Removal of Inconsistencies Arising from Multiplicity of Transformation Parameters in Nigeria

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Key words: Coordinate transformation, inconsistencies, interpolation methods, geodetic datums

SUMMARY

In Nigeria, several efforts had been made in the past, by both Nigerian and foreign agencies, to determine parameters for co-ordinates transformation between the World Geodetic System of 1984 (WGS84) and the Nigerian (Minna B) Geodetic datum. None of the sets has given satisfactory results when applied in routine geodetic and engineering surveying using the GPS satellite positioning technique. Moreover, there is no set officially adopted by the government at present. Consequently, currently in the Nigerian Petroleum industry, at least eight of such transformation parameter sets are applied by different Companies. The various sets differ very significantly – in some cases giving inconsistencies as large as 45 metres. This paper studies eleven (11) of these transformation sets and describes a method for removing inconsistencies arising from their application. Corrections for the inconsistencies are estimated with a combination of Kriging and Inverse Distance Weighted (IDW) interpolation methods. This combination approach has been adopted because of the paucity of good points common to both datums (Common Points).Results obtained show that the inconsistencies were reduced (on the average) from 45metres to 0.060m (6cm), for all the transformation sets, by the method applied.

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1. INTRODUCTION

In Nigeria, it has been noticed that when coordinates of points given in the global WGS-84 (GPS) datum are transformed into the Nigerian geodetic datum (Minna B datum) via seven-parameter Helmert similarity transformation, the values recovered usually do not agree with the Official Minna B datum values. The discrepancy is usually high and is often attributed to errors arising from poor astrogeodetic definition of the origin of the Minna B datum. Several efforts had been made in the past, by both Nigerian and foreign agencies, to compute parameters for co-ordinates transformation between the World Geodetic System of 1984 (WGS84) and the Nigerian (Minna B) Geodetic datum.

None of the sets has given satisfactory results when applied in routine geodetic and engineering surveying using the GPS satellite positioning technique. Moreover, there is no transformation set officially adopted by the government at present. Consequently, currently in the Nigerian Petroleum industry, at least eight of such transformation parameter sets are applied by different Companies. The various sets differ very significantly – in some cases giving inconsistencies as large as 45 metres.

In this paper, eleven (11) different sets of transformation parameters available in the country have been studied. They were used to transform between the Minna datum and the WGS84 datum. Large discrepancies between the “transformed” and “official” coordinates were noticed for most of the sets (in some cases the discrepancy were as high forty-five (45) metres). In order to remove the inconsistencies existing between these transformation sets and hence facilitate accurate transformation between Minna and WGS84 datums, corrections for the inconsistencies were estimated with a combination of Kriging and Inverse Distance Weighted (IDW) interpolation methods. A (FORTRAN) computer program has been written by the authors to give high accuracy transformation with any 7-parameter transformation set.

The software is able to do this because it has a subroutine which takes a transformation set, determines the corresponding discrepancies at the 110 grid nodes covering the study area, and uses IDW to digitally interpolate the corrections to be applied to the 7-parameter transformed X, Y, and Z coordinates of a given point. These (X, Y, Z) corrections are determined with accuracies better than 10cm.

2. GEODETIC NETWORKS IN NIGERIA

2.1. GPS Networks in Nigeria

Observations made with Global Positioning System (GPS) navigation satellites are currently used to establish many geodetic controls all over Nigeria. In the recent past (2009/2010) the Federal government of Nigeria established eleven (11) Continuously Operating Reference Stations (CORS) located at strategic positions in the country, which capture and stream data on continuous basis to the Office of the Surveyor-General of the Federation (OSGoF) Coordinating Centre in Abuja (the Federal Capital territory). However, before this, many Oil Companies operating in the Niger Delta region of the country had established various GPS control networks to facilitate their oil exploration operations.
All these GPS observations are reduced and computed on the World Geodetic System of 1984 (WGS84 - datum) which uses a geocentric ellipsoid with the following dimensions:

$a = 6378137.0$ m
$f = 1/298.257223563$

The GPS-derived coordinates may be expressed in Cartesian (X, Y, Z), geodetic (latitude, longitude and ellipsoidal height), or Universal Transverse Mercator (UTM) plane system.

2.2. The Nigerian (Minna B) Geodetic Network

Nigeria is covered with first-order triangulation chains and traverse control networks. These networks were computed on the Nigerian geodetic datum which was established by astrogeodetic method with its origin located at station L40 (the northern terminal of the Minna base of the Nigerian Primary triangulation network). Hence the datum is a local geodetic datum called "Minna B" datum (the Minna datum applied in the west of the Republic of Cameroun is called "Minna A"). The Minna B datum is based on the Clarke 1880 ellipsoid (Semi-major axis, a = 6378249.145m; Flattening, f = 1/293.465).
The L40 origin has the following adopted geodetic co-ordinates (Uzodinma and Ezenwere, 1993):

Latitude φ = $09^{o}\ 38'\ 09''$ N
Longitude λ = $06^{o}\ 30'\ 59''$ E
Height H = 279.6m above the geoid.

Details of the establishment of Nigerian Datum can be found in (Omoigui,D.A and Fadahunsi,O., 1980).

2.3. Interconversions between a Global and Local Datum

The Bursa-Wolf and Molodensky-Badekas models are widely applied in seven-parameter three-dimensional (3-D) similarity transformation between global and local datums (Al Marzooqi, etal, 2005). The Bursa-Wolf parameters are preferred in transformations between two global geocentric datums; while the Molodensky-Badekas model is applied in transformations between a geocentric (global) datum and a non-geocentric datum (e.g. local astrogeodetic datum like the Minna datum).

The Bursa-Wolf model is expressed in matrix form with 7 parameters (Al Marzooqi, etal, 2005):

$$\begin{pmatrix} X_T \\ Y_T \\ Z_T \end{pmatrix} = M * \begin{pmatrix} 1 & -R_Z & +R_X \\ +R_Z & 1 & -R_X \\ -R_Y & +R_X & 1 \end{pmatrix} * \begin{pmatrix} X_S \\ Y_S \\ Z_S \end{pmatrix} + \begin{pmatrix} dX \\ dY \\ dZ \end{pmatrix} \text{------------- } 2.1$$

Where

X_T, Y_T, Z_T -------------------- Coordinates in the new (global) datum
X_S, Y_S, Z_S --------------------- Coordinates in the old (global) datum
R_X, R_Y, R_Z ------------------------------- Rotation Matrix
dX, dY, dZ--------------------- Translation Vector
M --------------------- Scale Factor

The Molodensky-Badekas model is the best model for datum transformation between the Nigerian (local) Minna datum and the global WGS84 datum. The model in its matrix-vector form could be written as (Al Marzooqi, Y etal, 2005):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} + \begin{bmatrix} X_M \\ Y_M \\ Z_M \end{bmatrix} + \begin{bmatrix} 1+\Delta L & R_Z & -R_Y \\ -R_Z & 1+\Delta L & R_X \\ R_Y & -R_X & 1+\Delta L \end{bmatrix} \begin{bmatrix} X'-X_M \\ Y'-Y_M \\ Z'-Z_M \end{bmatrix} \text{ ……. } 2.2$$

With:

$$X_M = \frac{1}{n}\sum_{i=1}^{n} Xi\, , \; Y_M = \frac{1}{n}\sum_{i=1}^{n} Yi\, , \; Z_M = \frac{1}{n}\sum_{i=1}^{n} Zi$$

Where:

n = the number of common points
X_M, Y_M, Z_M = the mean of the Cartesian coordinates of “common” points in the local datum.
X, Y, Z = Cartesian coordinates in the global datum
$\Delta X, \Delta Y, \Delta Z$ = the translation parameters
R_X, R_Y, R_Z = the rotation parameter
ΔL = the scale factor
X’, Y’, Z’ = Cartesian coordinates in the local datum

2.4 The Study Area and Data Used for Study

The study area covers the southern part of Nigeria as shown on Fig. 3.2 below. The data used for this study were results of a quality control project for Shell Petroleum Company of Nigeria (SPDC) limited, Port Harcourt for improved determination of Nigeria Geodetic Datum Transformation parameters for effective use of GPS for locating oil wells. In the quality control project, the GPS observations were processed using the precise ephemeris while the coordinates of points were computed in the WGS84 datum and in the relative positioning mode referenced to five IGS (International GPS service) permanent reference stations at Fortaleza in Brazil, Hartebeesthoek in South Africa, Madrid in Spain, Maspalomas 2 in Canary Islands, and Wettzel in Germany (Fubara, 1995).

Eight "common" and four "validation" points were used for our study (see Tables 3.3 and 3.4).

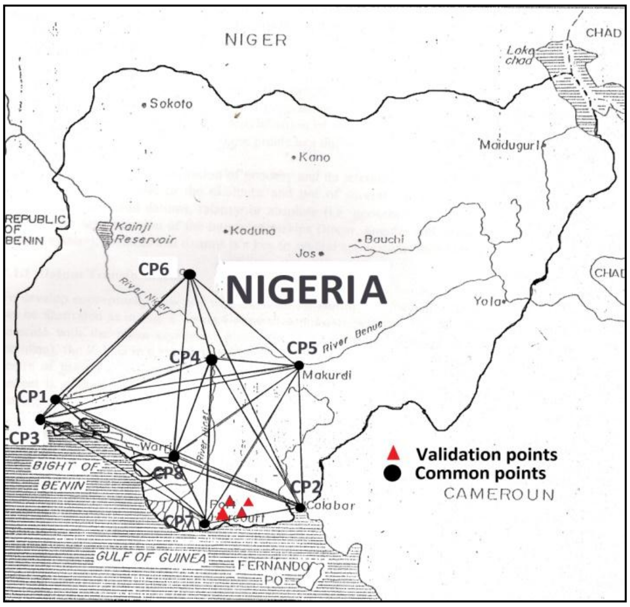

Fig.3.2: Control Network points of the Study Area (Fubara, 1995)

TABLE 3.2: OFFICIAL COORDINATES OF COMMON POINTS (degree decimals)

S/NO	STATION ID	MINNA DATUM COORDS. LATITUDE	LONGITUDE	HEIGHT(Mean Sea Level) m	WGS 84(ITRF 2008) COORDS. LATITUDE	LONGITUDE	HEIGHT (Ellipsoidal) m
1.	CP1	07 12 14.635	03 20 44.397	195.378	07 12 15.833	03 20 41.619	198.168
2.	CP2	05 07 17.371	08 20 22.008	111.265	05 07 19.304	08 20 19.778	105.584
3.	CP3	06 37 35.451	03 19 26.009	68.256	06 37 36.847	03 19 23.227	70.634
4.	CP4	07 48 26.201	06 42 49.262	438.934	07 48 27.462	06 42 46.824	437.548
5.	CP5	07 27 44.488	08 36 13.662	366.022	07 27 45.803	08 36 11.535	362.025
6.	CP6	09 38 19.885	06 33 33.980	471.012	09 38 20.581	06 33 31.311	470.679
7.	CP7	04 50 50.575	07 02 54.441	39.941	04 50 52.685	07 02 52.134	35.590
8.	CP8	05 32 19.445	05 44 18.970	25.970	05 32 21.410	05 44 16.472	23.590

3. THE CHALLENGE OF MULTIPLICITY OF TRANSFORMATION PARAMETERS IN NIGERIA

In the Nigerian Petroleum industry very many WGS84/Minna datum transformation sets are applied by different Companies. In this paper we have studied those derived for use by the Defense Mapping Agency (DMA) of the United States of America, KARIALA Consulting of

Port-Harcourt (KARIALA), Shell Petroleum Developing Company (SPDC), Consolidated Oil Company (CONOIL), AGIP, CHEVRON, NORTEC, ELF and EXXON-MOBIL Oil Companies. Their transformation parameters are shown in Table 4.1. Some transformation parameters have also been derived by some university researchers. These are shown in Table 4.2.

Table 4.1: Some Transformation Parameters Used in the Petroleum Industry in Nigeria (WGS84 to Minna Datum) (Source: Fubara, 2011)

PARAMETER	SPDC	CHEVRON	EXXON-MOBIL	AGIP	DMA	NORTEC	KARIALA	ELF
ΔX	+111.916m±2.3m	+92.968 m	+94.031 m	+111.916 m	92m±3m	+93.200 m	+113.936±1.21m	+88.98
ΔY	+88.852m±2.3 m	+89.582 m	+83.317 m	+87.852m	93m±6m	93.310m	+88.918±1.21 m	+83.23
ΔZ	-114.499m±2.3 m	-116.39m	-116.708 m	-114.499m	-122m±5 m	-121.156 m	-113.701±1.21 m	-133.55
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	

Table4.2: Other Datum Transformation Parameters Derived for use in Nigeria (WGS84 to Minna) (Source: Ezeigbo, 2004)

PARAMETER	**FAJEMIROKUN)**	**EZEIGBO**	**AGAJELU**
ΔX (m)	-160.4±0.1	-92.9±1.6	-90.1±1.8
ΔY (m)	-67.4±0.0	-116.0±2.3	-107.7±1.8
ΔZ (m)	144.0±0.0	116.4±2.4	116.9±1.8
Rx	00.̋4±3.0	00.̋33±1.1	00.̋08±0.8
Ry	1.“20±4.6	04.“20 ±1.7	-00.“35 ±01.3
Rz	01.”70±3.7	01.”70±1.5	-01.”73±0.8
Scale(ppm)	1 ± 1.4	20± 6	3.43 ± 1.3

Geodetic computations in Nigeria face challenges from this multiplicity of transformation parameters. These challenges exist because transformations done for a given point with these different sets differ sometimes by as much as 45 meters (as mentioned earlier). This is particularly a major challenge in the Nigerian Petroleum industry because wrongly transformed coordinates can lead to wrong location of an oil-well head, so that, instead of drilling oil, water may be drilled! Or at best, drilling may hit oil, but, at the wrong elevation! Another dimension to this challenge is the fact that some of these transformation sets (e.g. DMA parameters) are embedded in the configuration suites of GPS instruments and used to determine Minna B datum coordinates during field observations. These usually differ from those determined from the transformation sets used by other companies. It must however, be pointed out that this situation exists because the Nigerian Government has not adopted an official WGS84/Minna datum transformation set.

4. INTERPOLATION METHODS APPLIED

4.1. Kriging Interpolation Method

Kriging is one of the most complex and powerful interpolators. It measures the relationships between all of the sample points and then predicts the cell value. It applies sophisticated statistical methods that consider the unique characteristics of your dataset. A surface created with Kriging can exceed the known value range, but does not pass through any of the sample points (Wilson, C., 1996; Golden Software, Inc., 2002).
Suppose we have a set of k known points, P. Each point, P_i has positional parameters of the form (x_i, y_i, z_i) where x_i and y_i are the horizontal coordinates of the known point and z the value to be interpolated (e.g. height value or correction value) (z_i is known at P_i). We can then estimate the value ($\hat{z}_j$) at an unknown point, P_j by calculating the weighted sum of the known points as follows:

$$\hat{z}_j(x_j, y_j) = \sum_{i=1}^{i=k} w_i z_i \quad ....(5.11)$$

Where w_i is the weighting given to the i^{th} known point. The kriging weights of ordinary kriging fulfill the unbiasedness condition.

$$\sum_{i=1}^{k} w_i = 1 \qquad ....(5.12)$$

The error of the i^{th} estimate, r_i is the difference of the estimated value ($\hat{z}_i$) and the true (or observed) value (z_i) at the same point:

$$r_i = \hat{z}_i - z_i \quad ....(5.13)$$

Kriging uses the semivariogram, in calculating estimates of the surface at the grid nodes. In our study, we applied the Surfer software by Golden Software Inc. to produce a graphical chart for the inconsistencies in the area of study from which the inconsistencies at 30'-interval grid nodes were extracted manually and used as database for the Inverse Distance Weighted (IDW) interpolation.

4.2: Inverse Distance Weighted Interpolation Method

Inverse Distance Weighted (IDW) interpolation method takes the concept of spatial autocorrelation literally. It assumes that the nearer a sample point is to the cell whose value is to be estimated, the more closely the cell's value will resemble the sample point's value. Data are weighted during interpolation such that the influence of one point relative to another declines with distance from the grid node. Weighting is assigned to data through the use of a weighting power that controls how the weighting factors drop off as distance from a grid node increases (Davis, John C., 1986). The greater the weighting powers, the less effect points far from the grid node have during interpolation. As the power increases, the grid node value approaches the value of the nearest point. For a smaller power, the weights are more evenly distributed among the neighbouring data points.IDW works best for dense, evenly-spaced sample point sets.

Given n number of known points, P_i, with coordinates (x_i, y_i) and variable, z_i; the corresponding value of $\hat{z}_j$ at an unknown point, P_j (x_j, y_j) can be computed from (Davis, John C., 1986),:

$$\hat{z}_j = \frac{\sum_{i=1}^{n} \frac{z_i}{h_{ij}^{\beta}}}{\sum_{i=1}^{n} \frac{1}{h_{ij}^{\beta}}} \quad ....(5.21)$$

$$h_{ij} = \sqrt{d_{ij}^2 + \delta^2}$$

where:

h_{ij} = is the effective separation distance between grid node "j" and the neighbouring point "i"

$\hat{z}_j$ = is the interpolated value for grid node "j";

z_i are the neighbouring points;

d_{ij} is the distance between the grid node "j" and the neighbouring point "i" $= [(x_i - x_j)^2 + (y_i - y_j)^2]^{½}$

β is the weighting power (the *Power* parameter); and

δ is the *Smoothing* parameter.

In our application of equation (5.21), the study area was covered with grids at 30 arc minutes intervals both in latitude and longitude. The value of 2 was assigned to the power parameter,β while the value of zero was given to the smoothing parameter, δ.

5. ESTIMATION AND REMOVAL OF INCONSISTENCIES

5.1. Estimation of Inconsistencies

In order to estimate the magnitudes of the inconsistencies between the different transformation sets under study, we transformed WGS84 coordinates of "Common" points (i.e. points common to both the WGS84 and Minna B datums) to the Minna B datum and compared with the official Minna datum values obtained from the Office of the Surveyor-General of the Federation (OSGoF). The difference gives the inconsistencies in X, Y, and Z. The magnitudes of the inconsistencies depend on the quality (accuracy) of the transformation parameters applied. Good quality transformation parameters will yield small inconsistencies while poor quality ones will give large discrepancies. In our study, inconsistencies (dX, dY, dZ) are computed for the X, Y and Z of all the 8 common points available to us and contour charts produced for each transformation set using Kriging interpolation (Fig. 6.1).
The values of the inconsistencies at the grid nodes (and the 8 common points) are extracted from the chart and shown in Table 6.1. These grid node values shall be used in the Inverse Distance Weighted (IDW) interpolation of corrections for non-common points while the common point values shall be used as validation points(for the IDW-derived corrections).

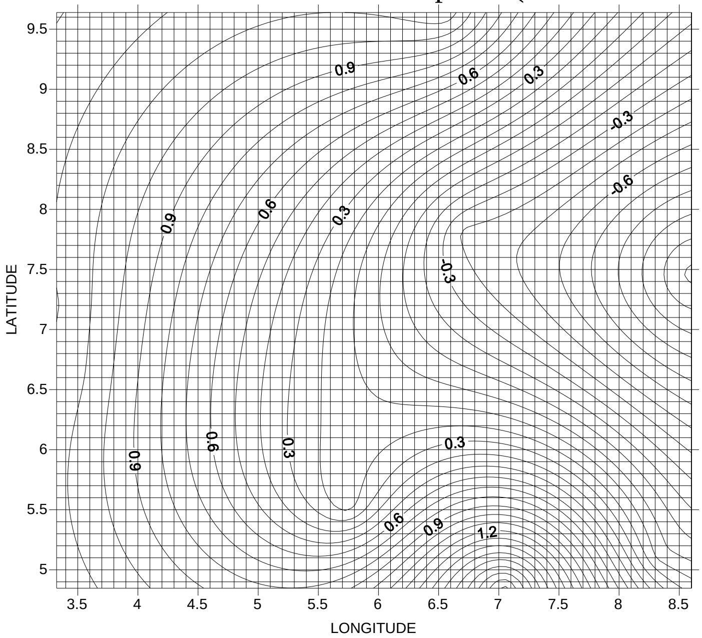

Fig. 6.1: Kriging Contour chart for corrections along the X-axis

5.2. Removal of Inconsistencies

To remove inconsistencies at a given point (non-common point), its WGS84 coordinates are transformed to Minna B datum (X_T, Y_T, Z_T). The IDW interpolation method is then used to estimate the corrections (dX_{cor}, dY_{cor}, dZ_{cor}) for the inconsistencies at the given point. Finally, these corrections are applied to the transformed coordinates (X_T, Y_T, Z_T) to obtain improved coordinates (X_I, Y_I, Z_I) from:

$$\left.\begin{array}{l} X_I = X_T + dX_{cor} \\ Y_I = Y_T + dY_{cor} \\ Z_I = Z_T + dZ_{cor} \end{array}\right\} \quad (6.1)$$

One disadvantage of this approach is that a different set of charts has to be prepared for each transformation set. In order to have one set of charts for all the transformation sets, we made some modifications to the method described above.

In the modified approach, the improved coordinates (instead of inconsistencies) of each grid node are determined (Fig. 6.2) and used to estimate correction for inconsistencies of all the transformation sets (for any given point).

6. RESULTS AND DISCUSSIONS

Table 7.1: Discrepancies from different transformation sets

STN	COMPONENTS	DISCREPANCIES										
		SPDC	CHEVRON	EXXON-MOBIL	AGIP	DMA	NORTEC	KARIALA	ELF	FAJEMIROKUN	EZEIGBO	AGAJELU
CP1	dx	1.344	20.400	19.337	1.344	21.368	22.414	-0.457	24.388	275.026	202.330	200.754
	dy	0.644	2.421	8.686	1.644	-0.997	-11.177	5.596	8.773	160.842	215.985	200.421
	dz	8.228	6.885	7.203	8.228	12.495	9.390	0.948	24.045	-254.320	-222.552	-225.509
CP2	dx	2.939	21.184	20.121	2.939	22.152	22.603	-0.493	25.172	269.960	194.537	206.666
	dy	-7.363	-3.555	2.71	-6.363	-6.973	-7.575	1.663	2.797	154.496	199.071	192.906
	dz	2.093	5.808	6.126	2.093	11.418	-1.786	4.941	22.968	-253.913	-217.519	-225.640
CP3	dx	1.475	20.470	19.407	1.475	21.438	22.775	-0.448	24.458	274.736	200.971	200.888
	dy	0.243	2.606	8.871	1.243	-0.813	-11.623	6.366	8.958	161.215	216.373	200.572
	dz	7.943	6.577	6.895	7.943	12.187	7.766	0.615	23.737	-254.614	-221.751	-225.587
CP4	dx	2.832	21.561	20.498	2.832	22.529	22.319	0.372	25.549	273.567	202.613	205.042
	dy	-2.006	-0.886	5.379	-1.006	-4.304	-6.034	1.635	5.466	156.699	204.844	196.165
	dz	-2.420	-0.365	-0.047	-2.420	5.245	0.008	-2.893	16.795	-260.681	-229.699	-232.912
CP5	dx	3.616	22.088	21.025	3.616	23.056	22.295	0.639	26.075	272.188	201.118	207.451
	dy	-7.643	-6.21	0.055	-6.643	-9.628	-7.317	-3.373	0.142	151.053	195.244	190.336
	dz	-2.293	1.671	1.989	-2.293	7.281	-0.746	1.057	18.831	-258.073	-226.110	-230.705
CP6	dx	0.84	19.788	18.725	0.840	20.756	19.556	-1.180	23.776	273.156	205.656	202.856
	dy	6.397	5.667	11.932	7.397	2.249	1.939	6.331	12.019	162.649	211.249	202.949
	dz	-4.761	-2.87	-2.552	-4.761	2.740	1.896	-5.559	14.290	-263.260	-235.660	-236.160
CP7	dx	1.011	19.377	18.314	1.011	20.345	21.413	-2.178	23.365	269.121	192.847	203.648
	dy	-8.921	-4.811	1.454	-7.921	-8.229	-12.109	0.709	1.541	153.619	200.873	191.965
	dz	-0.168	2.241	2.559	-0.168	7.851	-4.628	0.062	19.401	-257.851	-221.151	-229.122
CP8	dx	2.759	21.354	20.291	2.759	22.322	23.534	0.030	25.342	272.728	197.384	204.247
	dy	-4.253	-0.821	5.444	-3.253	-4.239	-10.486	4.017	5.531	157.683	207.720	196.346
	dz	-0.701	0.377	0.695	-0.701	5.987	-3.497	-3.135	17.537	-260.126	-224.959	-231.288

Table 7.2: Corrections to DX, DY, DZ estimated by IDW

STN	COMPONENTS	CORRECTIONS										
		SPDC	CHEVRON	EXXON-MOBIL	AGIP	DMA	NORTEC	KARIALA	ELF	FAJEMIROKUN	EZEIGBO	AGAJELU
CP1	dx	-1.344	-20.399	-19.336	-1.344	-21.367	-22.411	0.459	-24.387	-275.021	-202.315	-200.752
	dy	-0.693	-2.479	-8.744	-1.693	0.939	11.134	-5.661	-8.831	-160.900	-216.047	-200.481
	dz	-8.200	-6.856	-7.174	-8.200	-12.466	-9.343	-0.917	-24.016	254.348	222.559	225.535
CP2	dx	-2.918	-21.160	-20.0974	-2.918	-22.128	-22.568	0.520	-25.148	-269.912	-194.490	-206.666
	dy	7.372	3.560	-2.705	6.372	6.978	7.532	-1.663	-2.792	-154.485	-199.012	-192.897
	dz	-2.043	-5.7818	-6.100	-2.043	-11.392	1.849	-4.939	-22.942	253.931	217.519	225.664
CP3	dx	-1.485	-20.478	-19.415	-1.485	-21.446	-22.775	0.442	-24.466	-274.726	-200.966	-200.915
	dy	-0.092	-2.454	-8.719	-1.092	0.964	11.730	-6.215	-8.806	-161.058	-216.177	-200.415
	dz	-7.956	-6.610	-6.928	-7.956	-12.220	-7.778	-0.668	-23.770	254.575	221.708	225.553
CP4	dx	-3.018	-21.747	-20.684	-3.018	-22.715	-22.495	-0.559	-25.735	-273.757	-202.812	-205.227
	dy	2.005	0.885	-5.380	1.005	4.303	6.041	-1.635	-5.467	-156.696	-204.846	-196.171
	dz	2.417	0.364	0.047	2.417	-5.246	-0.010	2.895	-16.796	260.678	229.687	232.912
CP5	dx	-3.614	-22.096	-21.033	-3.614	-23.064	-22.318	-0.657	-26.084	-272.267	-201.207	-207.390
	dy	7.620	6.199	-0.066	6.620	9.617	7.456	3.374	-0.153	-151.073	-195.411	-190.367
	dz	2.147	-1.747	-2.065	2.147	-7.357	0.567	-1.063	-18.907	258.016	226.086	230.636

CP6	dx	-0.858	-19.800	-18.737	-0.858	-20.768	-19.607	1.174	-23.788	-273.136	-205.500	-202.864
	dy	-6.248	-5.591	-11.856	-7.248	-2.173	-1.752	-6.329	-11.943	-162.599	-211.230	-202.874
	dz	4.732	2.858	2.540	4.732	-2.752	-1.757	5.564	-14.302	263.249	235.512	236.120
CP7	dx	-0.993	-19.367	-18.304	-0.993	-20.335	-21.373	2.179	-23.355	-269.166	-193.023	-203.621
	dy	8.769	4.734	-1.531	7.769	8.152	11.972	-0.710	-1.618	-153.675	-200.945	-192.047
	dz	0.152	-2.251	-2.569	0.152	-7.861	4.440	-0.066	-19.411	257.846	221.291	229.141
CP8	dx	-2.749	-21.348	-20.285	-2.749	-22.316	-23.532	-0.031	-25.336	-272.763	-197.439	-204.206
	dy	4.227	0.809	-5.456	3.227	4.227	10.543	-4.016	-5.543	-157.698	-207.809	-196.369
	dz	0.632	-0.410	-0.728	0.632	-6.020	3.395	3.138	-17.570	260.103	224.965	231.261

Table 7.3: Discrepancies after applying corrections (DX, DY, DZ)

STN	COMPONENTS	NEW DISCREPANCIES										
		SPDC	CHEVRON	EXXON-MOBIL	AGIP	DMA	NORTEC	KARIALA	ELF	FAJEMIROKUN	EZEIGBO	AGAJELU
CP1	dx	0	0.001	0.001	0	0.001	0.003	-0.065	-0.058	0.005	-0.062	-0.06
	dy	-0.049	-0.058	-0.058	-0.049	-0.058	-0.043	0.031	0.029	-0.058	0.007	0.026
	dz	0.028	0.029	0.029	0.028	0.029	0.047	0.027	0.024	0.028	0.047	0
CP2	dx	0.021	0.024	0.0236	0.021	0.024	0.035	0	0.005	0.048	0.059	0.009
	dy	0.009	0.005	0.005	0.009	0.005	-0.043	0.002	0.026	0.011	0	0.024
	dz	0.05	0.0262	0.026	0.05	0.026	0.063	-0.006	-0.008	0.018	0.005	-0.027
CP3	dx	-0.01	-0.008	-0.008	-0.01	-0.008	0	0.151	0.152	0.01	0.196	0.157
	dy	0.151	0.152	0.152	0.151	0.151	0.107	-0.053	-0.033	0.157	-0.043	-0.034
	dz	-0.013	-0.033	-0.033	-0.013	-0.033	-0.012	-0.187	-0.186	-0.039	-0.199	-0.185
CP4	dx	-0.186	-0.186	-0.186	-0.186	-0.186	-0.176	0	-0.001	-0.19	-0.002	-0.006
	dy	-0.001	-0.001	-0.001	-0.001	-0.001	0.007	0.002	-0.001	0.003	-0.012	0
	dz	-0.003	-0.001	0	-0.003	-0.001	-0.002	-0.018	-0.009	-0.003	-0.089	0.061
CP5	dx	0.002	-0.008	-0.008	0.002	-0.008	-0.023	0.001	-0.011	-0.079	-0.167	-0.031
	dy	-0.023	-0.011	-0.011	-0.023	-0.011	0.139	-0.006	-0.076	-0.02	-0.024	-0.069
	dz	-0.146	-0.076	-0.076	-0.146	-0.076	-0.179	-0.006	-0.012	-0.057	0.156	-0.008
CP6	dx	-0.018	-0.012	-0.012	-0.018	-0.012	-0.051	0.002	0.076	0.02	0.019	0.075
	dy	0.149	0.076	0.076	0.149	0.076	0.187	0.005	-0.012	0.05	-0.148	-0.04
	dz	-0.029	-0.012	-0.012	-0.029	-0.012	0.139	0.001	0.01	-0.011	-0.176	0.027
CP7	dx	0.018	0.01	0.01	0.018	0.01	0.04	-0.001	-0.077	-0.045	-0.072	-0.082
	dy	-0.152	-0.077	-0.077	-0.152	-0.077	-0.137	-0.004	-0.01	-0.056	0.14	0.019
	dz	-0.016	-0.01	-0.01	-0.016	-0.01	-0.188	-0.001	0.006	-0.005	-0.055	0.041
CP8	dx	0.01	0.006	0.006	0.01	0.006	0.002	0.001	-0.012	-0.035	-0.089	-0.023
	dy	-0.026	-0.012	-0.012	-0.026	-0.012	0.057	0.003	-0.033	-0.015	0.006	-0.027
	dz	-0.069	-0.033	-0.033	-0.069	-0.033	-0.102	-0.065	-0.058	-0.023	-0.062	-0.06

Table 7.4: 3-D discrepancies before ("OLD") and after applying corrections ("NEW")

STN	DISCREPANCIES (m)	TRANSFORMATION SETS										
		SPDC	CHEVRON	EXXON-MOBIL	AGIP	DMA	NORTEC	KARIALA	ELF	FAJEMIROKUN	EZEIGBO	AGAJELU
CP1	OLD	8.362	21.666	22.389	8.498	24.773	26.749	5.694	35.354	407.662	370.292	362.388
	NEW	0.056	0.064	0.065	0.056	0.065	0.064	0.077	0.069	0.065	0.078	0.065
CP2	OLD	8.200	22.252	21.207	7.315	25.879	23.905	5.237	34.190	401.521	353.254	361.714
	NEW	0.055	0.036	0.035	0.055	0.036	0.084	0.006	0.028	0.052	0.059	0.037
CP3	OLD	8.082	21.658	22.425	8.174	24.673	26.723	6.411	35.240	407.797	369.297	362.594
	NEW	0.152	0.156	0.156	0.152	0.155	0.108	0.246	0.242	0.162	0.283	0.245
CP4	OLD	4.231	21.582	21.192	3.859	23.528	23.120	3.344	31.060	409.082	368.476	367.112
	NEW	0.186	0.186	0.186	0.186	0.186	0.176	0.018	0.009	0.190	0.090	0.061
CP5	OLD	8.761	23.005	21.119	7.903	26.025	23.477	3.592	32.164	404.358	360.131	363.990
	NEW	0.148	0.077	0.077	0.148	0.077	0.228	0.009	0.078	0.099	0.230	0.076
CP6	OLD	8.018	20.783	22.350	8.837	21.057	19.743	8.507	30.232	412.765	377.434	371.632
	NEW	0.153	0.078	0.078	0.153	0.078	0.239	0.005	0.078	0.055	0.231	0.089
CP7	OLD	8.980	20.091	18.549	7.987	23.308	25.031	2.291	30.409	403.128	355.595	361.690
	NEW	0.154	0.078	0.078	0.154	0.078	0.236	0.004	0.078	0.072	0.167	0.094
CP8	OLD	5.118	21.373	21.020	4.323	23.496	26.001	5.096	31.311	408.546	364.3	365.736
	NEW	0.074	0.036	0.036	0.074	0.036	0.117	0.065	0.068	0.044	0.109	0.070
Mean	**OLD**	**7.469**	**21.551**	**21.281**	**7.112**	**24.092**	**24.344**	**5.022**	**32.495**	**406.857**	**364.847**	**364.607**

Value	**NEW**	**0.122**	**0.089**	**0.089**	**0.122**	**0.089**	**0.157**	**0.054**	**0.081**	**0.092**	**0.156**	**0.092**
										Overall Mean, (m)	**OLD**	**116.334**
											NEW	**0.104**

From the discrepancies shown in Tables 7.1 and 7.4, it can be noticed that the transformation sets can be categorized into three in accordance with the magnitudes of their discrepancies as follows:

(i) Kariala, Agip, and SPDC transformation sets which gave mean discrepancies within the range 5-7.5 metres.

(ii) Exxon-Mobil, Chevron, DMA, Nortec, and ELF where mean discrepancies are within the range 21.3 -32.5m.

(iii) Agajelu, Ezeigbo, and Fajemirokun where the range of mean discrepancies is 364.6-406.9m.

Table 4.1 shows that the first category consists of 7-parameter transformation sets derived from the SPDC GPS – re-observed and reprocessed coordinates of some National primary triangulation points; while the second set comprises mainly of 3-parameter transformation sets (except for Nortec) [Fubara, 2011]. The third category is suspected to have been derived from Transit (Doppler) satellite data captured in the ADOS (African Doppler Survey) project which was computed on the WGS 72 datum and later transformed to WGS84 (Ezeigbo, 2004; Jackson, 2011). This third category was deliberately included in this study to show the power of our method in improving results obtained from transformation sets derived from heterogeneous data.

Tables 7.1 and 7.4 also show the levels of discrepancies existing among transformed coordinates used presently in the various oil companies. The absolute discrepancies can be as large as 35 metres at some stations. On the other hand, Tables 7.2, 7.3 and 7.4 show the capability of our method to reduce the absolute discrepancies to a mean value of 0.104 metres (10.4 cm) for all the transformation sets (shows 2^{nd}-order improvement).

7. CONCLUSION AND RECOMMENDATIONS

From the discussions above, the following conclusions can be drawn:

1) If the WGS84 coordinates of a given point are given, our method can use any of the transformation sets to transform them into the Minna datum (and vice-versa) with mean accuracy of 0.104m (10.4cm).

2) The Minna datum curvilinear coordinates (ϕ, λ, H) of existing primary triangulation points can be transformed to the WGS84 datum (and consequently to the African geodetic Reference Frame, AFREF) with accuracy better than 0.104m (10.4cm).

The method is therefore recommended for the reduction of the inconsistencies arising from the multiplicity of transformation sets currently used by the various petroleum exploration companies in Nigeria to the level of 10.4cm.

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