https://dx.doi.org/10.4314/dujopas.v9i3b.27
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 9 No. 3b September 2023*

Geodetic Control Extension at Erosion Prone Areas Using Integrated CORS-GNSS in Benin City, Edo State Nigeria

[1]Akhigbe R.A. [2]Oladosu S. O. and [3]Ehigiator-Irughe R.

[1]Department of Civil Engineering,
Faculty of Engineering,
PMB 1154, Benin City,
Edo State.

[2,3]Department of Geomatics,
Faculty of Environmental Sciences,
University of Benin,
P.M.B. 1154,
Edo State,
Nigeria.

Email: olushola.oladosu@uniben.edu

Abstract
This study addresses the imperative expansion of geodetic controls in erosion-prone areas of Benin City, with a focus on establishing controls in specific schools. Two observation campaigns were conducted on nine monumented controls with 36 baselines and another set of eight controls with 28 baselines. Data adjustments were successfully carried out using Trimble Business Centre software, at 10.00σ confidence level and 1.00% significance for the tau test in the second iteration of both campaigns. Analysis revealed varying accuracy levels among stations. Notably, stations ADLC_01, ADLC_02, and QSS_01 demonstrated a minimum latitude accuracy of 1.3 mm, while AGGS_01 and AGGS_02 showcased the highest accuracy at 1.7 mm. Similar trends were observed in longitude and height measurements. For longitude, the maximum standard deviation (3.3 mm) was recorded at ENV_101D station, while the minimum accuracy (1.7 mm) was obtained at station AGGS_01. The minimum accuracy in height (3.5 mm) was recorded at station AGGS_01, while the maximum accuracy (6.7 mm) was recorded at station SMGGS_01. These findings provide essential insights into the accuracy of geodetic controls in Benin City based on purposeful selected schools, serving as valuable information for future research, infrastructure development, and engineering projects execution.

Keywords: Control, Erosion, Extension, Geodetic, GNSS

INTRODUCTION
Control extension is a continuous exercise of providing control infrastructure to a geographical location where they are either lacking, displaced, or may have been removed ignorantly. According to Oladosu et al., (2022), the demand for control extension depends on factors such as urbanisation, structural monitoring, construction work, smart farming, precise agricultural management system, etc. The process leads to the breakdown of large triangulation network of figures into smaller ones, thereby adding to the existing controls within a defined network framework (Ghilani, 2010). Only first-order or zero-order accuracy controls with proven integrity and stability are suitable for further propagation of other

*Author for Correspondence

controls as occasion demand. Second-order and third-order control must be derived from the first-order and zero-order in a network. With the dawn of technological breakthroughs in satellite science in the 21st century, improvement in Global Navigation Satellite System (GNSS) hardware and software, and innovation in Continuously Operating Reference Station (CORS) Network systems have replaced the more tedious conventional methods of control densification with fast, quick, and accurate position delivery at the millimeter level (Nwilo et al., 2016).

There is more awareness and an increased knowledge of the applications of CORS and GNSS in Nigeria compare to the time it started in 2008 as reported by (Jatau et al., 2010). The evidences from the following research showed buttress the fact that both academia, private and public establishments are becoming more aware of the technological capability of CORS and GNSS (Oladosu et al., 2022; Ayodele et a., 2017; Ayodele et a., 2020; Erekosima and Onoriode, 2018). Some private owned CORS now exist such as the one used in this research which indirectly contribute to further strengthening of the geodetic network. The body controlling survey activities in Nigeria is the Surveyors Council of Nigeria (SURCON) and has made provision for GNSS as one of the acceptable methods to be used in control densification (Erekosima and Onoriode, 2018).

In some areas of Benin City, erosion and floods calls for concern and have already impacted the local economy and the environment through gullying and the pavement's ability to withstand heavy traffic. This article provides the solution in part, among other things needed to be provide in mitigating erosion, by establishing more control points in selected schools near the hotspots of erosion to lessen the threat of environmental challenges. The integration of the innovation of CORS and GNSS receivers in static observations mode and the post-processing of data provides the essential control point coordinates necessary for other applications.

METHODOLOGY

Study Area

The study area is located within Benin City. This is shown in Figure 1 using the image obtained from Google Earth Pro. The approximate location of control points highlighted with yellow pace marks and the names of the selected school labelled accordingly across the state are displayed on the map including their location in relation to the CORS_Geosystems tagged with red place mark. The network covered both built environment and water body and falls within latitudes and longitudes (6.41^0 N, 5.570 E; 6.28^0 N, 5.71 E) respectively.

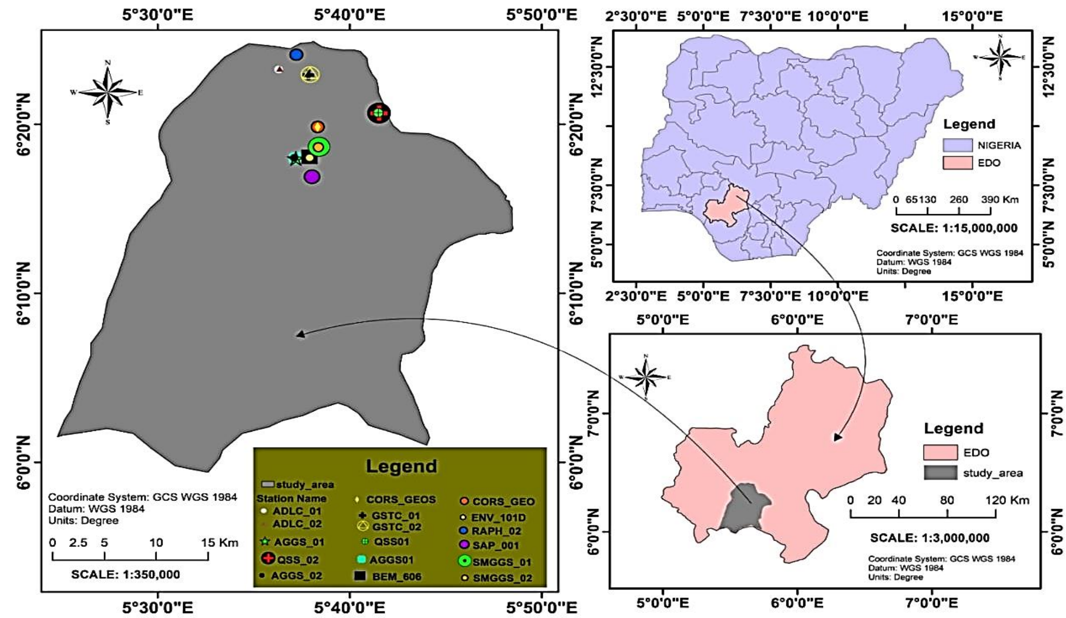

Figure 1: Map of the Study Area

Conceptual Framework

The conceptualization of this work is presented with the following diagram for easy understanding. Every stage was executed at the appropriate time until an acceptable value was obtained and the final coordinates of the control points derived. Figure 2 shows at glance, the summary of the processes taken.

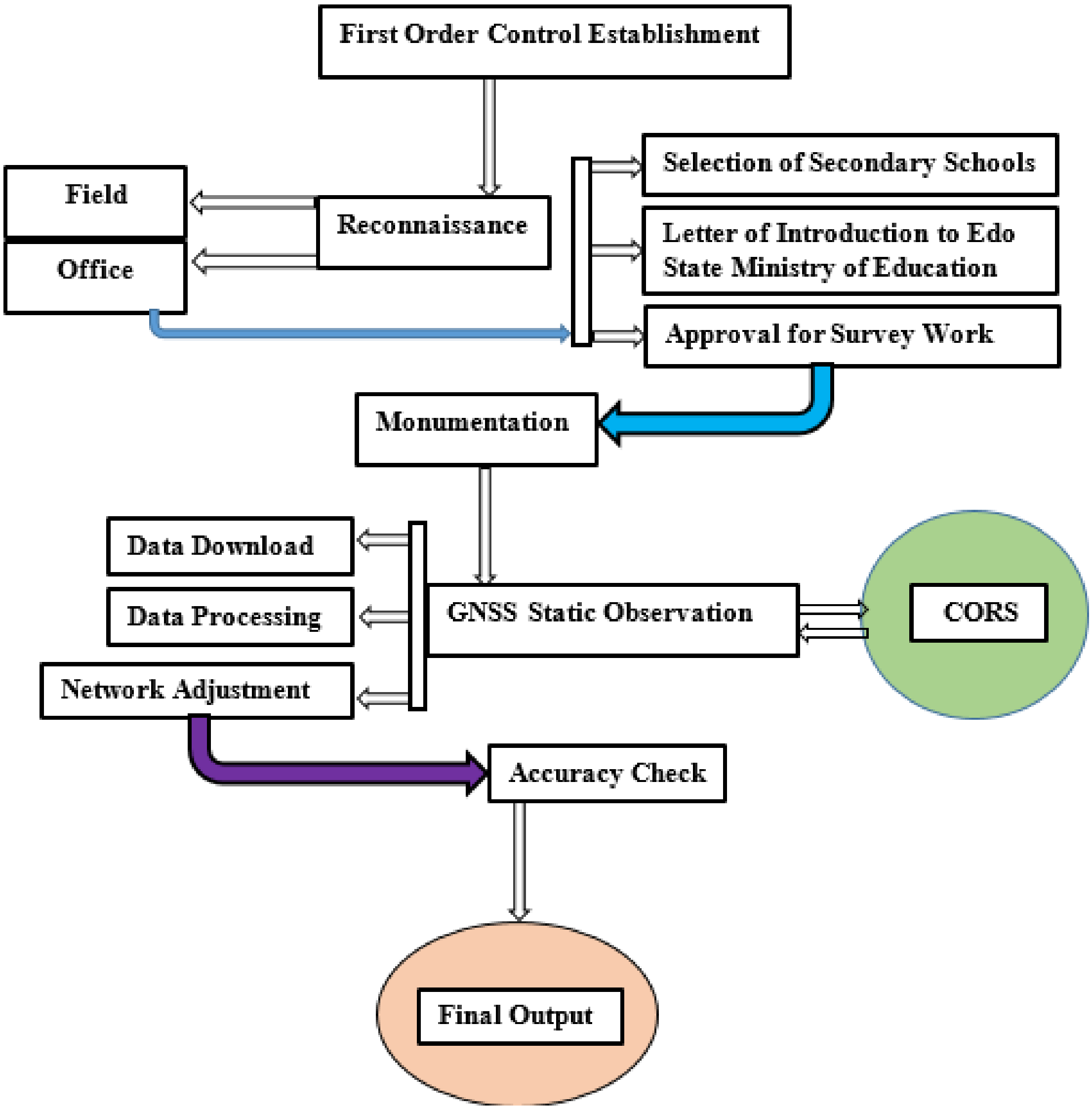

Figure 2: Conceptual framework diagram

Methods

The methods involved monumentation of two controls at intervisible locations with the selected schools following the specification for first other control as specified by SURCON. The tagging of the controls with their respective identification numbers and/or inscriptions. Observations were taken on two campaigns on different days using 6 units of GNSS receivers with time spent for data acquisition on each control not less than one hour. The data was adjusted using the Trimble Business Centre software and the results are presented afterward at the appropriate section. The following procedure serve as the background principles for adjustment process. Modified as occasion demands by the researchers are possible to suit the challenge at hand.

Minimum Least Squares Adjustment of Control Networks

The adjustment of control network is a critical exercise in Geomatics engineering. This is premise on the fact that errors are present in all observations but there is rule of thumb to guide in the amount of allowable errors in control orders but what is adopted by any state must comply to international best practices (Surveyors Council of Nigeria {SURCON,2007}). This guide was used to test the integrity of the control points to be established. The network adjustment was carried out using minimum squares method that minimizes the sum of squares of the residual in an observation.

The observation equation for satellite positioning is an iterative process that may start from and initial value obtained from total minimum squares. After neglecting the measurement error, the following nonlinear positioning observation equation can be established as in equation (1) (SURCON, 2007; Lu and Ma, 2016).

$$L_i = \sqrt{\left(X_{si} + X\right)^2 + \left(Y_{si} + Y\right)^2 \left(Z_{si} + Z\right)^2}, \quad i = 1, 2, 3, 4...., N \tag{1}$$

Where L is the position to be determined, (X_{si}, Y_{si}, Z_{si}) is position coordinates of *i*th satellite and N is the number of satellites participating in positioning calculation, (X , Y , Z) is position coordinate of the receiver.

Thus, it can be noticed that the final target is usually reached earlier when the initial is closer the selected initial position, thus fewer times of iteration leads to a faster convergence speed and the more accurate the positioning will be when the minimum square algorithm is used for iterative solution (SURCON, 2007; Lu and Ma, 2016).

In this work, the total minimum squares algorithm will be used to obtain more accurate initial value of receiver position according to equation (2) used by (Kang et al., 2021).

$$\begin{aligned} L_1 &= \sqrt{\left(X_{s1} + X\right)^2 + \left(Y_{s1} + Y\right)^2 \left(Z_{s1} + Z\right)^2} + cT \\ L_2 &= \sqrt{\left(X_{s2} + X\right)^2 + \left(Y_{s2} + Y\right)^2 \left(Z_{s2} + Z\right)^2} + cT \\ &\vdots \\ L_i &= \sqrt{\left(X_{si} + X\right)^2 + \left(Y_{si} + Y\right)^2 \left(Z_{si} + Z\right)^2} + cT \\ L_i &= \sqrt{\left(X_{sN} + X\right)^2 + \left(Y_{sN} + Y\right)^2 \left(Z_{sN} + Z\right)^2} + cT \end{aligned} \tag{2}$$

Where C, in equation 2 represents the propagated speed of electromagnetic wave in vacuum, T, is the clock difference between the receiver clock and the satellite clock during the period of signal travels.

The linear equation is obtained by summing the square of the variances represented in equation (2) to form what is contained in equation (3)

$$\frac{1}{2}\left(P_i^2 - P_1^2 + K_i^2 - K_1^2\right) = \left(X_{s1} - X_{si}\right)X + \left(Y_{s1} - Y_{si}\right)Y + \left(Z_{s1} - Z_{si}\right)Z + \left(P_1 - P_i\right)\left(-cT\right) \tag{3}$$

By combining the positioning observation equations of N satellites, the equations (4) and (5) can be obtained. P = JK.

$$P = \frac{1}{2}\begin{bmatrix} P_2^2 - P_1^2 + K_1^2 - K_2^2 \\ P_3^2 - P_1^2 + K_1^2 - K_3^2 \\ \vdots \\ P_N^2 - P_1^2 + K_1^2 - K_N^2 \end{bmatrix} \tag{4}$$

$$G=\begin{bmatrix} X_{s1}-X_{s2} & Y_{s1}-Y_{s2} & Z_{s1}-Z_{s2} & P_2-P_1 \\ X_{s1}-X_{s3} & Y_{s1}-Y_{s3} & Z_{s1}-Z_{s3} & P_3-P_1 \\ \vdots & \vdots & \vdots & \vdots \\ X_{s1}-X_{sN} & Y_{s1}-Y_{sN} & Z_{s1}-Z_{sN} & P_N-P_1 \end{bmatrix}, B=\begin{bmatrix} X \\ Y \\ Z \\ -cT \end{bmatrix} \quad (5)$$

Considering that there are errors in both the actual observed quantity P and the coefficient matrix G, the total minimum squares algorithm is used to solve the matrix [8; 9]. By constructing the augmented matrix first, this will mean C = [−P: G]. In this case, the rank of {C} = 5. Performing singular value decomposition, then equation (6) can be obtained (Kang et al., 2021).

$$C=U\sum V^T=\sum_{k=1}^{5}\sigma_k u_k v_k^T\left(k=1,2,3,4,5\right) \quad (6)$$

Where, u_k and v_k are the left and right singular vectors of the augmented matrix respectively. σ_k is the singular value corresponding to C. There is a unique solution to a matrix represented in equation (7) (Kang et al., 2021).

$$C=\left[\frac{v_4(2)}{v_4(1)}\frac{v_4 3}{v_4(1)}\frac{v_4(4)}{v_4(1)}\frac{v_4(5)}{v_4(1)}\right]^T \quad (7)$$

Here taking the estimate as the initial value of the receiver position coordinates (X_0, Y_0, Z_0). Weighted Minimum Squares Algorithm It is linearized first, since the positioning equation is a nonlinear equation. The Taylor series expansion of equation (1) is performed at the initial value, and the higher-order terms are omitted. The final linear equation becomes equation (8).

$$P_i=\left(X_0,Y_0,Z_0\right)-\frac{X_{si}-X_0}{F\left(X_0,Y_0,Z_0\right)}\left(X-X_0\right)-\frac{Y_{si}-Y_0}{F\left(X_0,Y_0,Z_0\right)}\left(Y-Y_0\right)-\frac{Z_{si}-Z_0}{F\left(X_0,Y_0,Z_0\right)}\left(Z-Z_0\right)+cT \quad (8)$$

Where, P_i is the refined pseudo-distance measurement value after applying correction to errors between the satellite and the receiver as shown in equation (9).

$$P_i=\left(X_0,Y_0,Z_0\right)=L_i=\sqrt{\left(X_{si}+X_0\right)^2+\left(Y_{si}+Y_0\right)^2\left(Z_{si}+Z_0\right)^2},\quad\left(X_{si},Y_{si},Z_{si}\right) \quad (9)$$

P*i* is position coordinates of ith satellite (i=1, 2,…,N, and N is the number of satellites in positioning calculation. The matrix reduces to equation (10) and further clarification of terms are shown in equations (11) and (12).

$$\Delta P=H\Delta \mathrm{B}+E_i \quad (10)$$

Where.

$$\Delta P=\begin{bmatrix} F\left(X_0,Y_0,Z_0\right)-P_1 \\ F\left(X_0,Y_0,Z_0\right)-P_2 \\ \vdots \\ F\left(X_0,Y_0,Z_0\right)-P_N \end{bmatrix}, \quad (11)$$

$$H = \begin{bmatrix} \frac{X_{s2}-X_0}{F(X_0,Y_0,Z_0)} & \frac{Y_{s1}-Y_0}{F(X_0,Y_0,Z_0)} & \frac{Z_{s1}-Z_0}{F(X_0,Y_0,Z_0)} & 1 \\ \frac{X_{s2}-X_0}{F(X_0,Y_0,Z_0)} & \frac{Y_{s2}-Y_0}{F(X_0,Y_0,Z_0)} & \frac{Z_{s2}-Z_0}{F(X_0,Y_0,Z_0)} & P_3-P_1 \\ \vdots & \vdots & \vdots & \vdots \\ \frac{X_{sN}-X_0}{F(X_0,Y_0,Z_0)} & \frac{Y_{sN}-Y_0}{F(X_0,Y_0,Z_0)} & \frac{Z_{sN}-Z_0}{F(X_0,Y_0,Z_0)} & 1 \end{bmatrix}, B = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \\ -cT \end{bmatrix} \tag{12}$$

Where (ΔX, ΔY, ΔZ) is offset between the estimated value and the initial value, $\Delta X = X - X_0$, $\Delta Y = Y - Y_0$, $\Delta Z = Z - Z_0$. E*i* is an unknown amount of error in a measurement. In the calculation process, weights can be selected according to needs. In this work, the signal-to-noise ratio was selected as the weight value at instance of observation of each control points, the weighting matrix of each is thus represented as shown in equation (13) (Kang et al., 2021; Ghilani, 2010).

$$W = \begin{bmatrix} \omega_1 & 0 & 0 & 0 \\ 0 & \omega_2 & 0 & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & 0 & \omega_N \end{bmatrix} \tag{13}$$

When the number of positioning satellites is greater than 4, the minimum least squares algorithm is used to solve the problem, and the estimated value of the offset is obtained by using equation (14) (Kang et al., 2021).

$$\Delta \mathrm{B} = \left(H^T W H\right)^{-1} H^T W \Delta P \tag{14}$$

The root mean square of the iteration result was compared with the threshold value. When the requirement is not met, the current offset is added to the initial value to get the initial value of the next iteration. If the requirements are met, then the iterative operation is stopped or truncated to estimate the value of the current receiver position (Ghilani, 2010).
The coordinates transformation was achieved using equation (15) which has the capacity to produce the rotational matrix from which coordinates in one reference frame can be mirrored into another using appropriate scale factor not greater than one (1) (Szabova and Duchon, 2016).

$$\begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix} = R_z\left[-\left(\frac{\pi}{2}+\lambda\right)\right] R_E\left[-\left(\frac{\pi}{2}-\varphi\right)\right] \begin{bmatrix} \Delta e \\ \Delta n \\ \Delta u \end{bmatrix} \tag{15}$$

RESULTS
The results of the adjusted controls for the first set of observation and the second sets of observations is presented in this section in Tables and discussion of results follows immediately after the presentation of each Tables accordingly.

Least Squares Adjustment of First Set of Established Control Points

The first set of controls involved in the survey campaign and other relevant information are presented in Tables 1 - 3.

Table 1: Statistical report of baseline adjustment

Name	Value
Number of GNSS Baselines:	36
Number of Adjusted Points:	9
Confidence level:	10.00σ
Significance Level for Tau Test:	1.00%
Ratio of Standard Error of Unit Weight:	0.5672
x2 Test Value:	47.6435
x2 Test Range:	54.3677 - 121.1263

Table 2: Adjusted Points in WGS 84

Station Name	Lat.	Std.Dev_ Lat(mm)	Lon.	Std.Dev_ Lon(mm)	H(m)	Std.Dev_ H(mm)
ADLC_01	006:23:16.12795N	1.3	005:36:15.41218E	1.7	125.0966	2.9
ADLC_02	006:23:19.02096N	1.3	005:36:18.52004E	1.7	124.3554	2.9
AGGS_01	006:18:00.77371N	1.7	005:37:09.35988E	2.1	84.4540	3.5
AGGS_02	006:18:02.50598N	1.7	005:37:04.46734E	1.8	82.3859	3.5
CORS_GEOS	006:19:51.73746N	0.0	005:38:17.82973E	0.0	109.6260	0.0
GSTC_01	006:22:57.17381N	1.5	005:37:48.72877E	1.8	107.4544	3.4
GSTC_02	006:22:58.16319N	1.4	005:37:53.91796E	1.9	108.9666	3.4
QSS_02	006:20:41.31335N	1.4	005:41:29.26117E	1.5	103.3929	2.9
QSS01	006:20:41.95941N	1.3	005:41:26.80002E	1.5	103.1147	2.8

Table 3: Adjusted Points in Target System (NEU)

Station Name	N(m)	Std.Dev_ N(mm)	E(m)	Std.Dev_ E(mm)	U(m)	Std.Dev_ U(mm)
ADLC_01	706677.1870	1.3	788178.3913	1.7	231.3686	2.9
ADLC_02	706766.5931	1.3	788273.5079	1.7	230.6268	2.9
AGGS_01	696992.3571	1.7	789886.1819	2.1	190.9401	3.5
AGGS_02	697044.8492	1.7	789735.4436	1.8	188.8691	3.5
CORS_GEOS	700413.7536	0.0	791974.7563	0.0	216.0690	0.0
GSTC_01	706109.1408	1.5	791050.8550	1.8	213.7724	3.4
GSTC_02	706140.3660	1.4	791210.2713	1.9	215.2859	3.4
QSS_02	701967.8427	1.4	797854.2664	1.5	209.8757	2.9
QSS01	701987.3098	1.3	797778.4721	1.5	209.5963	2.8

Least Squares Adjustment of Second Set of Established Control Points

The second set of controls involved in the survey campaign and other relevant information are presented in Tables 4 - 6.

Table 4: Statistical Report of Baselines Adjustment

Name	Value
Number of GPS Baselines:	28
Number of Adjusted Points:	8
Confidence level:	10.00σ
Significance Level for Tau Test:	1.00%
Ratio of Standard Error of Unit Weight:	0.9691
x2 Test Value:	61.0555
x2 Test Range:	37.8382 - 95.6493

Table 5: Adjusted Points in WGS 84

Station Name	Lat.	Std.Dev_ Lat(mm)	Lon.	Std.Dev_ Lon(mm)	H(m)	Std.Dev_ H(mm)

AGGS01	006:18:00.77384N	1.4	005:37:09.35995E	1.7	84.4139	3.5
BEM_606	006:18:06.05257N	1.9	005:37:52.12759E	2.2	83.9242	4.9
CORS_GEO	006:19:51.73748N	0.0	005:38:17.82975E	0.0	109.6260	0.0
ENV_101D	006:18:02.20591N	2.2	005:37:52.56920E	3.3	83.6335	5.4
RAPH_02	006:24:08.05715N	2.3	005:37:11.00661E	2.8	122.5381	4.5
SAP_001	006:16:54.88601N	1.6	005:38:00.05811E	1.9	79.1118	4.1
SMGGS_01	006:18:39.73136N	2.6	005:38:19.72862E	2.9	97.6582	6.7
SMGGS_02	006:18:41.92903N	1.9	005:38:22.11602E	2.3	97.8905	4.8

Table 6: Adjusted Points in Target System

Station Name	N(m)	Std.Dev_ N(mm)	E(m)	Std.Dev_ E(mm)	U(m)	Std.Dev_ U(mm)
AGGS01	696992.3613	1.4	789886.1840	1.7	190.8999	3.5
BEM_606	697161.2229	1.9	791200.7071	2.2	190.4228	4.9
CORS_GEO	700413.7542	0.0	791974.7569	0.0	216.0690	0.0
ENV_101D	697043.0531	2.2	791214.8841	3.3	190.1346	5.4
RAPH_02	708282.0286	2.3	789879.7989	2.8	228.7985	4.5
SAP_001	694974.9413	1.6	791455.6188	1.9	185.6571	4.1
SMGGS_01	698200.7226	2.6	792044.3638	2.9	204.1462	6.7
SMGGS_02	698268.6459	1.9	792117.4470	2.3	204.3780	4.8

DISCUSSION

Table 1, contains information on the statistical analysis of the first set of control points adjustment which involved 36 baselines and 9 control points. The confidence level was 10.00σ at 1.00% significance level. Thus, the result of the analysis showed that the controls are up to the standard specified by SURCON for first order control extension project. Similar degree of accuracy was achieved by Ehigiator et al., (2017) withing the same locality of Benin City for control densification except that GNSS only was used in contrary to what was adopted in this work where the integration of CORS and GNSS was explored.

Table 2 shows the adjusted control points in WGS 84 consisting of 9 control points each. The respective latitude and longitude coordinates and orthometric heights of each controls are shown as well. The standard deviation revealed that three station ADLC_01, ADLC_02, and QSS_01 have the minimum accuracy in latitude (1.3 mm) while the maximum accuracy in latitude (1.7 mm) was recorded at AGGS_01, AGGS_02 stations. For longitude, the maximum standard deviation of (1.9 mm) was recorded at GSTC_02 while the minimum accuracy (1.5 mm) was obtained at stations QSS01 and QSS_02 respectively. In the same manner, the standard deviation in height of (3.5 mm) was recorded at stations AGGS_01 and AGGS_02, the minimum accuracy was (2.8 mm) at QSS01. The horizontal coordinates are more accurate in all cases compare to the vertical coordinates for the stations, the accuracy obtained is in consistence with (Ehigiator et al, 2017a: Fotiou et al., 2006: Botsyo et al, 2020).

Table 3, contains the adjusted points in the target system. The explanation of this Table is very similar to that of Table 2 except that the axes have been rotated according to equation (15) using the scale factor and the rotational parameters. Table 3 contains the result of the rotations that yielded the target system coordinates for the case of Benin City. The ENU is a local frame of reference in the target system that is based on the origin of the navigation system. The E (X) and N (Y) axes point toward the geodetic East and North, respectively, while the U (Z) axis is directed upward in the ellipsoidal normal line. The procedures involve two basic transformation between the Earth-Centre-Earth-Fixed and the East-North-Up. The initial rotation from the ENU to ECEF frame is a (90-φ) clockwise rotation over the East (X) axis. By the first rotation, the Up (Z) axis and Z-ECEF axis are brought into alignment. The second rotation is a (90+λ) clockwise rotation around the Z-axis. The East (X) and X-ECEF axes are brought into alignment by this rotation This method was used to achieve similar rotation parameter for network adjustment by (Ehigiator et al., 2017b; Szabova and Duchon, 2016). Table 4, contains information on the statistical analysis of the second set of control points adjustment which involved 28 baselines and 8 control points. The confidence level was 10.00σ at 1.00% significance level. Thus, the result of the analysis showed that the controls are up to the standard specified by SURCON for first order control extension project This work further confirmed the suitability of control network established within the same vicinity in Benin City (Oladosu et al., 2022).

Table 5 shows the adjusted control points in WGS 84 consisting of 8 control points, each control is with their respective latitude and longitude coordinates and the corresponding orthometric heights. The standard deviation revealed that station AGGS_01 has the minimum accuracy in latitude (1.4 mm) while the maximum accuracy in latitude (2.3 mm) was recorded at, SMGGS_01 station. For the longitude, the maximum standard deviation of (3.3 mm) was recorded at ENV_101D while the minimum (1.7 mm) was obtained at station AGGS_01. The minimum standard deviation in height (3.5 mm) was recorded at station AGGS_01 while the maximum value (6.7 mm) was recorded at SMGGS_01. The horizontal coordinates are more accurate in all cases compare to the vertical coordinates for the stations. The heights presented here are the ellipsoidal heights. These results are consistent with Alademomi et al, (2020) except that the total number of controls used are less than was used in this work.

In Table 6, the transformation process represented in equation (15) has taken effect. This makes it possible to achieve the coordinates of control points in the local system. The eastings, the northings and the up values are represented for each control stations. The heights presented here has been corrected based on the orthometric height propagated to the controls by spirit levelling and adjusted by least squares principle adopted in (Ayeni, 2010; ASzabova and Duchon, 2016).

CONCLUSION

This article explored the indispensable capability of integrating CORS and GNSS observations in the extension of first order geodetic control infrastructure within erosion hotspot in Benin City. The work was accomplished and the final coordinates of the new geodetic control points were derived based on adjustment of the observations using appropriate algorithms. The controls can now serve the purpose of surveying, erosion control, and mapping including other applications. It is therefore recommended that these controls are protected by the Edo State government as they will assist greatly, the recent Edo Geographic Information Services in the delivery of quality mapping and land acquisition process leading to seamless production of accurate certificate of occupancy to the people as more revenue comes to the state government while the problem of inconsistency in survey plan and other documentation can be laid to rest.

ACKNOWLEDGEMENT

The authors sincerely appreciate Geosystems and Environmental Engineering Company LTD. No. 140, 2nd East Circular Road, Benin City for the CORS_Geosystems and the GNSS receivers used for data acquisition.

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