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Comparative study and determination of transformation parameters between: the permanent station system, the datum (58) and the Benin geodetic system

Leopold Degbegnon* and Pedro Aïzo
[1]Engineer in Geodesy, Department of Civil Engineering of the Polytechnic School of Abomey-Calavi, Benin
[2]Geometry Engineer, Research Master in Geomatics and Environment, University of Abomey Calavi, Benin
leopolddegbegnon@yahoo.fr

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Abstract

Topographic work in BENIN has been carried out in three different systems. The first works that were carried out before 1980 are in the Datum system (58), the second ones that were developed in the mid-90s are in the Geodetic System of Benin (SGB) and the last ones that date from 2010 are calibrated in the called Permanent Stations System (RSPB). The problem for geomatics players is to find a bridge to bring back the old works in the last system, since the system of permanent stations will now be the only system of our works according to the decree N ° 0068 / MUHRFLEC / DC / SGM / lGN / DGURF / SA of 28 December 2009. Indeed, two alternatives arise: The resumption of observations on the ground for all the old works, which is very tedious and expensive when it is possible. This alternative is only possible if the physical terminals or points actually exist, this is not the case for the first BENIN cards for which the terminals were destroyed. The second is the elaboration from the very precise GNSS observations on the entire national territory of the calculation of the transformation parameters from the BURSA - WOLF formula. We directed our research on the determination of these parameters after observing a total of 18 first-order geodesic terminals in the system of permanent stations whose coordinates were known in the Datum 58 system and the BENIN Geodetic Network. The calculation of the parameters for each system made it possible to verify the quality of our work by calculating the coordinates of certain terminals from the seven (07) parameters. The transformed coordinates were compared with those obtained by observations. An Excel application has been developed for ease of use. We have come to the conclusion, that the research must continue, to reach centimeter precision, but the results obtained are satisfactory to solve the problem of land insecurity due to a pluralism of system, because now instead of a gap of 170m between different systems, we have reached a precision of less than 1m.

Keywords: Datum 58, BENIN Geodetic System, Permanent Station System, Transformation Parameters, BURSA-WOLF.

Introduction

A geodetic system is associated with a geodetic network, a set of points whose coordinates have been determined from the same basic measurements. Geodetic systems are determined from angular measurements and astronomical distances[1]. Today the whole world having entered the era of new technologies, space techniques by their unprecedented spatio-temporal sampling of data, have fundamentally changed activities in this field, replacing a process of development of terrestrial geodetic networks by essentially global networks[2]. Space techniques have made it possible to define "global" or "international" geodetic systems, by combining precise orbitography methods of satellites and measurements of angles or distances or, rather, of signal propagation time between these satellites and points of the globe; the geodesic network is now virtual, and it is the orbital elements of the satellites and the positions of the tracking stations that now define the geodesic system.

Traditional geodetic systems were associated only with small areas of the globe, usually located on the same tectonic plate[3]; their accuracy was much lower than that of current geodetic systems. The relative variation of the coordinates due to the deformation of the network due to the tectonic movements was negligible. Modern geodetic systems are very accurate, and can express in the same system the coordinates of points on different tectonic plates: the relative movements of these plates cannot be neglected anymore.

Thus, to make a contribution to the geomatic sciences in the case of Benin, we carried out a comparative study and determination of the transformation parameters between: the datum (58), the geodetic system of Benin and the system of permanent stations.

Background and justification: By Order No. 78-26 of August 14, 1978, the Beninese State decided to create the National Institute of Cartography (INC). In 1998, it was called National Geographic Institute (IGN) which is a public institution with social and scientific character created by Decree No. 98-477. As such, the IGN has been entrusted with a main mission of ensuring the establishment of the national geodetic network.

For example, geodetic and cartographic work in Benin before the end of the 1980s are made in the Datum system 58 (1981). The first maps of Benin and the first topographical work has been made in this system whose characteristics are as follows:
Reference ellipsoid: Clarke 1880
Semi-major axis (a): a = 6 378 249,2 m
Inverse of the flattening (1 / f): 293, 46602129363

Projection: UTM (Universal Transverse Mercator)
Area number: 31
Central Meridian: 3°00'00.00000 "E
Hemisphere: North
Factor scale at the central meridian: 0.9996
Arbitrary abscissa: 500 000 m
Arbitrary order: 0 m.

Transformation parameters: Translations zero, rotation zero, scale factor = 1.

According to the order No. 0068 / MUHRFLEC/DC/SGM/IGN/ DGURF/SA on December 28, 2009, setting the standards and technical specifications for topographic and cartographic work in the Republic of Benin, Benin has two geodetic systems: the geodetic system of Benin (GBS) and the Datum of the permanent stations of Benin (SGSPB)[4].

From 1995 to 1996, the official geodetic network was installed throughout the territory. The official national geodetic network of Benin is under the WGS 84 datum, which is now the most widely used system in the world associated with the GPS positioning system. This system is associated with the UTM projection and attached to the International Terrestrial Reference System (ITRS), which unifies the terrestrial and astronomical references. The points on the whole territory are chosen by densification GPS in accessible protected and secured areas in ways to cover the whole surface of the country. Thus the characteristics of the geodetic system of Benin are as follows:

Ellipsoid reference: WGS 1984
Semi-major axis (a): 637837.0000 m
Inverse of the flattening (1 f): 298.25722356300
ITRF 1993 (epoch 1995.9)

Projection: UTM (Universal Transverse Mercator)
Area number: 31
Central Meridian: 3°00'00.00000 "E
Hemisphere: North
Factor scale at the central meridian: 0.9996
Arbitrary abscissa: 500 000 m
Arbitrary order: 0 m.

Transformation parameters: Translations zero, rotation zero, scale factor = 1.

This geodetic system corresponds to the geodetic network of Benin (RGB). It includes the geodetic network of first-order and second-order geodetic network.

The first-order geodetic network consists of 60 points at an average distance of 40km, whose planimetric accuracy is 1cm and the altimetric accuracy is 10cm.

The second-order geodetic network consists of 500 points, 8 km apart on average, with the same precision as the first-order network.

Indeed, the 'Access to land' project whose goal is to ensure land security in Benin addressed the recurring problems of geodetic infrastructure in Benin by the implementation in 2008, a network of seven permanent stations. These features are as follows:
Reference ellipsoid: GRS 80
Half Grand Axis (a): 6378137.0000m
Inverse of I ' flattening (1 f): 298.257222101
ITRF 2000 (epoch 1997.0)

Projection: UTM (Universal Transverse Mercator)
Area number: 31
Central Meridian: 3°00'00.00000 "E
Hemisphere: North
Factor scale at the central meridian: 0.9996
Arbitrary abscissa: 500 000 m
Arbitrary order: 0 m.

Transformation parameters: Translations zero, rotation zero, scale factor = 1.

This geodesic system corresponds the Network of Permanent Stations of Benin (RSPB). It currently includes seven (07) permanent stations located respectively at: Cotonou, Abomey, Savalou, Parakou, Nikki, Kandi, Natitingou.

Indeed, this pluralism of system has failed to bring security to the Beninese land. The major concern of actors in geomatics is to move from legacy systems to the new single system which is one of the permanent stations. Then, instead of resume all work made in systems into a single system that would be not only expensive but also tedious, we have adopted a way of transformation of the two former systems to single third system.

The similar challenges faced by researchers in the previous work outside Benin, served as guide to lead our methodological approach. In its publication in the journal XYZ No. 97 4th quarter[5], showed the interest to work in the new system of reference R.G.F.93 in force in France. At the end of his study, he concluded that it can be easy to transform decimetric precision data using established models such as that of the GR3DF97A conversion grid. Obtained gaps range from 2 to 23cm with the use of the vehicles data, which shows the inadequacy of this method of transformation because it generates a loss of accuracy of the data.

In his search for definition of datum, ITRF[6] application, preferred method of standard combination of realization of global reference systems. According to it if the combination is properly built, an appropriate weighting is applied and the precise geodetic ties between co-localisees stations are available. This combination is based on a Euclidean similarity to 14 parameters. This method is recommended for global systems while Benin is locally compared to the global system.

Meanwhile only focused on the transformation of similarity to seven (07) settings[7]. They point out that when an old system was determined by triangulation, it is not advisable to use the same transformation parameters for the whole of the country. Local transformations should be calculated if you want a centimetric precision. The analysis of the results of earlier work, and taking into account their limit, we have advocated the model which combines the work of two great figures of the Geodesy namely: i. Milan Bursa (common Czech) and. ii. Helmut Wolf (German common).

Hence the "Bursa-Wolf" Method. The particular aspect of our study lies in the fact that this method allows to remain at the local scale of Benin instead of being global (global) and at the same time to remain faithful to centimetric precision. It is the simplified form of the Russian method known as "Molodensky".

Study area: One the countries of the Francophone West Africa, Benin, with an area of 112.622 square kilometers, is located in the intertropical zone between the Equator and the Tropic North, between 6°30' and 12°30' latitude North and between 1° and 3° 40' longitude is. It extends from the Atlantic ocean to Niger River over a length of 700Km. Its width varies from 125 Km along the coast at 325Km in the northern part. Its bordering neighbours are Togo to the West, Nigeria to the East, Niger in the North East and Burkina Faso to the Northwest.

Materials and methods

Our work consisted of surveying boundaries whose coordinates are already known in the Benin geodetic system and the datum system 58.

Material: The receiver used is the GNSS X 91 of the CHC company model. It is compact designed for surveys of high precision and high productivity even in a difficult environment. With a heart of 220 channels, the X 91 GNSS represents a more affordable and professional solution for any mission of surveying.

The CGO (CHC Geo Office) software is a certified data processing software that uses a physical key.

Methodology: BURSA-WOLF model has been used to determine the seven (07) transformation parameters which are constants between two systems[8].

The transformation parameters from one system to another are: i. Three rotation parameters (r_x, r_{is}, r_z); ii. The scale factor between the two systems (m); iii. Three Translation parameters (T_x, T's, T_z).

T_x: translation along the axis of the x ((1) to (2)), $T_{'s}$: translation along the axis of y (from (1) to (2)), T_z: translation along the axis of the ((1) to (2)) z, m: scale factor (of (1) to (2)) between the two systems, r_x: angle of rotation around the x axis, in radians (from (1) to (2)), r_y: angle of rotation around the y-axis, in radians (from (1) to (2)), r_z: angle of rotation around the z-axis, in radians (from (1) to (2)).

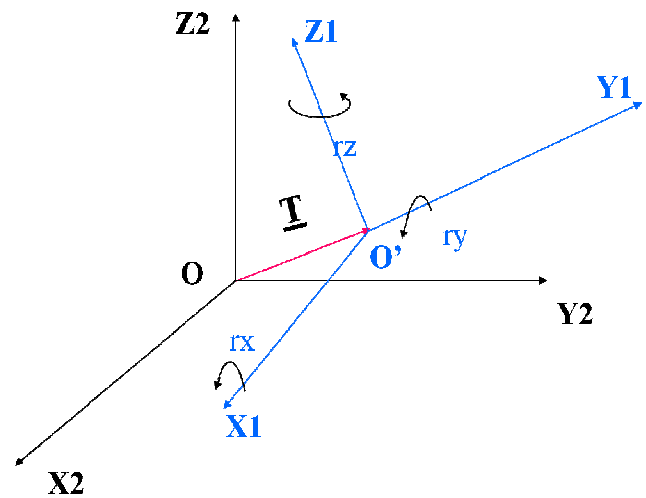


Figure-1: Transformation parameters[8].

According to the BURSA-WOLF model, the determination of coordinates (X_2) in the system (2) from the points (X_1) known in the system (1) is written in vector form[9]:

$$X_2 = T\,(Tx, Ty, Tz) + (1+m).\ R\,(rx, ry, rz).\ X_1 \quad (1)$$

The knowledge of the constants Tx, Ty, Tz, rx, ry, rz allows us to determine the coordinates of a system from another. After the model of BURSA - WOLF, the resolution of the equation N ° 1 by least-squares is given by the equation N°2 [10]:

For a point of coordinates (X_1; Y_1. $_1$Z) and (X_2; Y_2. Z_2) in both respective S_1 and S_2, we have:

$$\begin{pmatrix} X_2 - X_1 \\ Y_2 - Y_1 \\ Z_2 - Z_1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & X_1 & 0 & -Z_1 & Y_1 \\ 0 & 1 & 0 & Y_1 & Z_1 & 0 & -X_1 \\ 0 & 0 & 1 & Z_1 & -Y_1 & X_1 & 0 \end{pmatrix} \begin{pmatrix} T_X \\ T_Y \\ T_Z \\ m \\ rx \\ ry \\ rz \end{pmatrix} \quad (2)$$

In equation (2), the parameters *Tx, Ty, Tz, m, Rx, ry, rz* are strangers to determine.

(X_1, Y_1Z_1) and (X_2, Y_2Z_2) are the coordinates of a point respectively in the first and the second system.

Using equation (2) for the n points common in systems 1 and 2 and asking:

$$L = \begin{pmatrix} X_{2i} - X_{1i} \\ Y_{2i} - Y_{1i} \\ Z_{2i} - Z_{1i} \end{pmatrix};\ Avec\ i\ allant\ de\ 1\ à\ n$$

$$U = (T_X, T_Y, T_Z, m, rx, ry, rz)^T$$

A is the matrix 3n x 7 (3n rows and 7 columns), called matrix of coefficients

$$A = 3n \times 7 = \begin{pmatrix} 1 & 0 & 0 & X_1 & 0 & -Z_1 & Y_1 \\ 0 & 1 & 0 & Y_1 & Z_1 & 0 & -X_1 \\ 0 & 0 & 1 & Z_1 & -Y_1 & X_1 & 0 \end{pmatrix}$$

$$\begin{pmatrix} X_2 \\ Y_2 \\ Z_2 \end{pmatrix} = \begin{pmatrix} T_X \\ T_Y \\ T_Z \end{pmatrix} + (1+m) \begin{pmatrix} 1 & rz & -ry \\ -rz & 1 & ry \\ ry & -ry & 1 \end{pmatrix} . \begin{pmatrix} X_1 \\ Y_1 \\ Z_1 \end{pmatrix}$$

and V is the vector of the method of least squares[11] residues, the determination of the unknown parameters is done by the resolution by the least-squares equation: A.U = L + V. The resolution of this equation is given by equation (3).

Soit: With T: the transpose of matrix A and L: the matrix of free terms.

$$\overline{U} = (A^T.A)^{-1}.A^T.L \qquad (3)$$

Choice of observed points: This step was decisive and very important for budgetary reasons. The choice of points was made according to the following criteria: i. Cover the entire territory with a minimum of homogeneity between the first order terminals; ii. Observe the maximum point; iii. Take into account the proximity of the terminals to the permanent stations; iv. Choose the terminals, the most accessible. Thus, about 20 terminals were chosen, the third (1/3) of the First-order terminals.

After this step, the coordinates of the first order terminals retained in the two (02) systems as well as those of the permanent stations were provided by the IGN.

The IGN is depositary and guarantor of the geodetic network of Benin, it has placed at our disposal of the information relating to the terminals of the first order. Indeed, the bounds were observed in the Benin geodetic system, in the datum system 58 and that of the permanent stations.

Results and discussion

Comparative analysis: The analysis of the results is made in a comparative table between the data of each system.

Table-1: Comparison of results between the network of permanent stations in Benin (RSPB) and the Datum58 system.

N° Terminals	Locations	ΔE ($E_{Permanent}$ station- $E_{Datum58}$)m	ΔN ($N_{Permanent\ station}$ - $N_{Datum58}$)m	ΔH ($H_{Permanent\ station}$ - $H_{Datum58}$)m
101	Hilacondji	-138.173	170.036	0.482
102	Ouidah	-138.808	169.913	1.075
103	Cotonou	-138.418	169.466	-0.169
106	Houegbo	-138.287	169.514	0.48
107	Aplahoue	-138.186	169.365	1.403
109	Abomey	-138.395	169.23	1.134
116	Kanahoun	-137.805	169.316	0.958
117	Save	-138.106	169.812	2.188
118	Aklamkpa	-138.475	169.295	0.502
121	Biguina	-138.547	168.738	2.753
126	Parakou	-138.737	168.663	1.328
137	Natitingou	-138.463	168.099	1.169
143	Tiele	-138.152	167.89	1.809
145	Kerou	-139.073	167.292	-17.558
149	Porga	-138.173	167.698	2.59
159	Bodjekali	-138.559	167.858	1.211

From this summary Table-1 can make the following analyzes: i. The difference in coordinates varies from one geodesic point to another and sometimes changes the sign. This variation is stronger on the plane coordinates (E, N) than the height (H). ii. The column of abscissa (E) or East only includes only negative values. iii. These values vary from -139.073m (KEROU) to -138.106m (SAVE); an amplitude of -0.967m. iv. The ordinate (N) or North column contains exclusively positive values.

These values are between 167.292m (KEROU) and 170.036m (HILACONDJI); an amplitude of +2.744m.

Table-2 below presents, as in the previous paragraph, the differences between the coordinates of the Benin geodetic system and those of the permanent station system.

From this summary Table-2, the following analyzes emerge: i. No point has a deviation of ± 10cm which is the accuracy of a geodesic point. ii. The difference between the coordinates is not a constant therefore varies from one geodesic terminal to another and sometimes changes sign. This variation is smaller on the plane coordinates (E, N) than the height (H). iii. The column of abscissa (E) or East includes negative and positive values. These values vary from -0.546m (KEROU) to 0.694m (BODJEKALI); an amplitude of 1.240m. iv. The ordinate (N) or North column contains exclusively positive values. Between the two systems, the ordinates of the RSPB points are well above those of the GBS.

These values are between 0.08m (KEROU) and 1.250m (SAVE); an amplitude of 1.17m.

In the last column, that of the heights, the remarks are identical at the level of the Datum 58 system, because the heights have the same values in the two systems (DATUM 58 and SGB).

After analyzing the last columns of Tables-1 and 2, we notice that the heights on both sides are almost the same. In this article, we will not look at this case. Because Benin does not have a geoid, which is a fundamental element in the resolution of the heights, we will come back to it in the next articles, once its establishment made.

Table-2: Comparison of results between the network of permanent stations of Benin (RSPB) and the geodetic system of Benin (SGB).

N° Terminals	Locations	$\Delta E(E_{RSPB} - E_{SGB})$m	$\Delta N(N_{RSPB} - N_{SGB})$m	$\Delta H(H_{RSPB} - H_{SGB})$m
101	Hilacondji	-0.03	0.72	0.482
102	Ouidah	-0.484	0.638	1.075
103	Cotonou	0.054	0.192	-0.1691
106	Houegbo	0.081	0.422	0.48
107	Aplahoue	-0.022	0.34	1.403
109	Abomey	-0.09	0.302	1.134
116	Kanahoun	0.372	0.753	0.958
117	Save	0.456	1.25	2.188
118	Aklamkpa	-0.055	0.814	0.502
121	Biguina	-0.355	0.541	2.753
126	Parakou	-0.064	0.693	1.328
137	Natitingou	-0.339	0.674	1.169
143	Tiele	-0.088	0.683	1.809
145	Kerou	-0.546	0.08	-17.558
149	Porga	-0.212	0.664	2.59
159	Bodjekali	0.694	1.05	1.211

Results interpretation: i. The data of the Geodetic System of Benin are close to those of the permanent stations because the two systems have the same projections (UTM 31 N), practically the same ellipsoids. Only the gap observed between the two systems is due to the fact that they do not have the same origins, the first having been observed from France and Brazil and the second from the United States. ii. The differences that we observe at the level of the two (2) systems do not correspond to any mathematical logic, hence the need to use the method of BURSA-WOLF, only that this method works only if one provides the position (X, Y, Z) in the world geocentric system called WGS 84 (World Geodetic System 1984), and we want to determine the transition of the transformation from the world geodetic system to the national or local geodetic system.

Calculation of the seven (07) parameters to transform the Datum 58 system into the permanent station system of Benin: The matrix A, is the matrix of the coefficients, and L that of the free terms.

The resolution is made from the equation (Equation-2)

where, $L = \begin{pmatrix} X_2 - X_1 \\ Y_2 - Y_1 \\ Z_2 - Z_1 \end{pmatrix}$ and

$$A = \begin{pmatrix} 1 & 0 & 0 & X_1 & 0 & -Z_1 & Y_1 \\ 0 & 1 & 0 & Y_1 & Z_1 & 0 & -X_1 \\ 0 & 0 & 1 & Z_1 & -Y_1 & X_1 & 0 \end{pmatrix}$$

The matrix L is a unicolon matrix whose number of lines is equal to n x 3 (n being the point number in both systems). Matrix A is a matrix of 7 columns and n x 3 lines.

Applying the formula of the equation (Equation-3); after determining the L and A matrices in the Datum 58 system and in the Benin geodetic system; the seven (07) transformation parameters presented in the following Table-3 are obtained.

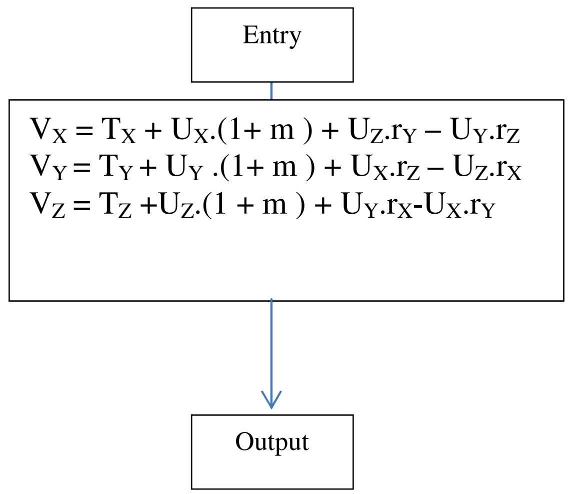
Table-3: The Seven (07) Parameters to Transform the Datum 58 System in the System of Permanent Stations of Benin.

Parameters	Datum system 58	Geodetic system of Benin
Tx	−136.79373740802892073m	−0.46516187526433296694 m
Ty	172.18973759431664295m	0.039376119537412495159 m
Tz	0.70843686625195341083m	0.7076339352491023018 m
m	−3.5059370147218400071x10^{-6}	7.4987759099512651438 x10^{-7}
rx	−2.0494720614674323403x 10^{-6} rad	−2.048078668119654289x10^{-6} rad
ry	−3.5017490810237821723x 10^{-6} rad	−3.5006151407727427995x10^{-6} rad
rz	−2.2733358818134662265x 10^{-7} rad	1.702847672058730625x 10^{-7} rad

Between the three systems, the rotation is practically zero, as well as the scale factor. The translation seems weak at the level of the SGB, but strong with the Datum 58. The SGB is very close to the permanent station system.

Calculation of the coordinates of the points observed and comparison with the measurements made: The seven (07) parameters thus now known, we checked the reliability of the work by calculating the coordinates five (05) other points that were not used to calculate the parameters and they were compared with their counterparts measured in the field.

A program has been written in Excel following the flowchart below.



Analysis and interpretation of the results: The two (02) Tables-4 and 5 allow us to draw the following conclusions: i. After the transformation, none of the coordinates gave a difference of less than 10 cm, which is the precision of the geodesic points; ii. Coordinate transformation using the BURSA-WOLF method is not a compensation method and does not improve the quality of measurements; iii. However, the obtained results can already be used for the realization of small and medium scale topographic works.

Conclusion

The results obtained from our work make it possible to have metric precision, whereas we were more than 170m. The problem of land tenure insecurity due to the pluralism of systems is definitely solved, because no parcel can be overlapped with another, but one can just observe boundary encroachments that can be solved by field measurements.

The research must continue by exploring other options, that is to say instead of only thinking of determining the parameters; we will work on the establishment of a three-dimensional transformation system taking into account our realities. Pending the implementation of this system, we strongly advise geomatics stakeholders to use the three (03) translation parameters in a local manner that is to say following each terminal.

Table-4: Transformation of Datum 58 Coordinates into the System of Permanent Stations.

N°PT	Locations	E (m) Calculated in RGSP (Ecallus)	E (m) Calculated in RGSP (Ecallus)	N (m) Calculated in RGSP (Ncallus)	E(m) Observed in RGSP (Eobs)	N(m) Observed in RGSP (Eobs)	H(m) Observed in RGSP (Hobs)	(E_{obs}) -(E_{cal})	(N_{obs}) -(N_{cal})	(H_{obs}) -(H_{cal})
106	Houegbo	408498,7811	752240,8474	148,7555118	408498,55	752240,901	148,638	-0,231	0,053	-0,117
107	Aplahoue	353694,9556	767411,3377	159,5544717	353694,63	767411,283	160,583	-0,325	-0,055	1,028
112	Setto	397696,6524	828619,3881	127,5132228	397696,147	828619,152	106,04	-0,505	-0,236	-21,473
140	Mani	475756,5321	1158962,499	327,0828372	475755,273	1158961,29	311,146	-1,26	-1,21	-15,936
143	Tiele	303556,2686	1186840,721	193,3131638	303555,706	1186840,65	195,783	-0,562	-0,071	2,467
145	Kerou	403007,9527	1196701,673	320,6667647	403006,816	1196701,06	302,213	-1,137	-0,613	-18,453

Table-5: Transformation of the coordinates of the Benin geodetic system to the system of permanent stations

N°PT	Locations	E (m) Calculated in RGSP (Ecallus)	N (m) Calculated in RGSP (Ncal)	N (m) Calculated in RGSP (Ncallus)	E(m) Observed in RGSP (Eobs)	N(m) Observed in RGSP (Eobs)	H(m) Observed in RGSP (Hobs)	(E_{obs}) -(E_{cal})	(N_{obs}) -(N_{cal})	(H_{obs}) -(H_{cal})
106	Houegbo	408498,1815	752241,1523	148,7550933	408498,55	752240,901	148,638	0,368	-0,251	-0,117
107	Aplahoue	353694,3208	767411,6184	159,5541842	353694,63	767411,283	160,583	0,309	-0,335	1,029
112	Setto	397695,9975	828619,7187	127,5128341	397696,147	828619,152	106,04	0,149	-0,567	-21,473
140	Mani	475755,5921	1158962,9	327,0836723	475755,273	1158961,29	311,146	-0,319	-1,614	-15,937
145	Kerou	403006,9941	1196701,987	320,6677106	403006,816	1196701,06	302,213	-0,178	-0,926	-18,454

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