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Enhancing Geodetic Control Points through GNSS and CORS Integration: A Case Study of Ibadan, Nigeria

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Abstract
The second order geodetic control points in Ibadan are experiencing several challenges ranging from outdated infrastructure, positional inaccuracies and urbanization demands, which can be solved by enhancing the accuracies of these control points. The existing network of control points, which were established a long time ago, revealed several inconsistencies such as positional shift up to 1 meter and inaccessible or missing control points (6.8% of 2,101 points surveyed). This research aimed to enhance the accuracy and reliability of the control points by incorporating Global Navigation Satellite Systems (GNSS) and Continuously Operating Reference Stations (CORS). Static GNSS observations with a minimum of 60 minutes observation session were conducted on 1,958 control points, the baseline distances ranges from 30 to 120 km. Data processing, encompassing least squares adjustments and data quality assessments, achieved residuals within ±2 mm and root mean square errors (RMSE) under ±20 mm for all axes, aligning with second-order geodetic standards. The enhanced network improved positioning accuracy and consistency, agrees with international geodetic frameworks, and supports significant applications such as infrastructure development, environmental monitoring, and disaster management. This study demonstrates that integrating GNSS and CORS technologies notably improves the reliability of geodetic control networks, thereby ensuring their utility for sustainable urban development.

Keywords: *Geodetic control points, GNSS, CORS, Positional accuracy, Urban development*

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1. Introduction

Accurate geodetic control networks are vital to the effective implementation of various applications in current urban environments, ranging from land surveying and infrastructure development to environmental monitoring and disaster management (Apeh et al., 2019). Many cities, especially in developing countries like Nigeria, face substantial challenges in upholding accurate and reliable control networks due to outdated technologies, weakening infrastructure, and the swift development of urban areas (David et al., 2020). In Ibadan, Nigeria, the existing second- order geodetic control network has been bewildered by these issues, reducing the usefulness of geospatial data for urban management and development (Apeh et al., 2019).

Second-order geodetic control points provide a practical result for urban and regional applications, ensuring a balance between the accuracy, accessibility, and usability of geospatial data (Hofmann-Wellenhof et al., 2008).

GNSS technology has revolutionized the field of geodesy by offering high-precision positioning proficiencies over massive geographic areas. In contrast to traditional methods, GNSS permits real-time, satellite-based observations, presenting accuracy within millimeters to centimeters, reliant on the configuration (Langley, 1998). Differential GNSS (DGNSS) positioning method further boost GNSS accuracy, making it perfect for upgrading cost, accuracy, and accessibility (Rajabifard et al., 2002). However, the innate shortcomings of these networks, such as inaccuracies owing to obsolete observational techniques and waning physical monuments, emphasize the urgent need for modernization (David et al., 2020). Combining modern geodetic technologies such as GNSS and CORS renders an opportunity to address these challenges and greatly improve existing geodetic control networks (Hofmann-Wellenhof et al., 2008).

CORS network is known to provide non-stop GNSS data from motionless locations, disseminate real-time corrections, enhancing positional accuracy and ensuring consistency across immense regions (Rajabifard et al., 2002).

In location like Ibadan, Nigeria, a city facing speedy urbanization, there is a crucial need to update and harmonize the geodetic control network to take care of the demands of infrastructure growth (Goodchild, 2007). The existing second-order control points, which were established decades ago, suffer from decline and inaccuracies due to the challenging terrain and archaic technology. Integrating GNSS observations with CORS networks presents an auspicious solution to address these problems and create a more consistent geodetic framework. Previous studies in other urban centres have shown that the integration of GNSS and CORS can yield considerable enhancements in the accuracy of geospatial data, enabling better decision-making in urban management (Langley, 1998; David et al., 2020).

2. Materials and methods

2.1 Study area

The study was conducted in Ibadan, Nigeria, a swiftly urbanizing city situated between latitudes 7°2'N and 7°44'N and longitudes 3°30'E and 4°9'E as found in Fig. 1. The city covers an area of nearly 3,080 km², with terrain elevations ranging from 150 to 275 meters above sea level. Ibadan's urban growth and infrastructure development demand an updated and reliable geodetic control network.

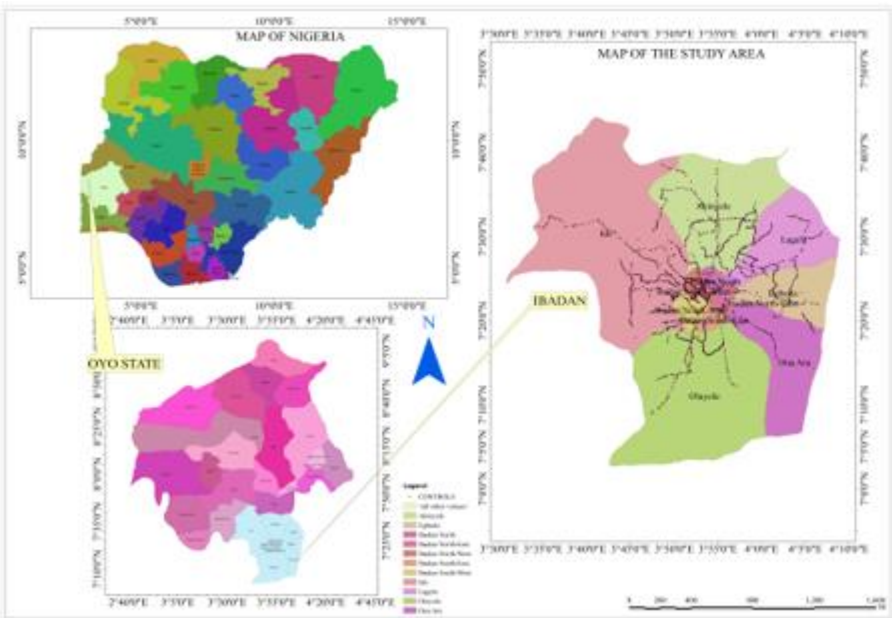

Fig. 1: Map of the study area

2.2 Data acquisition

The existing control points observed are distributed throughout Ibadan City totaling one thousand, nine hundred and fifty-eight (1958) points. These points were observed using GNSS equipment in static observation mode with at least 60 minutes observation session on each point. Table 1 shows the details of the data used for this study, Table 2 shows the datasets obtained from the Federal School of Surveying, Oyo, and the Lagos State NIS Office, while Table 3 shows the coordinates of second order control points obtained from the Office of the Surveyor General, Oyo State.

Table 1: Details of data acquired for this study

Dataset	Source	Order	Uses
Coordinates of Continuously Operating Reference (COR) Station	Federal School of Surveying, Oyo	First Order	Served as the main reference for enhancing GNSS observations, aligning control points
Additional Control Points		First order	Used to test and validate GNSS receivers, confirming the reliability of field

			measurements
Coordinates of COR Station	Lagos State NIS Office	First Order	Provided stable reference for enhancing positional accuracy across the survey network
Second Order Control Points	Office of the Surveyor General, Oyo State	Second order	Used for navigating to the existing geodetic second order control points
Observed Coordinates from Field GNSS Survey	Field observations during GNSS survey	Second order	Collected as primary field data; used to enhance and validate control points across the area

Table 2: Cartesian coordinates of reference controls used (WGS 84)

Station	X	Y	Z	Data Source
FSS CORS	6304182.612	435465.335	864624.149	FSS, SIWES UNIT
LAGOS CORS	6325140.932	370840.8822	730182.062	LAGOS NIS OFFICE
XSN07	6304202.139	435238.211	864566.891	FSS, SIWES UNIT
XGA 1	6304209.928	435239.322	864528.780	FSS, SIWES UNIT
XGA 2	6304169.182	435338.960	864723.419	FSS, SIWES UNIT

Table 3: Sample of the control points used for this study in UTM Zone 31(WGS 84)

Pillar ID	Eastings	Northings	Height
YZM051	648510.041	892856.784	418.046
YZM052	649162.092	893263.904	421.478
YZM053	649606.932	893483.250	419.061
YZM054	650291.909	893588.200	425.872

The tools and materials listed in Table 4 were cautiously chosen to ensure precision, efficiency, and compatibility throughout the study. The blend of high-performance GNSS receivers and robust processing software enabled seamless data acquisition, processing, and analysis

Table 4: Hardware and software used

Category	Item	Description/Specifications
Hardware	CHC NAV DGNSS Receivers and Accessories	Two high-precision GNSS receivers with multi-frequency support.
	Unistrong G70 Pro II DGNSS and Accessories	GNSS receiver with advanced satellite tracking and precision capabilities.
	Tribrach and Tripod	Four units for stable receiver setup during field observations.
	Laptop	HP Intel CORE i7, 4GB RAM, 500GB HDD, Windows 10.
	Unistrong and CHC NAV Downloading Cable	Cables for data transfer from GNSS receivers.
Software	Trimble Business Centre	GNSS data processing software for baseline computation and adjustments.
	RTKlib	Software for GNSS data quality assessment and residual analysis.
	Geographic Calculator	For Coordinate Conversion
	Microsoft Word and Excel	Tools for analysis, documentation, and report generation.

2.3 Project planning

Project planning involved developing a work plan to achieve the survey objectives effectively. It required gathering relevant data, studying the project area, and formulating tactics to ensure the goals were met. Planning was divided into office planning and field reconnaissance. Office planning focused on preparation for fieldwork, this includes obtaining coordinates of second-order control points from the Office of the Surveyor General of Oyo State, deciding on the Static Differential GNSS technique, and collecting COR station coordinates from FSS Oyo and NIS Lagos. Other activities included studying SURCON's geodetic survey specifications, acquiring Google imagery, and dividing the study area into four zones for field observations. Field reconnaissance involved visiting 2,101 control points using a GARMIN GPSmap 76 to ascertain their condition as seen in Fig. 2. Table 5 shows the summary of their conditions:

Table 5: Summary of conditions of control points

Control Status	Number	Percentage %
Existing Controls	1958	93.194
Inaccessible Controls	57	2.713
Missing Controls	81	3.855
Wrong Coordinates	5	0.238
Total	2101	100.000

a. Pillar YZN 167 b. Pillar YZN1802 c. Pillar YZN1164

Fig. 2: The samples of control points (a, b, c)

2.3.1 Test of Unistrong and CHC NAV GNSS receivers

Prior to the main fieldwork, the GNSS Receivers used were tested to examine their suitability for the job at hand. Static observation was conducted on three control points for this test and it started by setting a base receiver (CHC NAV) on control station XSN07 which was situated within Federal School of Surveying premises. The instrument was centred and levelled on the control station and the data logger was configured in order for the receiver to commence observation to the satellite in static mode. Another receiver was taken to station XGA 1 for static observation for a period of one hour. Finally, a Unistrong GNSS Receiver was taken to the third point named XGA 2 for observation as well. The data was downloaded, processed and compared with the given coordinates. Table 6 shows the observed and given geocentric coordinates of control points used for this task while Table 7 shows the baseline vectors.

Table 1: Observed and given Geocentric coordinates of XSN 07, XGA 1 and XGA 2

STN	Easting (m)	Northing (m)	Height (m)
XSN07 (Fixed)	6304202.139	435238.211	864566.891
XGA 1 (Given)	6304209.928	435239.322	864528.780
XGA 2 (Given)	6304169.182	435338.960	864723.419
XGA 1 (Observed)	6304209.932	435239.317	864528.769
XGA 2 (observed)	6304169.171	435338.979	864723.430

Table 2: Baseline vector of XSN 07, XGA 1 and XGA 2

From	To	ΔX	ΔY	ΔZ	Length
XSN07	XGA 1	7.793	1.106	-38.122	38.9261
XGA 1	XGA 2	-40.757	99.657	194.65	222.4439
XGA 2	XSN07	32.968	-100.768	-156.539	189.0649
Sum		0.004	-0.005	-0.001	450.4349

2.3.2 Analysis of loop closure of control check

Loop closure $(L_c) = (\Delta X_{Sum}^2 - \Delta Y_{Sum}^2 - \Delta Z_{Sum}^2)^{½}$ (1)

Expression in part per million (ppm) = Loop closure/Total length (2)

where ΔX_{Sum}, ΔY_{Sum}, ΔZ_{Sum} are the summation of errors in X, Y and Z. Having examined the result of the above observations, discrepancies showed that the allowable limit of accuracy was met.

2.3.3 Static GNSS observation

The static GNSS observation involved observation sessions as seen in Fig. 3 lasting at least 60 minutes and more for specific control points to enhance accuracy. A minimum of six satellite locks was maintained per epoch, often ranging between six and nine in order to achieve precise data collection. GNSS receivers were set up at control points, with instrument heights carefully measured. Observations spanned distances of 30 to 120 km from base stations, such as FSS CORS and LAGOS CORS, optimizing baseline computations. Data from these sessions were subjected to differential GNSS processing to achieve high-accuracy results. The Rinex file (observation and navigation) for each day of observation for FSS COR and LAGOSCOR stations were obtained from Siwes and Practical Units, FSS and NIS Head Office, Lagos State respectively.

Fig. 1: Static GNSS observation sessions

2.4 Data quality

The quality of the original coordinates obtained and that of the observed rinex file was examined and are discussed below:

2.4.1 Data quality assessment of original coordinates

The original coordinates of the 1958 control points exhibited a general agreement with contemporary standards; however, discrepancies of up to 1 meter in some points demonstrated a need for enhanced precision. The data quality of the original coordinates was computed with specific focus on positional accuracy and consistency issues that made enhancement necessary.

2.4.2 Quality assessment of the observed rinex files

To analyse the quality of GNSS data collected from control points, an open-source GNSS processing software named Real Time Kinematic Library (rtklib) was used. The rinex files, each corresponding to a control point observation, were processed through rtklib's rtkpost module. This module permits precise positioning by analysing raw GNSS data such as pseudorange, carrier phase, and signal-to-noise ratio (SNR) values. Several metrics were extracted through rtklib, the extracted metrics as seen in table 8 were then saved for further statistical analysis, concentrating on data reliability and signal stability. Below are the important metrics:

i. Total Observations: The count of all data points recorded for each observation point.
ii. Mean Signal-to-Noise Ratio (SNR): The average signal quality, reflecting how clear and strong the received signal was.
iii. SNR Consistency: This measures the variability of SNR across observations.
iv. Number of Satellites Observed: The count of satellites detected during each observation epoch.
v. Average Signal Strength: An average measure of signal quality across all observed satellites.
vi. Dilution of Precision (DOP) Values: Including Position DOP (PDOP), Horizontal DOP (HDOP), and Vertical DOP (VDOP), reflect satellite geometry and its effect on positioning accuracy.

vii. Data Completeness: This shows the percentage of recorded data relative to the expected data for each observation point.

Table 3: The summary of a sample of extracted data quality results

Observatn Point	Total Observations	Mean SNR (dB)	SNR Consistency	Satellites Observed	Avg. Signal Strength (dB)	PDOP	HDOP	VDOP	Data Completeness (%)
YCA066	10627.0	42.7	17.4	8.0	42.0	1.5	1.2	2.1	100.0
YCA067	9986.0	43.0	14.4	7.0	38.0	1.8	1.4	2.4	98.0
YCA068	10439.0	58.8	16.7	9.0	40.0	1.3	1.1	2.0	100.0
YCA069	10419.0	54.7	11.0	6.0	37.0	2.0	1.6	2.6	96.0
YCA070	10473.0	43.3	17.5	8.0	41.0	1.4	1.2	2.2	99.0

2.5 Data processing

The data processing phase focused on ensuring the accuracy and usability of static GNSS data for precise surveying and mapping. With the use of Trimble Business Centre software, the process included project setup with UTM Zone 31N WGS 84 parameters, GNSS data import in RINEX format, and baseline processing. The static GNSS data were processed relative to two COR Stations (FSSCOR and LAGOSCOR) to ensure positional accuracy, the sample of the result of processing is in Table 9.

Table 4: Sample of the observed control points coordinates in ECEF WGS84

Pillar number	Easting	Northing	Elevation	Var(X)	Cov(XY)	Cov(XZ)	Var(Y)	Cov(YZ)	Var(Z)
ICS 1001T	6309847.170	431788.419	823843.000	9.13E-05	7.39E-05	4.27E-05	1.46E-05	8.79E-05	5.85E-05
ICS 1002T	6309844.361	431970.399	823830.180	7.11E-05	5.79E-05	2.23E-05	4.43E-05	7.41E-05	6.83E-05
ICS 1003T	6309825.180	432226.770	823855.391	2.14E-05	2.93E-05	6.27E-05	7.98E-05	3.42E-05	6.24E-05
ICS 1004T	6309806.380	432390.880	823961.980	1.13E-05	6.14E-05	4.04E-05	8.21E-05	4.94E-05	5.48E-05

2.5.1 Network pre-adjustment analysis

Before adjusting the GNSS networks, a series of measures were followed to analyse the data for internal consistency and to eliminate probable blunders (Ghilani and Wolf, 2014). No control points are required for these analyses. Contingent on the actual observations taken and the network geometry, a loop closure analysis was employed.

2.5.2 Analysis of loop closures

The control network comprised many interconnected closed loops. For example, a closed loop was formed by points FSS-YZ3-YZ1. Similarly, FSS-YZ1-YZ4, FSS-YZ2-YZ4, and so on, are other closed loops. For each closed loop, the algebraic sum of the X, Y, Z components should equal zero respectively. An unusually large misclosure within any loop indicate that either a blunder or a large random error exists in one (or more) of the baselines of the loop. To compute loop misclosures, denoted as cx, cy and cz, the baseline components are added for the loop chosen.

$$Cx1 = \Delta Xfss - YZ3 + \Delta XYZ3 - YZ3 + \Delta XYZ1 - fss \tag{3}$$

$$Cy1 = \Delta Yfss - YZ3 + \Delta YYZ3 - YZ3 + \Delta YYZ1 - fss \tag{4}$$

$$Cz1 = \Delta Yfss - YZ3 + \Delta ZYZ3 - YZ3 + \Delta ZYZ1 - fss \tag{5}$$

Solutions from the Equations (3, 4 and 5) are used in computing for the resultant closure for the loops in each session. The resultant closure is given by the Equation (6).

$$Resultant\ Vector\ (ce) = \sqrt{(cx^2 + cy^2 + cz^2} \tag{6}$$

For evaluation purposes, loop misclosures are expressed in terms of the rations of resultant misclosures to the total loop lengths. They are given in part per million (ppm).

$$Resultant\ Vector\ (ce) = \sqrt{(cx^2 + cy^2 + cz^2} \tag{7}$$

ppm = (ce/Loop Length) *1,000,000
where 'ce' is the Loop closure error. The results of the closures and ppm values, as shown by Table 10, indicate a high level of consistency in the observations. It further indicates that there were neither possible blunders nor random errors in any of the measured loops.

Table 5: Sample of loop closure analysis

Loop	Baseline	ΔX	ΔY	ΔZ	Distance	Miscl.	PPM Ratio
NIS-YZ4-YZ1	NIS-YZ4	-20766	61821.98	134267.8	149268.3		
	YZ4-YZ1	704.837	2050.286	-6155.37	6526.031		
	YZ1-NIS	20061.17	-63872.3	-128112	144550.7		
	ERROR	0.039	0.008	0.016	300345	0.042906876	0.142859
NIS-FSS-YZ1	NIS-FSS	-20958.4	60624.34	13441.91	65538.14		
	FSS-YZ1	897.18	-752.073	-6329.49	6436.842		
	YZ1-NIS	20061.17	-59872.3	-7112.42	63543.1		
	ERROR	-0.011	0.002	0.005	135518.1	0.012247449	0.090375

Table 6: The observed, computed residual and adjusted coordinate of some control points

	Observed			Residual			Adjusted		
Pillar No.	X	Y	Z	X	Y	Z	X_adj	Y_adj	Z_adj
YZN 1216	6310122.170	448208.170	812720.419	0.002	-0.001	-0.004	6310122.172	448208.169	812720.415
YZN 1217	6310113.840	448407.700	812664.041	-0.004	0.002	-0.001	6310113.836	448407.702	812664.040
YZN 1218	6310088.250	448901.200	812445.610	0.004	-0.007	-0.002	6310088.254	448901.193	812445.608

3. Results

3.1.1 Examination of result of least squares adjustment of control point coordinates

The dataset examined comprised of the adjusted coordinates and residuals for all the survey control beacons, including their Easting, Northing, and Elevation values. Table 12 contains the result of the Examination of the residual and adjusted coordinates adopting the below techniques:

i. Residual Analysis and Statistical Measures

a) For the second-order standards, these residuals were examined to confirm their adherence to the defined tolerance (e.g., ±2 cm or 20 mm).

b) The mean of residuals should ideally be close to zero (within ±2 mm) for each direction (X, Y, Z), indicating minimal bias, while small standard deviations imply consistent alignment within tolerance across directions.

c) RMSE values should be under ±20 mm for each axis in a second-order survey, as such, the values computed fell within the established tolerance, reinforcing the reliability of the adjustment.

ii. 3D positional accuracy assessment

Horizontal positional accuracy was evaluated through the computation of the horizontal error

$$\sqrt{X^2 residual + Y^2 residual} \quad (19)$$

and vertical accuracy was checked using Z-residuals independently. The total 3D positional error was derived as

$$\sqrt{X^2 residual + Y^2 residual + Z^2 residual} \quad (20)$$

This 3D error was then compared against the standards for second-order survey accuracy, confirming compliance with required accuracy levels.

iii. Consistency Checks

a) An assessment of relationships between residuals along the X, Y, and Z axes was performed to detect any systematic error patterns. High correlations would have indicated potential systematic errors; For two variables X and Y, the Pearson correlation coefficient r is calculated as:

$$r = \frac{\sum(xi-\overline{x})(yi-\overline{y})}{\sum(xi-\overline{x})^2(yi-\overline{y})^2} \quad (21)$$

where Xi and Yi are individual control points, $\overline{X}$ and $\overline{Y}$ are the means of X and Y, r ranges from -1 to +1, with values close to zero implying low correlation

b) A Chi-square test on the residuals was conducted to assess if they conformed to the expected error distribution within second-order survey standards. The results supported alignment with the expected distribution, validating the complete adjustment's consistency.

$$X^2 = \frac{\sum(Oi-Ei)^2}{Ei} \quad (22)$$

where: Oi is the observed frequency in each bin, Ei is the expected frequency for each bin

Table 7: Result of the examination of the residual and adjusted coordinates

Metric	Computed Value	Expected Standard (Second Order)	Comments
Mean Residual (X)	0.000057	±2 mm	Mean close to zero; meets second-order standard
Mean Residual (Y)	-0.000087	±2 mm	Mean close to zero; meets second-order standard
Mean Residual (Z)	-0.000043	±2 mm	Mean close to zero; meets second-order standard
Standard Deviation (X)	0.006397	±20 mm	Well within tolerance
Standard Deviation (Y)	0.006342	±20 mm	Well within tolerance
Standard Deviation (Z)	0.006427	±20 mm	Well within tolerance
RMSE (X)	0.006396	±20 mm	Well within tolerance
RMSE (Y)	0.006341	±20 mm	Well within tolerance
RMSE (Z)	0.006426	±20 mm	Well within tolerance
Horizontal Positional Error	0.009008	±20 mm	Within tolerance for second-order standard
Metric	Computed Value	Expected Standard (Second Order)	Comments
Vertical Positional Error	0.006427	±25-30 mm	Within tolerance for second-order standard
3D Positional Error	0.011066	±30 mm	Within tolerance for second-order standard
Correlation (X, Y, Z)	X-Y: -0.0116, X-Z: 0.0181, Y-Z: -0.0136	Low correlation, ideally close to zero	Indicates no systematic bias in any direction
Chi-Square Test	Chi^2 Stat: 4.115, P-value: 0.661	95% within ±20 mm in each direction	Confirms residual distribution fits second-order

4. Discussion

This section analyses the findings presented above, providing insights into the implications and significance of the results.

3.2.1 Analysis of original data quality assessment

Most of the original datasets are accurate in relation to SURCON standards and some exhibited positional irregularities when compared to GNSS-adjusted coordinates which raised major concerns. These comprised positional shift, where substantial aberrations of up to 1 meter were observed in some control points, indicating that influences such as environmental changes, aging survey markers, and limitations in surveying methods may have introduced errors over time. This lack of homogeneity emphasized the need for an updated process using GNSS technology to ensure consistent precision across the network.

3.2.2 Analysis of RINEX file quality

The analysis of RINEX file quality metrics displayed consistent and reliable data across observation points, appropriate for second-order standards. All points have almost the same number of observations, signifying robust data availability for accurate analysis. Mean Signal-to-Noise Ratio (SNR) values ranged from 42.7 to 58.8 dB, which is well above the commonly accepted 30 dB minimum, showing strong signal quality. Furthermore, SNR consistency values between 14 and 17 dB indicate minimal fluctuations, implying stable observation conditions. Satellite counts per epoch varied from 6 to 9, agreeing with the second-order standard of at least 6 satellites. Average signal strength remained consistently high, emphasizing the observations' quality. The Dilution of Precision (DOP) values, with PDOP ranging from 1.3 to 2.0 and equally low HDOP and VDOP values, support both horizontal and vertical positioning accuracy by minimizing geometric distortion. Data completeness was remarkably high, with most points accomplishing full data capture, supporting the reliability and integrity of each observation. Finally, the extracted metrics reliably meet second-order standards, supporting the dataset's reliability and precision.

3.3 Result adjustment computation

3.3.1 Residual analysis

The residual means for X, Y, and Z directions are close to zero (within ±2 mm), which meets the expected second-order standard. This indicates that there is no significant bias in any direction, suggesting that adjustments made to the observations effectively minimized directional errors. Furthermore, the standard deviations in each direction (X, Y, Z) are all within the ±20 mm tolerance, this shows that the spread of residuals remains well within acceptable limits. The Root Mean Square Error (RMSE) values agree closely with the standard deviations, reinforcing the consistency of the residuals across all three axes.

3.3.2 3D positional accuracy

The residual results and low spread within X, Y, and Z suggest that positional errors remain within the second-order permissible limits. This is basically true given the low residual means and standard deviations, which imply a stable adjustment process.

3.3.3 Consistency checks

The low correlation values (X-Y: -0.0116, X-Z: 0.0181, Y-Z: -0.0136) suggest minimal correlation between the directions, which indicate an absence of systematic bias along any particular axis. This low correlation across axes implies that errors in one direction do not strongly influence errors in the others. Additionally, the chi-square test statistic of 4.115 with a p-value of 0.661 indicates that the distribution of residuals aligns well with the expected distribution within ±20 mm tolerance. The high p-value suggests a good fit to the expected second-order distribution, confirming that the observed residuals are well-controlled.

5. Conclusion

Modern geodetic technologies, such as GNSS and CORS, offer transformative proficiencies that can meaningfully boost the network's accuracy and usability. These technologies offer high-precision positioning and the ability to conduct surveys in challenging terrains, addressing the limitations of traditional systems. The integration of GNSS and CORS in the enhancement process not only improves positional accuracy but also ensures compliance with international standards, which enables seamless interoperability with global geodetic frameworks. The enhancement process demonstrated remarkable improvements in data quality and network consistency. Positional errors were minimized, residuals fell within acceptable limits, and standard deviations adhered to second-order geodetic standards, ensuring high precision across the network. Such advancements not only enhance the reliability of the geodetic framework but also provide a foundation for more efficient decision-making in urban management. Conclusively enhancing Ibadan's geodetic control points with GNSS and CORS technologies is not just an upgrade but a vital step toward building a robust and modern geodetic framework. This initiative ensures that the network meets current urban demands while establishing a foundation for sustainable development.

Conflict of interest statement

The authors declare that there are no conflicts of interest related to this work. No financial, personal, or professional relationships exist that could be perceived to have influenced the findings of this study.

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