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# Impact of Baseline Lengths on GNSS Positioning Accuracy

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**Abstract**
Global Navigation Satellite Systems (GNSS) encompass a variety of positioning systems capable of providing the necessary precision for establishing Ground Control Points (GCPs). This study delves into the impact of baseline lengths (short, medium, and long) on the positional accuracy of GNSS observable. The research involved gathering positional data from seven control stations and analyzing the effects of different baseline lengths on GNSS positioning accuracy. Satellite observations were collected at seven points within three local government areas in Oyo State (Oyo East, Atiba, and Afijo L.G.A). GNSS Receivers were utilized to collect data in static mode with 1 hour and 30-minute observation sessions at each of the seven points connected to the active CORS station. Short baselines covered distances not exceeding 5km and 56km from the test rover points to a base station within the Federal School of Surveying Oyo and a CORS located in Osun State, respectively. The medium baseline spanned distances not exceeding 103km and 153km from the test control points to CORS stations in Abeokuta and Lagos states, respectively. The long baseline extended not more than 412km from the test control points to a CORS in Abuja. An analysis of variation for all stations for each baseline was conducted. Results revealed that the precision of processing the baselines between the base stations and the rovers relies on the baseline length. The best results were attained when using long baselines of not more than 412km, as they provided better results than short baselines, although various factors can influence this.

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**Keywords:** Baseline Length, GNSS, CORS, Accuracy, Ground Control Points

## 1. Introduction

The evolution of Global Navigation Satellite Systems (GNSS) has transitioned from passive geodetic control networks to active continuous operating reference stations (CORS). These active reference stations are being modeled into a network system that can reduce the number of ground stations over a coverage area by extending baseline length while simultaneously improving the accuracy of processing the baselines between reference stations and rovers. This can be achieved through networked GNSS stations connected to a central control station for data correction and modeling, or by using the Virtual Reference Station (VRS) network concept. (Retscher, 2002) [11].

The baseline, which is the distance between the rover and the base station, plays a crucial role in DGNSS positioning and directly impacts the accuracy of position determination. Furthermore, satellite geometry and sources of error within GNSS have implications for positioning accuracy (Lonchay, 2009) [8].

Differential Global Navigation Satellite System (DGNSS) positioning involves determining the position of a rover station relative to a base station and satellites. Both stations observe the same satellites in space, requiring pseudo-range corrections based on the rover station's position relative to the base station. Differential correction in DGNSS positioning enhances GPS position determination accuracy and is useful in oil exploration, construction, mapping, and deformation monitoring, compared to Precise Point Positioning (PPP), etc. (Rizos, 1999).

In addition to the GPS, several other satellite constellations have been developed and are still being developed, including the Russian GLONASS, the European Galileo, the Chinese BeiDuo/COMPASS, and the Japanese QZSS. Currently, three GNSS constellations (GPS, GLONASS, and QZSS) are fully operational, while COMPASS and Galileo are actively being deployed. New satellite constellations increase available satellites, requiring proper synchronization for GNSS access. The two clocks must be properly synchronized as a deviation of 1 nanosecond is equivalent to 30cm in distance (Trimble, 2012). This combination of satellite systems allows for better coverage in previously obscured areas. Modern GNSS rovers are now able to reach these previously inaccessible areas. The independent operation of multiple navigation systems has significantly enhanced the awareness and accuracy of real-time positioning and navigation. Furthermore, a combined GNSS system that utilizes the GPS, GLONASS, and Galileo systems simultaneously boasts a constellation of approximately 75 satellites. The availability of these satellites has greatly improved the accessibility of GNSS receivers, especially in urban canyons (Xu, 2007) [13].

This study investigates the impact of baseline length variations on the accuracy of Global Navigation Satellite Systems (GNSS) observable. It examines the theoretical principles governing GNSS measurements and how fluctuations in baseline length may lead to errors or uncertainties in observable data. Furthermore, the research illustrates the practical implications of baseline length variations on GNSS accuracy. Therefore, the expert in the field of geomatics can now measure spatial distances – baselines and estimate 3D coordinates of a new point (rover) relative to a reference point located a few too many tens of kilometers away (Fotiou, *et al.* 2006) [5].

In geodetic and mapping projects, achieving high levels of accuracy is crucial. Global Navigation Satellite Systems (GNSS) offer a range of positioning capabilities that can deliver the required precision for establishing Ground Control Points (GCPs). However, the accuracy of GNSS survey results is affected by factors such as session duration and baseline length. This study aims to determine the level of accuracy provided by GNSS for specific baseline lengths in the context of GCP establishment and densification.

The study collected positional data from seven control stations using a GNSS receiver. The collected data was processed to create short, medium, and long baselines from a conventional base station. The study's results were meticulously analyzed and subsequently presented. Our analysis of the GNSS data indicates that optimal results are attained when utilizing long baselines not exceeding 412km.

## 2. Study Area Setting

Figure 1 depicts the geographical location of the research area, encompassing the administrative boundaries of three local governments in Oyo town: Atiba, Oyo East, and Oyo West, all situated within Oyo state in Nigeria. Oyo, located 32 miles (51 km) north of Ibadan, was established in the 1830s as the capital of the remaining territory of the historical Oyo empire. Locally referred to as 'New Oyo' (Ọ̀yọ́ Àtìbà) to distinguish it from the abandoned former capital 'Old Oyo' (Ọ̀yọ́-Ilé) to the north, the city is predominantly inhabited by the Yoruba people, with the Alaafin of Oyo as its ruler. The Yoruba ethnic group is the main population in Oyo State, primarily engaging in agriculture but also preferring to live in densely populated urban areas. The indigenous population consists mainly of the Oyos, the Oke-Oguns, the Ibadans, and the Ibarapas, all part of the Yoruba family and native to the African city.

The area under consideration in this article pertains to a specific portion of Oyo Town. It is situated between latitude 070 51' 41.46" N and latitude 070 49' 22.16'' N, and longitude E to 030 55' 50.14" E and longitude 030 58' 08.89E. This particular area covers an approximate circumference of 12.5 km and has a 2 km radius with control station XSN07 at its center, which has been established within the Federal School of Surveying Oyo.

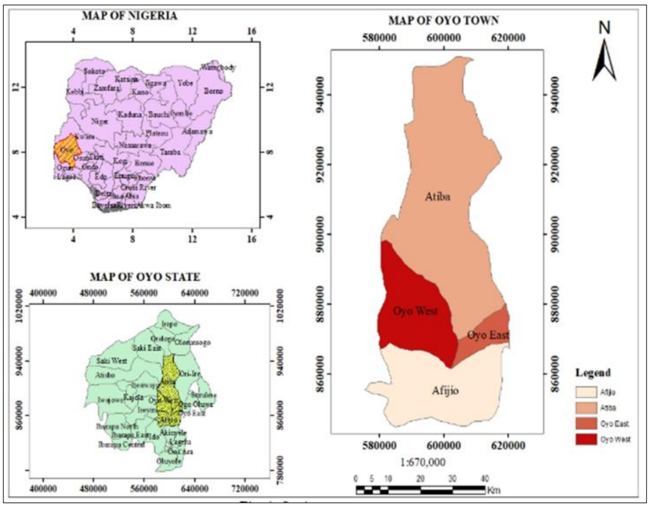


**Fig 1:** Study area map

## 3. Material and Methods

### 3.1. Dataset

The study initially involved office planning, which included conducting a comprehensive data search. This phase encompassed gathering all relevant existing information and data required for the research. Specifically, the existing coordinates detailed in Table 1 were acquired to capture the coordinates of the first-order control stations XSN07, FSS/CORS1, and FSS/CORS2. These coordinates, situated within Oyo State, were sourced from the Student Work Experience Scheme department and the practical unit of the Federal School of Surveying, Oyo. The purpose of collecting these values was to utilize the points as control stations for the research.

**Table 1:** Coordinate Values of Control Stations

| Control Station Id | Survey Order | ME | MN | Elevation(m) | Datum |
|---|---|---|---|---|---|
| XSN07 | First Order | 604755.785 | 866879.146 | 309.972 | Minna Z (31) |
| FSS1/GPS/17 | First Order | 601051.714 | 863523.691 | 312.983 | Minna Z (31) |
| FSS1/11 | First Order | 603074.355 | 865927.578 | 315.779 | Minna Z (31) |

**Source:** Siwes and Practical Unit, Federal School of Surveying, Oyo

We utilized the existing second-order control points' coordinates to evenly distribute stations within a portion of Oyo town. Seven control points were strategically placed along the circumference of a 2km radius circle using AutoCAD. These points were evenly distributed and then exported to Google Earth to determine their respective latitudes and longitudes. By using Google Maps, we were able to pinpoint the location of each point. Additionally, we obtained a map of the study area to provide further guidance.

### 3.2. Research Framework

The research methodology comprises four main steps, each essential for comprehending the impact of base length differences on GNSS observable accuracy and processing software. The initial step involves conducting an instrument test using GNSS receivers for each control. This test determines the operational status of the available GNSS receiver. It involves using the GNSS receivers to conduct observations on the three control stations: XSN07, FSS1/CORS1, and FSS1/11, with each GNSS receiver being operated to acquire 30 minutes of GNSS data. The XSN07 serves as the known station, and the other two controls depend on it. One GNSS receiver is set up on the base station (XSN07) and is powered on to log data beyond the rovers' recording time. The remaining two receivers are set up on FSS1/CORS1 and FSS1/11 and are assigned as rover stations. The rovers are each timed to log 30 minutes of GNSS data. Data from all receivers are then downloaded, processed, and analyzed. The resulting report indicates that the GNSS receivers were in good working condition.

### 3.3. Control Check

The data collected from the instrument test underwent processing to obtain adjusted coordinates. These adjusted coordinates were compared with the existing data to analyze any discrepancies. Table 2 illustrates the differences observed between the new and existing set of coordinates.

**Table 2:** Discrepancies Existing Between Existing and Newly Observed Coordinate

| | Existing Values | | | |
|---|---|---|---|---|
| **STN ID** | **Northing** | **Easting** | **Height** | **Datum** |
| FSS117 | 863523.698 | 601051.694 | 312.957 | Minna Zone (31) |
| XSN07 | 866879.146 | 604756.658 | 310.945 | |
| | **New Values** | | | |
| STN ID | Northing | Easting | Height | Datum |
| FSS117 | 863523.700 | 601051.684 | 312.954 | Minna Zone(31) |
| XSN07 | 866879.146 | 604756.658 | 310.945 | |
| | **Discrepancy** | | | |
| STN ID | Error in Northing | Error in Easting | Error in Height | Datum |
| XSN07 | 0.000 | 0.000 | 0.000 | Minna Zone(31) |
| FSS117 | -0.002 | 0.010 | 0.003 | |

**Source:** Field Observation (June, 2023)

The variation illustrates the contrast between the new and existing values. Station XSN07 displays no variation, as all values remain unchanged. However, station FSS117 exhibits slight variations in the north, east, and height values. There is a decrease of 0.002 in the north value, an increase of 0.010 in the east value, and a decrease of 0.003 in the height value. Upon closer examination of the data, these variations appear to be minor and mostly inconsequential. Specifically for station FSS117, the northing value has decreased by 0.002, the easting value has increased by 0.010, and the height value has decreased by 0.003. These variances are relatively small and may be attributed to measurement inaccuracies or minor refinements in the data.

### 3.4. GNSS field observation

The way positional coordinates are measured by surveyors and other professional engineers has been significantly altered by the Global Navigation Satellite System. These specialists can now calculate the 3D coordinates of a new point (rover) to a reference that is positioned anywhere from a few to many tens of kilometers away, as well as measure spatial distances and baselines (Fotiou *et al*.., 2006) [5]. During this investigation, we conducted GNSS field observations following careful planning. We utilized three dual-frequency GNSS receivers, with one serving as the base station receiver set up on a well-established first-order control point. The other two receivers functioned as rover receivers and were deployed to survey the positions of 7 designated points. Having two rover receivers allowed us to simultaneously conduct GNSS surveys on two points, doubling our efficiency compared to surveying one station at a time. FSS117 identifies the first known station, while the identities of the 7 stations with determined positions are FSS2/01, FSS2/02, FSS2/05, FSS2/06, FSS2/07, FSS2/09, and FSS2/10. Acquiring GNSS data for these points involves several observation steps: i. Setting up the master GNSS receivers on FSS1/11, ensuring they are well-centered and leveled above the stations, and powering them on. ii. Registering a GNSS field log sheet for each observation session, recording station identity, GNSS receiver's serial number, observation file name, receiver height, operator's name, start and stop time of the session log, observation date, antenna model, and receiver model. iii. Accessing the receivers via their data logger, an Android device.

Configuring the following settings: selecting the Static Survey menu, entering the station identity (e.g., FSS1/11) on the static menu window, and selecting Record to start recording and performing these steps for all the receivers. It was ensured that the base receiver was powered on before the rover receivers, and the rover receivers were powered off before the base receivers. Each monumented station was occupied sequentially, and the instrument height was measured at each station.

### 3.5 Data Processing

The method used to detect post-classification changes involved downloading observed GNSS data from the memory of the GNSS receivers for further processing. The data processing relied on two main techniques according to the aim of the research. The downloaded GNSS data were processed using Trimble Business Centre (TBC). The distances between the test control points and base stations FSS117 (5km), Osun CORS (56km), ABKC CORS (103km), SACR CORS (153km), ABFC (412km) were grouped as short (5km and 56km), medium (103km and 153km), and long baselines (412km). The coordinates of the seven test control points were then processed relative to individual base stations. Subsequently, the newly obtained coordinates were compared with the existing coordinates to assess the impact of baseline length on the accuracy of the observations.

After making the necessary configurations, we selected "Import" to bring in the organized GNSS RINEX files. A window popped up on the right-hand side of the PC screen, allowing us to browse the "BaseFSS17" folder. All the RINEX files in the folder were displayed on the TBC import window. we chose to import all of the displayed RINEX files and clicked "import" from the TBC import window. Once the RINEX files were successfully imported, a window with detailed information about the imported files appeared. In this window, we set the manufacturer column to "South" and the antenna type to "Galaxy G1 582D". After ensuring that all details were correctly set and satisfactory, we clicked "ok" to view the unprocessed baseline as shown in Fig. 2.

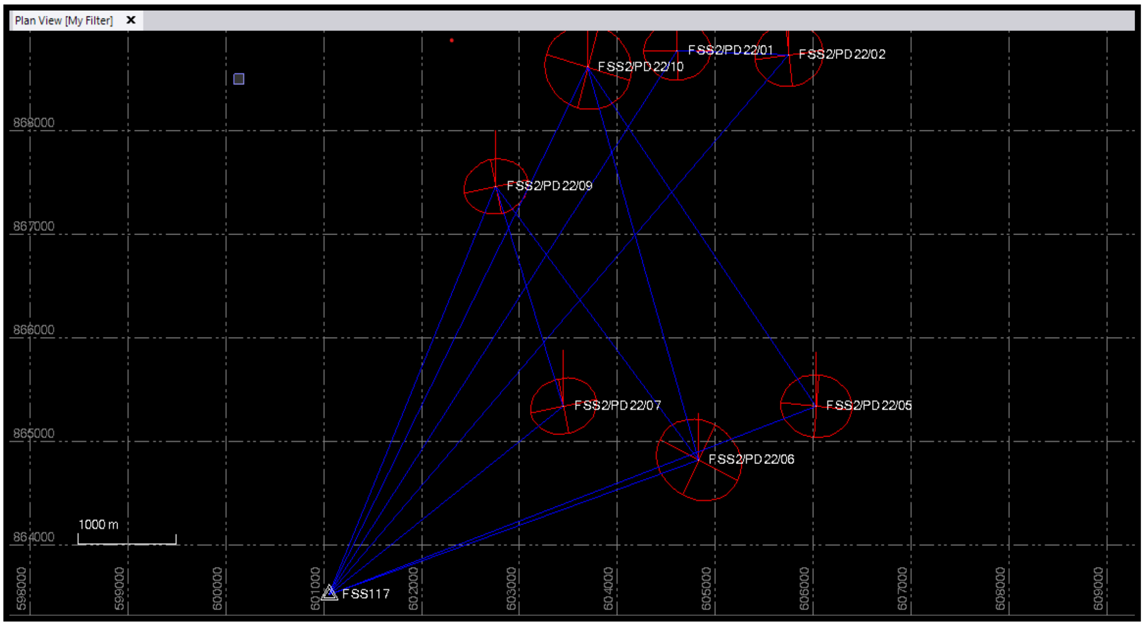


**Fig 2:** Unprocessed baselines

## 4. Result and Discussion

### 4.1. The variance in coordinates between the standard data and the processed data of the other control.

The current coordinates of the test control points were consistently labelled as 'STANDARD DATA.' These standard coordinates were then compared against the coordinates obtained from five different base stations (FSS1/11, OSUN CORS, SACR CORS, ABKC CORS, and ABFC CORS) by calculating their differences. The results are as follows in Fig. 3.

### Short Baselines

The variance between the standard data and the coordinates acquired for FSS117 was noted, and the findings are detailed in Table 3.

**Table 3:** Variance between Standard Data and FSS117 coordinates

| STANDARD DATA | | | | FSS117 / 5km | | | VARIANCE | | |
|---|---|---|---|---|---|---|---|---|---|
| STN. ID. | Easting | Northing | Height | Easting | Northing | Height | E | N | H |
| FSS2/01 | 604609.032 | 868774.895 | 282.771 | 604608.124 | 868775.157 | 281.799 | 0.908 | -0.262 | 0.972 |
| FSS2/02 | 605747.361 | 868733.984 | 289.567 | 605746.389 | 868734.271 | 288.128 | 0.972 | -0.287 | 1.439 |
| FSS2/05 | 606026.182 | 865342.79 | 310.904 | 606025.315 | 865343.215 | 309.425 | 0.867 | -0.425 | 1.479 |
| FSS2/06 | 604828.017 | 864823.902 | 328.904 | 604827.174 | 864824.313 | 327.545 | 0.843 | -0.411 | 1.359 |
| FSS2/07 | 603446.555 | 865342.899 | 310.288 | 603445.809 | 865343.273 | 309.014 | 0.746 | -0.374 | 1.274 |
| FSS2/09 | 602756.911 | 867468.233 | 294.432 | 602756.119 | 867468.482 | 293.106 | 0.792 | -0.249 | 1.326 |
| FSS2/10 | 603695.037 | 868618.042 | 279.298 | 603694.186 | 868618.269 | 277.993 | 0.851 | -0.227 | 1.305 |

The smallest variances in Eastings, Northings, and Heights are 0.746m, 0.227m, and 0.972m respectively, while the largest variances in Eastings, Northings, and Heights are 0.908m, -0.425m, and 1.439m respectively.

The variation between XSN07 and OSUN obtained coordinates was analyzed and the results are expressed in Table 4. of the STANDARD DATA/FSS117.

**Table 4:** Variation between Standard Data and OSUN coordinates

| STANDARD DATA | | | | OSUN / 56km | | | DIFFERENCES | | |
|---|---|---|---|---|---|---|---|---|---|
| **STN. ID.** | **Easting** | **Northing** | **Height** | **Easting** | **Northing** | **Height** | **E** | **N** | **H** |
| FSS2/01 | 604609.032 | 868774.895 | 282.771 | 604608.264 | 868776.020 | 284.980 | 0.768 | -1.125 | -2.209 |
| FSS2/02 | 605747.361 | 868733.984 | 289.567 | 605746.527 | 868735.133 | 291.702 | 0.834 | -1.149 | -2.135 |
| FSS2/05 | 606026.182 | 865342.79 | 310.904 | 606025.732 | 865344.174 | 313.660 | 0.450 | -1.384 | -2.756 |
| FSS2/06 | 604828.017 | 864823.902 | 328.904 | 604827.727 | 864825.451 | 332.016 | 0.290 | -1.549 | -3.112 |
| FSS2/07 | 603446.555 | 865342.899 | 310.288 | 603446.026 | 865344.096 | 313.358 | 0.529 | -1.197 | -3.070 |
| FSS2/09 | 602756.911 | 867468.233 | 294.432 | 602756.338 | 867469.306 | 297.465 | 0.573 | -1.073 | -3.033 |
| FSS2/10 | 603695.037 | 868618.042 | 279.298 | 603694.619 | 868619.244 | 282.257 | 0.418 | -1.202 | -2.959 |

The smallest differences in Eastings, Northings, and Heights are 0.290m, -1.073m, and -2.135m, respectively, while the largest differences are 0.834m, -1.549m, and -3.112m, respectively.

**Medium Baselines**

STANDARD DATA / SACR: The difference between XSNO7 and SACR obtained coordinates was observed and results are expressed in Table 5

**Table 5:** Difference between STANDARD DATA and SACR coordinate

| STANDARD DATA | | | | SACR / 153km | | | DIFFERENCES | | |
|---|---|---|---|---|---|---|---|---|---|
| **STN. ID.** | **Easting** | **Northing** | **Height** | **Easting** | **Northing** | **Height** | **E** | **N** | **H** |
| FSS2/01 | 604609.032 | 868774.895 | 282.771 | FLOAT | FLOAT | FLOAT | FLOAT | FLOAT | FLOAT |
| FSS2/02 | 605747.361 | 868733.984 | 289.567 | 605748.456 | 868733.818 | 291.585 | -1.095 | 0.166 | -2.018 |
| FSS2/05 | 606026.182 | 865342.79 | 310.904 | 606027.283 | 865342.796 | 313.262 | -1.101 | -0.006 | -2.358 |
| FSS2/06 | 604828.017 | 864823.902 | 328.904 | 604829.153 | 864823.885 | 313.262 | -1.136 | 0.017 | 15.642 |
| FSS2/07 | 603446.555 | 865342.899 | 310.288 | 603447.802 | 865342.812 | 331.393 | -1.247 | 0.087 | -21.105 |
| FSS2/09 | 602756.911 | 867468.233 | 294.432 | 602758.114 | 867468.019 | 312.880 | -1.203 | 0.214 | -18.448 |
| FSS2/10 | 603695.037 | 868618.042 | 279.298 | 603696.157 | 868617.840 | 281.825 | -1.120 | 0.202 | -2.527 |

The least differences in Eastings, Northings, and Heights are -1.095m, -0.006m, and -2.018m respectively while the highest differences in Eastings, Northings, and Heights are -1.247m, 0.214m, and -21.105m respectively

STANDARD DATA / ABKC: The difference between XSN07 and ABKC obtained coordinates was observed and results are expressed in Table 6

**Table 6:** Difference between STANDARD DATA and ABKC coordinates

| STANDARD DATA | | | | ABKC / 103km | | | DIFFERENCES | | |
|---|---|---|---|---|---|---|---|---|---|
| **STN. ID.** | **Easting** | **Northing** | **Height** | **Easting** | **Northing** | **Height** | **E** | **N** | **H** |
| FSS2/01 | 604609.032 | 868774.895 | 282.771 | 604610.039 | 868774.825 | 282.806 | -1.007 | 0.070 | -0.035 |
| FSS2/02 | 605747.361 | 868733.984 | 289.567 | 605748.303 | 868733.938 | 289.131 | -0.942 | 0.046 | 0.436 |
| FSS2/05 | 606026.182 | 865342.79 | 310.904 | 606027.214 | 865342.866 | 310.784 | -1.032 | -0.076 | 0.120 |
| FSS2/06 | 604828.017 | 864823.902 | 328.904 | 604829.076 | 864823.960 | 328.909 | -1.059 | -0.058 | -0.005 |
| FSS2/07 | 603446.555 | 865342.899 | 310.288 | 603447.715 | 865342.935 | 310.393 | -1.160 | -0.036 | -0.105 |
| FSS2/09 | 602756.911 | 867468.233 | 294.432 | 602758.024 | 867468.143 | 294.483 | -1.113 | 0.090 | -0.051 |
| FSS2/10 | 603695.037 | 868618.042 | 279.298 | 603696.082 | 868617.913 | 279.344 | -1.045 | 0.129 | -0.046 |

The smallest variances in Eastings, Northings, and Heights are -0.942m, -0.036m, and -0.005m respectively, while the largest variances in Eastings, Northings, and Heights are -1.160m, 0.129m, and 0.436m respectively.

**Long Baseline**

STANDARD DATA / ABFC: We observed the coordinates obtained from XSN07 and ABFC and the results are expressed in Table 7.

**Table 7:** Difference between STANDARD DATA AND ABKC coordinates

| STANDARD DATA | | | | ABKC / 412km | | | DIFFERENCES | | |
|---|---|---|---|---|---|---|---|---|---|
| **STN. ID.** | **Easting** | **Northing** | **Height** | **Easting** | **Northing** | **Height** | **E** | **N** | **H** |
| FSS2/01 | 604609.032 | 868774.895 | 282.771 | 604610.054 | 868774.826 | 282.816 | -1.022 | 0.069 | -0.045 |
| FSS2/02 | 605747.361 | 868733.984 | 289.567 | 605748.317 | 868733.938 | 289.162 | -0.956 | 0.046 | 0.405 |
| FSS2/05 | 606026.182 | 865342.79 | 310.904 | 606027.214 | 865342.866 | 310.784 | -1.032 | -0.076 | 0.120 |
| FSS2/06 | 604828.017 | 864823.902 | 328.904 | 604829.064 | 864823.974 | 328.907 | -1.047 | -0.072 | -0.003 |
| FSS2/07 | 603446.555 | 865342.899 | 310.288 | 603447.707 | 865342.952 | 310.392 | -1.152 | -0.053 | -0.104 |
| FSS2/09 | 602756.911 | 867468.233 | 294.432 | 602758.016 | 867468.159 | 294.387 | -1.105 | 0.074 | 0.045 |
| FSS2/10 | 603695.037 | 868618.042 | 279.298 | 603696.075 | 868617.932 | 279.357 | -1.038 | 0.110 | -0.059 |

The least differences in Eastings, Northings, and Heights are -0.956m, 0.046m, and 0.045m respectively while the highest differences in Eastings, Northings, and Heights are -1.152m, 0.110m, and 0.405m respectively.

Analysis of Tables 3 to 7 reveals the calculated linear differences of the coordinates of the observed stations. Within the tables, it is evident that the strongest baseline occurs within 102km, while the weakest is within 56km, based on the proximity of the differences to zero. Comparing the STANDARD DATA with FSS117 within 5km, the smallest differences in Eastings, Northings, and Heights are 0.746m, 0.227m, and 0.972m, respectively, while the largest differences are 0.908m, -0.425m, and 1.439m, respectively (refer to Table 3). When comparing the STANDARD DATA with OSUN within 56km, the smallest differences in Eastings, Northings, and Heights are 0.290m, -1.073m, and -2.135m, respectively, while the largest differences are 0.834m, -1.549m, and -3.112m, respectively (refer to Table 4). Between STANDARD DATA and SACR within 153km, the smallest differences in Eastings, Northings, and Heights are -1.095m, -0.006m, and -2.018m, respectively, while the largest differences are -1.247m, 0.214m, and -21.105m, respectively (see Table 5). When comparing with ABKC within 102km, the smallest differences in Eastings, Northings, and Heights are -0.942m, -0.036m, and -0.005m, respectively, while the largest differences are -1.160m, 0.129m, and 0.436m, respectively (see Table 6). Finally, comparing with ABFC within 412km, the smallest differences in Eastings, Northings, and Heights are -0.956m, 0.046m, and 0.045m, respectively, while the largest differences are -1.152m, 0.110m, and 0.405m, respectively.

### 4.2. Root Mean Square Error

Root Mean Square Error (RMSE) is a valuable mathematical model tool used to compare sets of GNSS results and to assess how the baseline length has affected our observations. The RMSE equation is illustrated below.

$$\text{Root Mean Square Error (RMSE)} = \frac{\sqrt{\sum N\,(xi - x)^2}}{N} \quad (1)$$

**Variable (i): represents each of the station's data**

The Number of non-missing data points is (N) which represents the number of stations involved.

The Independent variable (xi): That is the result obtained from **XSN07**

The Dependent variable(x): is the result obtained from other controls and CORS stations

The error analyses were made on Easting, Northing, and Height obtained using the Microsoft Excel program.

**Table 8:** Below shows the RMSE summary

| RMSE | FSS117 (5km) | OSUN (56kM) | SACR (153km) | ABKC (102km) | ABFC (412km) |
|---|---|---|---|---|---|
| RSME EASTING | 0.856868635 | 0.580009113 | 1.151690062 | 1.053179675 | 1.055162073 |
| RSME NORTHING | 0.328190929 | 1.249549919 | 0.142624215 | 0.077637436 | 0.073536839 |
| RSME HEIGHT | 1.316608413 | 2.779970606 | 2.499643641 | 0.177879574 | 0.174346876 |

The Root Mean Square Error (RMSE) serves as a measure to assess the accuracy of the X, Y, and Z coordinates of the observed stations in differential GNSS positioning. The closer the RMSE value is to zero, the higher the accuracy of the positioning.

In the RMSE table, the base within 412km has the RMSE value closest to zero, followed by the baseline within 102km, then the baseline within 5km, then the baseline within 56km, and lastly the baseline at 153km.

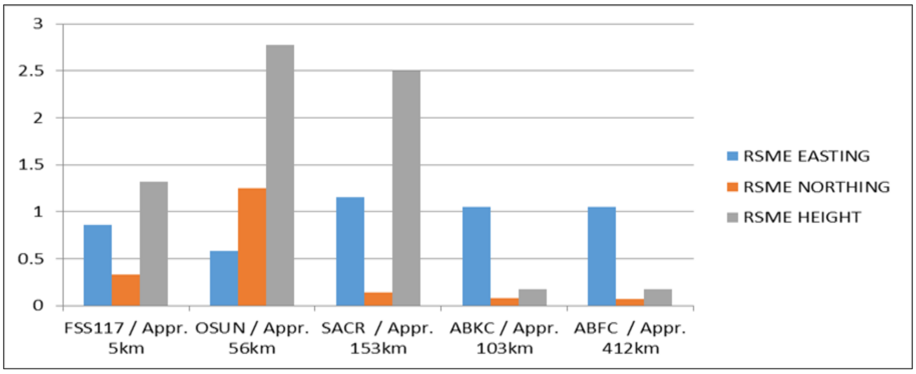


**Fig 3:** RMSE summary between XSN07 AND FSS117, OSUN, SACR, ABKC & ABFC

### 4.3. GNSS observed data analysis using Parts Per Million (PPM)

PPM stands for "parts per million" and is commonly used in surveying to denote the accuracy of measuring equipment. It represents the standardized measurement of error in millimeters per 1,000 meters for orthometric heights. For example, a PPM of 2 for an orthometric height would indicate a measurement error of 2 millimeters per 1,000 meters. Essentially, a mountain resort located 1,000 meters inland with a PPM of 2 millimeters would have an accurate elevation measurement within 2 millimeters.

Surveyors typically express the same error as a representative fraction, a fraction with 1 always in the numerator. Any representative fraction (or precision value) can be converted to a parts per million (PPM) value, and vice versa. Essentially, these terms are equivalent, and the difference lies in expressing the deviation in different ways, similar to how one person might measure a distance in feet and another in meters. Any representative fraction can be converted to PPM by dividing the denominator into a million to determine the

PPM value. For example, a representative fraction of 1:6,600 converts to 152 PPM. This is achieved by calculating 1/1,000,000 divided by 66,000, resulting in 0.0151 PPM. In becoming familiar with the PPM expression, one can immediately convert it to a representative fraction. When a surveyor calculates a representative fraction, converting it to PPM assists in becoming familiar with its usage.

**Table 9:** PPM Northing and Eastings of FSS17, OSUN, & SACR

| FSS117 | | | OSUN | | SACR | |
|---|---|---|---|---|---|---|
| **STN. ID.** | **PPM NORTHINGS** | **PPM EASTING** | **PPM NORTHINGS** | **PPM EASTING** | **PPM NORTHINGS** | **PPM EASTING** |
| FSS2/01 | 2.439908605 | -0.704026492 | 2.179618803 | -3.19280098 | -3.88229077 | 0.270857495 |
| FSS2/02 | 2.617726043 | -0.772929397 | 2.36987725 | -3.264974772 | -3.40600988 | 0.516344876 |
| FSS2/05 | 2.351415132 | -1.152654476 | 1.290715427 | -3.969667002 | -3.44958924 | -0.018798851 |
| FSS2/06 | 2.283333384 | -1.113226596 | 0.831939676 | -4.44370537 | -3.55229834 | 0.053159394 |
| FSS2/07 | 2.013257824 | -1.009327649 | 1.513324979 | -3.424291115 | -3.88229077 | 0.270857495 |
| FSS2/09 | 2.126002928 | -0.668402436 | 1.628800322 | -3.050092051 | -3.72385031 | 0.662430562 |
| FSS2/10 | 2.283468182 | -0.609103733 | 1.18570801 | -3.409619684 | -3.46721219 | 0.625336485 |

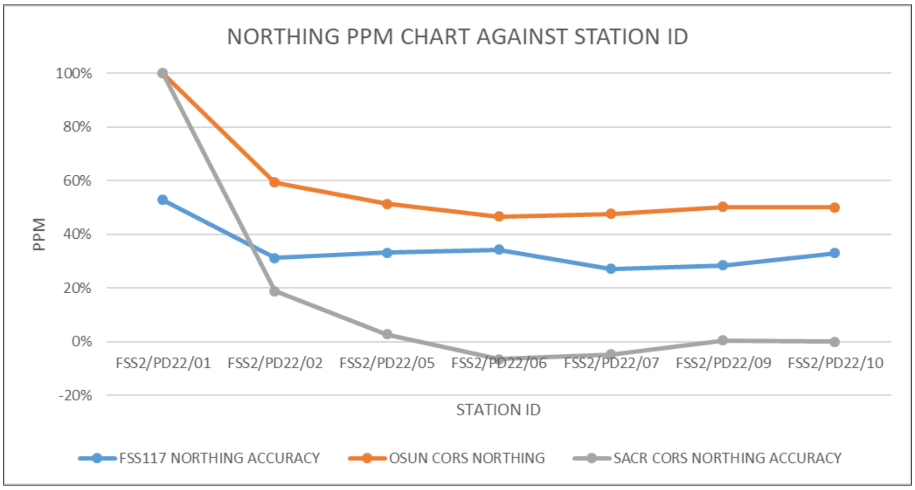


**Fig 4:** Northing PPM Chart between STANDARD DATA AND FSS117, OSUN & SACR

**Table 10:** PPM Northing and Eastings of ABKC & ABFC

| ABKC | | | ABFC | |
|---|---|---|---|---|
| **STN. ID.** | **PPM NORTHINGS** | **PPM EASTING** | **PPM NORTHINGS** | **PPM EASTING** |
| FSS2/01 | -2.705933882 | 0.188098681 | -2.900482313 | 0.195825127 |
| FSS2/02 | -2.536932029 | 0.123884155 | -2.716549941 | 0.130712654 |
| FSS2/05 | -2.798916281 | -0.206121742 | 0 | 0 |
| FSS2/06 | -2.868386778 | -0.15709767 | -3.003589104 | -0.20655054 |
| FSS2/07 | -3.130534954 | -0.097154533 | -3.295558366 | -0.151618571 |
| FSS2/09 | -2.987678357 | 0.241591242 | -3.141054721 | 0.210351176 |
| FSS2/10 | -2.804023796 | 0.346142651 | -2.944413671 | 0.312028424 |

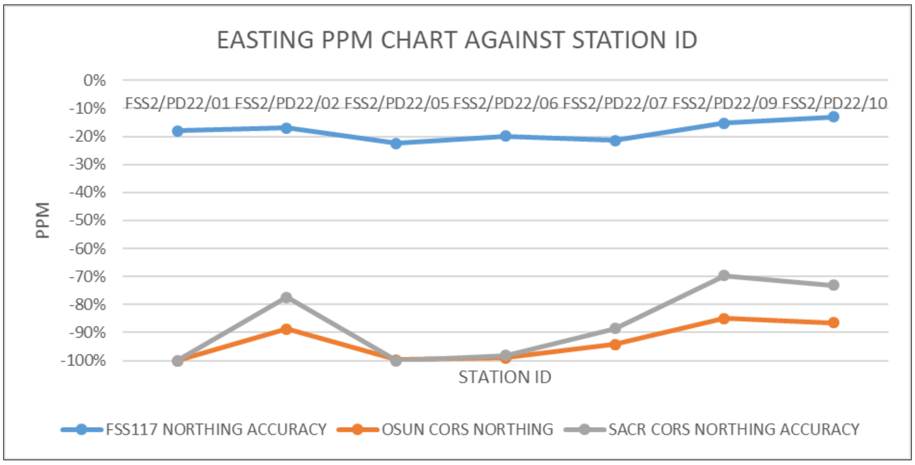


**Fig 5:** Easting PPM CHART between STANDARD DATA AND FSS117, OSUN & SACR

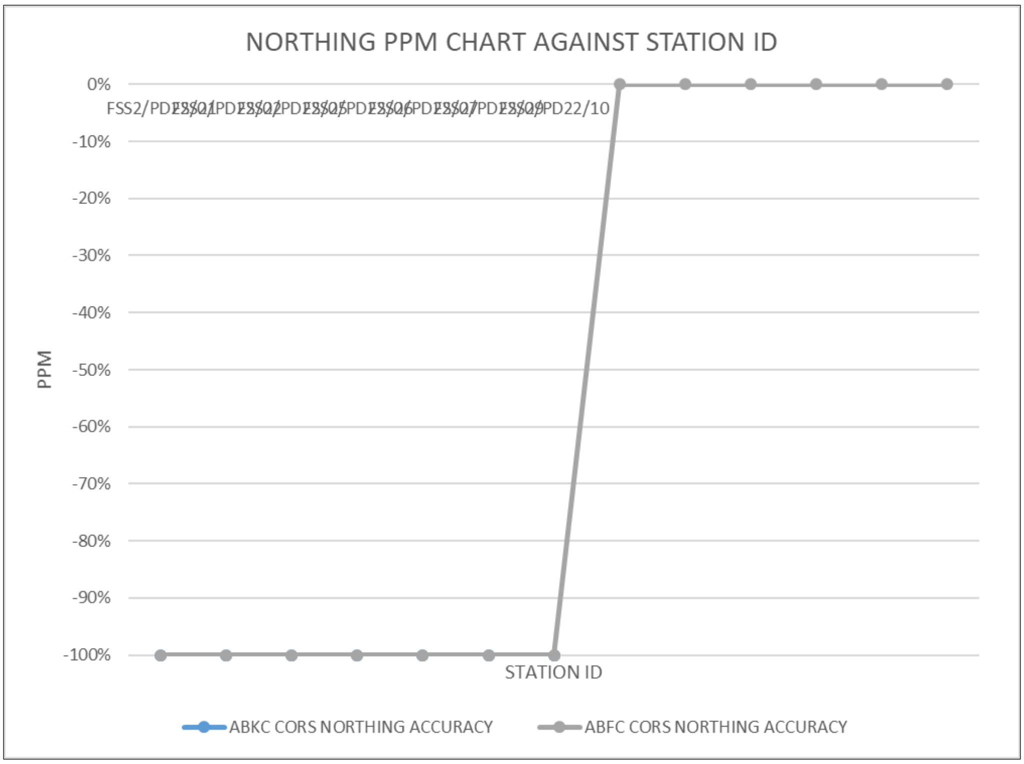


**Fig 6:** Easting PPM CHART between STANDARD DATA AND ABKC &ABFC

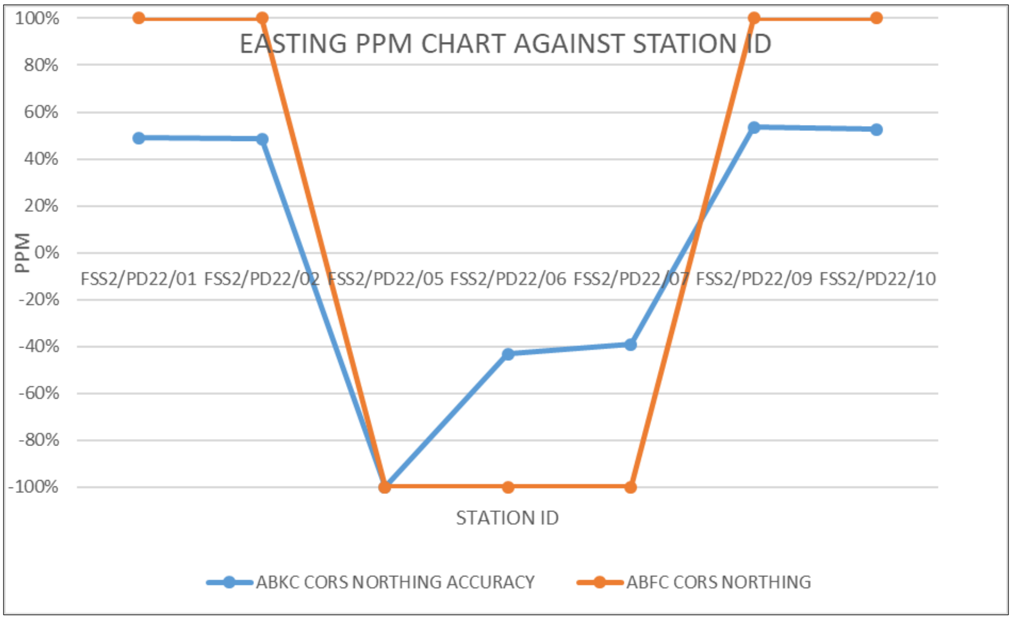


**Fig 7:** Easting PPM Chart against Station ID

The PPM (Part Per Million) values have been calculated for all the collected data. The maximum PPM values for Northing and Easting are 2.439908605 and 2.36987725 respectively, while the minimum PPM values for Northing and Easting are -2.536932029 and -0.018798851 respectively. This indicates that control points up to 412km away are still suitable for second-order surveying, as all PPM values fall within second-order accuracy.

The Pearson Correlation Coefficient computed about all baselines showed 100% accuracy, indicating a strong correlation among all the baselines.

Additionally, the Root Mean Square Error (RMSE) was calculated. The baseline of 412km provided the best RMSE for Northing, Easting, and Height (1.055162073, 0.073536839, & 0.174346876), whereas the baseline of 56km resulted in the highest RMSE for Northing, Easting, and Height (1.249549919, 0.580009113, & 2.779970606).

In a Sample T-test, if the P value is below 0.05, it is considered significant and the null hypothesis is rejected. If the P value is above 0.05, it is considered insignificant and the null hypothesis is accepted.

The standard deviation was calculated for different baselines. The baseline within 56km registered the highest standard deviation of approximately 1.632, while the baseline within 412km had the lowest standard deviation of approximately 14. A standard deviation close to zero indicates higher accuracy, suggesting that even the baseline as far as 412km still provides superior results.

In conclusion, after careful observation and analysis, it can be inferred that GNSS observations yield the most reliable results when dealing with long-distance baselines not exceeding 412km. Long baselines tend to provide better results compared to shorter ones, although this can be influenced by various factors. For instance, CORS stations are typically situated at elevated terrain, thus offering high accuracy. Additionally, nearby baselines may be affected by factors such as numerous canopies and reflective objects, among others. Lastly, evenly distributed satellite geometry is often achieved when dealing with long baselines, resulting in more accurate observed coordinates. This further shows conformity with the result obtained by Creager and Maggio (1998) [2]; Eckl *et al.*. (2001) [3]; Shen *et al.*. (2009) [12] Fatunmbi, O., & Ajayi, O. (2015) [4], and Wieser (2004) [14]

## 5. Conclusions

The study reveals that GNSS baseline processing precision depends on baseline length, with variations in horizontal and vertical precision influenced by static conventional base stations and CORS. The study achieved short, medium, and long baseline lengths with a control station.

Part Per Million (PPM) was computed for all the data obtained, with all baselines complying with the PPM accuracy standard for second-order surveys. This implies that short, medium, and long baselines are all suitable for second-order survey jobs. The Pearson Correlation Coefficient computed relative to all baselines showed an accuracy within 1.0000, and the value of 1.0000 represents a strong correlation, indicating that all the baselines are strongly correlated. The long baseline showed the smallest standard deviation value as well as the root mean square error value.

In conclusion, based on the observations and analyses conducted, it can be said that GNSS observations yield the best results when long baselines not exceeding 412km are involved, as they provide better results than short baselines, though this can be affected by many factors. For instance, CORS stations are typically positioned at elevated terrain, resulting in high accuracy. Furthermore, nearby baselines can be affected by factors such as various canopies and reflective objects in the vicinity. Finally, evenly distributed satellite geometry is mostly achieved when long baselines are involved, leading to more accurate observed coordinates.

## 6. Recommendation

In our study, we have examined the influence of baseline length on the accuracy of GNSS observations and its implications for establishing Ground Control Points (GCPs). It is important to acknowledge the limitations of our findings when evaluating the impact of baseline length in GNSS observations. We suggest further research on environmental factors such as satellite availability, multipath effects, and signal quality, which significantly affect the accuracy and precision of GNSS observations. These considerations should be integrated into data collection and analysis to ensure reliable results.

It is imperative for the government to closely monitor the establishment of Ground Control Points (GCPs) in the western region of the country and regularly inspect them for any potential shifts. Any individual found tampering with these monuments should be apprehended and prosecuted.

## 7. Author contributions

Research Concept and Design: F.S.S., Collection, and assembly of data: F.S.S., F.O.E., Data analysis and interpretation: F.S.S., I.I.U., Article writing: F.S.S., Critical revision of the article: O. O.S., and final approval of the article: F.S.S., O. O.S.

## 8. Data availability statement

The data that support the outcome of this research are available to download at https://sacredion.com. These are the continuous operating reference stations at OSUN, SACR (AKURE), ABKC(ABEOKUTA), and ABFC (ABUJA).

## 9. Acknowledgments

We would like to express our gratitude to the Student Work Experience Scheme and practical unit of the Federal School of Surveying (FSS), Oyo for providing the coordinates of the existing first-order control stations: XSN07, FSS/CORS1, and FSS/CORS2. Additionally, we extend our appreciation to Sacredion for supplying the CORS station login and IP used in this research.

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