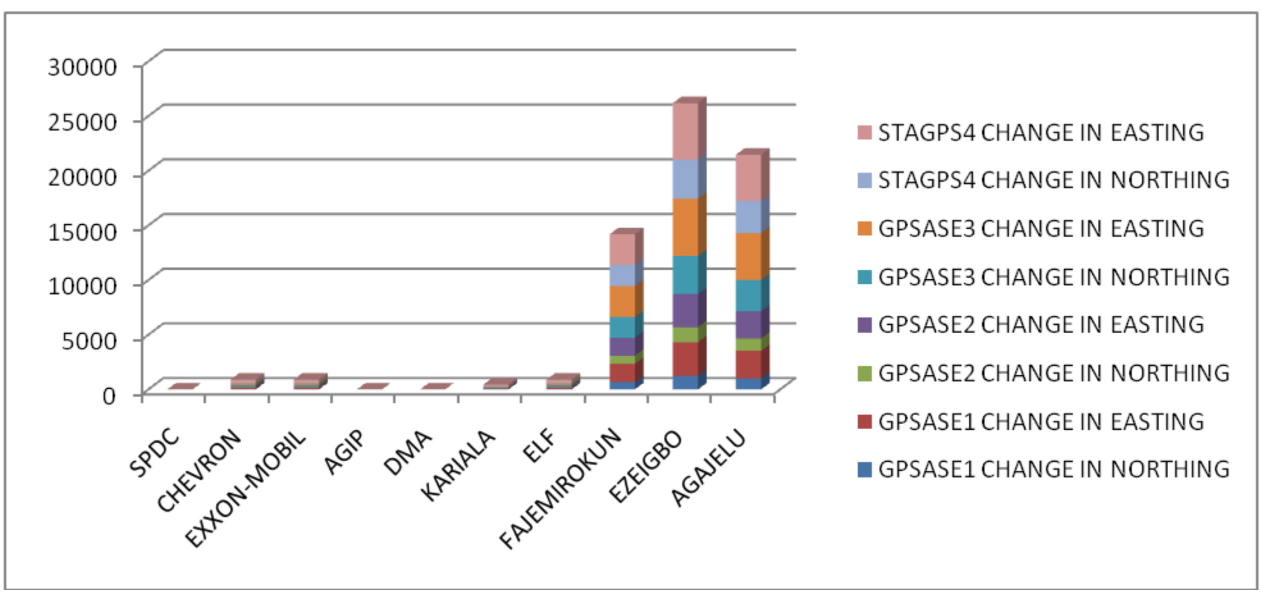

Fig. 5: Plot of Differences in Northings and Eastings

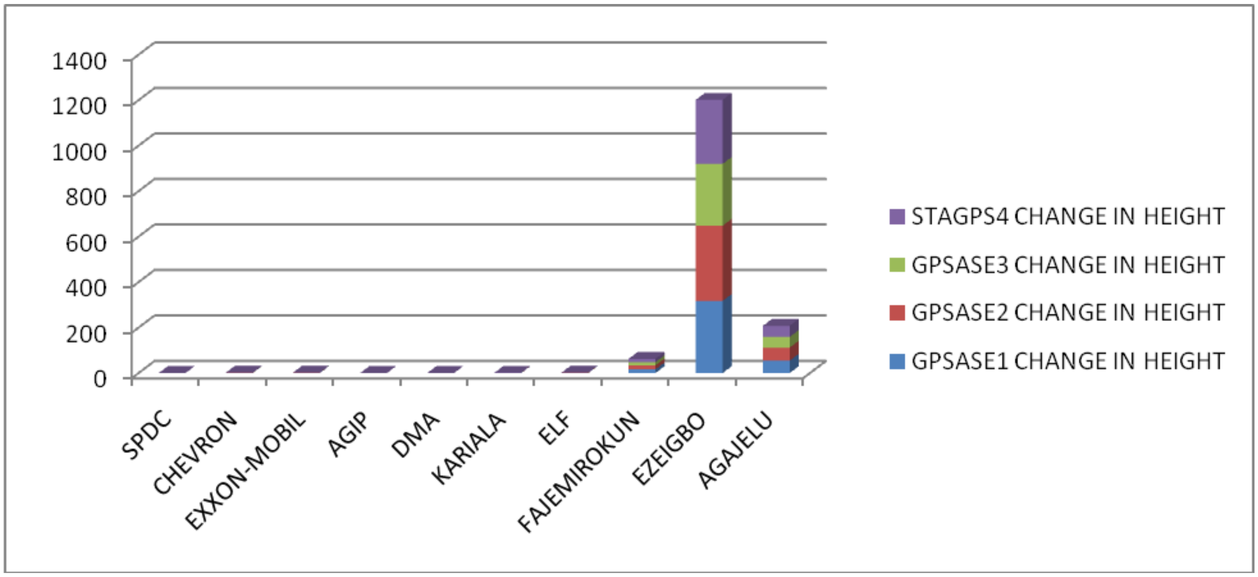

Fig. 6: Plot of Differences in Ellipsoidal Heights

CONCLUSION

Several transformation parameters were determined for use by various multinational oil companies in Nigeria. This was because there was no unified set of transformation parameters for processing of the DGPS/GNSS observations acquired on the WGS84 ellipsoid to obtain the positions of the observed points on the local datum, that is, Minna datum. Recently, a new set of transformation parameters has been derived by some academic scholars and singed into use as well published by the Office of the Surveyor-General of the Federation, OSGOF. Prior to the derivation of these new transformation parameters, the previously derived ones had been used for the computation of positions of various points in the country. In order to know those positions which were previously computed using the old sets of transformation parameters that agree with the positions computed with the new/unified transformation parameters, this paper has presented the comparison between the positions computed from DGPS/GNSS observations using the various, old sets and the unified transformation parameters. GNSS observations of four different points were processed with Compass post processing software using the various, old sets and the unified transformation parameters to obtain the positions of the points. The coordinates of each point obtained from the processing of the observations using the old sets of transformation parameters were compared with those obtained using the unified ones. The comparison results show that the positions computed using three different (SPDC, AGIP and DMA) old sets of transformation parameters are in agreement with those computed using the unified transformation parameters.

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