South African Journal of Geomatics, Vol. 8. No. 1, March 2019

Analysis of GNSS Baseline Solutions in Ghana

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DOI: http://dx.doi.org/10.4314/sajg.v8i1.1

Abstract

Accuracy is highly desired in all geodetic and mapping projects. Global Navigation Satellite Systems (GNSS) has many positioning capabilities which can produce the desired accuracies needed for establishing Ground Control Points (GCPs). However accuracy of positioning results from GNSS survey routines are influenced by session duration and baseline length. This study is targeted at determining optimum observation times for specific baseline lengths for GCP fixing and densification in Ghana. The study used four ground stations in Accra, Kumasi, Assin-Fosu and Sunyani. Each station was occupied for a total of four hours on three different days and the data were later split into various time segments to obtain different data sets. Using the Kumasi station as base, each of the baselines was processed three times for each of 3-day 4-hour observation sessions and the mean results accepted as the 'true' position values. Repeatability tests were carried out on the computed baselines and the ratios ranged between 1:1,141,100 and 1:4,918,000. All comparisons were based on the true position values. Root Mean Square Error (RMSE) and accuracies were computed from the differences. A plot of the RMSE against time showed that accuracy of positions continued to improve but after 50 minutes of observation there was no significant improvement in the accuracy of measured baselines. This study therefore set 50 minutes as the optimum duration for GNSS baselines up to 195km when using geodetic grade GNSS receivers in differential mode to establish GCPs.

Key words: *GNSS; Baselines; Differential GPS; Ground Control Points; Repeatability Test*

1. Introduction

The level of accuracy achieved in Global Navigation Satellite System (GNSS) positioning depends on the method of measurements and techniques of processing field data (Rizos, 1999; Seeber, 2003). As such, new innovations in GNSS measurements and data processing methods continue to emerge. Network adjustment of baseline solutions is one of the most accurate GNSS data processing techniques which computes redundant baselines and performs least squares adjustment to fix rover positions (Schwieger et al.,2009).

Burns et al. (2010) and Gopi (2005) in their studies have shown that accuracies of position solutions are influenced greatly by the session duration but the length of the baselines did not have a significant impact. In their report, Eckl et al. (2001) revealed that accuracies continue to improve with longer session durations leading to the recommendation that more time should be spent on rover positions in order to achieve better accuracies. The main challenge is to determine how much time (optimum duration) to be spent on rover positions in order to obtain the desired accuracy since different projects require different levels of accuracies. This study investigated optimum observation times for ground control points fixing using baselines of up to 195km tailored specifically for cadastral mapping.

None of the aforementioned studies has ever been carried out in our part of the world. Ghana is located near the equator, which presents interesting challenges with regards to the ionospheric and tropospheric situation. Conducting this study in Ghana therefore offers the opportunity to use data observed in Africa and for that matter results from this study stand to resonate well with many African researchers and surveyors.

2. Methodology and Data Processing

Currently the interstation distances between the existing CORS stations in Ghana span within 200km. Therefore 200km has been set as the maximum baseline for this study. Three CORS sites in Kumasi, Accra and Assin-Fosu were selected together with a passive control point in Sunyani to form three baselines keeping the Kumasi station as base, refer to Figure 1.

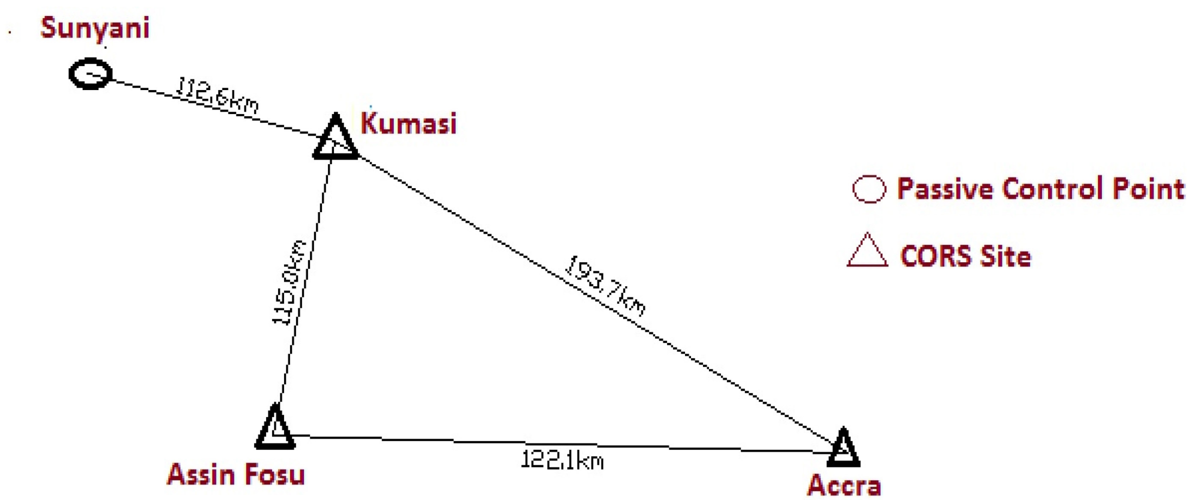


Figure 1. Study diagram showing stations and processed baselines in kilometres.

The Accra site was mounted with a Trimble NetR5 receiver and TRM29659 antenna. Assin Fosu and Kumasi sites were mounted with Sokkia GSR 2600 receivers and SOK600 antennas. The passive control point in Sunyani was mounted using a Trimble R4 receiver with TRMR4 antenna. Four hours of data were logged and downloaded for each of three days from the CORS sites and a passive control point in May 2007. The quality of these data was checked against multipath, data completeness and cycle slip using Leica GNSS QC v2.0 software (http://www.leica.com) and all the data passed. Precise ephemeris for these data was obtained from International GNSS service (IGS) via internet service (Kouba, 2009). The post processing criteria used included**:** epoch rate of 30 seconds**;** elevation cut-off angle of 10 degrees**;** L1/L2 fixed iono-free processing style and varying observation times.

Each of the 4-hr data for each day was partitioned into non-overlapping sub-sessions of several data sets. Thus, for each baseline, the length was kept fixed whilst the observation duration was varied from 5-minutes to 4-hours. The data were post processed using Topcon Tools processing software version 8.25 based on international terrestrial reference frame of 2008 (ITRF2008).

Each baseline was individually processed three times and the mean of the three results was used as the 'true' position of the rover stations. Three sets of measurements for each baseline were obtained and used for repeatability analysis. The positions of the rover stations were similarly computed from the sub-session data and compared with the 'true' positional coordinates to obtain differences in X, Y and Z coordinate values in the WGS84 reference frame Snay et al. (2002). These residuals were used to compute root-mean-squared errors (RMSE) and accuracies for various sub-sessions (Wing et al., 2005) and Deakin & Kildea (1999). RMSE and accuracies were plotted against session lengths in turns for each of the three baselines; Accra, Assin Fosu and Sunyani. Interpreting these graphs, useful discussions and conclusions were drawn. However comparison of accuracies from these baselines would have been more rigorous if identical GNSS receivers were for all the selected stations.

3. Results and Analysis

Using the methodology described above the mean coordinates of the selected stations, the repeatability ratios, positions from partitioned data, residuals and root mean square errors were computed and presented in this section. Graphs of RMSE against session durations have also been presented in this section. The original coordinates of the Kumasi site which was used as base station are presented in table 1.

Table 1. Base Station Coordinates Published by Geodetic Reference Network Office of Ghana

KUMASI BASE (WGS84)
X: 6333147.7330 ± 0.0022
Y: -173104.4837 ± 0.0009
Z: 736229.3232 ± 0.0004

Table 2 presents the mean positions after each baseline was processed three times for each of the 3-days. For purposes of meaningful analysis of horizontal and vertical positioning the coordinates were rotated to eastings, northings and up directions (ENU) via a simple rotation matrix.

Table 2. Mean Positions of Rover Stations from 4-hr Data

DATE	**ACCRA STATION**		
	N(m)	**E(m)**	**U(m)**
22-05-2007	618716.663 ±0.003	812167.207 ± 0.001	87.006 ± 0.056
23-05-2007	618716.670 ± 0.004	812167.213 ± 0.005	86.903 ± 0.047
24-05-2007	618716.664 ± 0.002	812167.204 ± 0.004	86.941 ± 0.009
MEAN	618716.666 ± 0.003	812167.208 ± 0.003	86.950 ± 0.037
	ASSIN FOSU STATION		
22-05-2007	630377.142±0.002	690533.554 ± 0.000	187.114 ± 0.047
23-05-2007	630377.145±0.001	690533.56 ± 0.006	187.016 ± 0.051
24-05-2007	630377.144±0.000	690533.549 ± 0.005	187.071 ± 0.004
MEAN	630377.144±0.001	690533.554 ± 0.005	187.067 ± 0.034
	SUNYANI STATION		
22-05-2007	811324.319 ± 0.019	573278.907 ± 0.001	330.266 ± 0.038
22-05-2007	811324.323 ± 0.015	573278.907 ± 0.001	330.365 ± 0.061
22-05-2007	811324.372 ± 0.034	573278.903 ± 0.003	330.281 ± 0.023
MEAN	811324.338 ± 0.023	573278.906 ± 0.002	330.304 ± 0.041

Pryseley et al. (2010) defined repeatability as the precision obtained, under repeatable conditions, when independent test results are obtained with the same method, on identical test items, by the same operator, using the same equipment, and within short intervals of time. Repeatability leads to an estimate of the minimum value of precision. In table 3 the repeatability ratios ranged between 1:1,141,100 and 1:4,918,000 indicating high precision in the position results used in this study.

Table 3. Computation of Baseline Repeatability for Three Different Days

Assin Fosu Baseline	**N(m)**	**E(m)**	**U(m)**	**Baseline (m)**
Date:				112086.898
Day 22-05-2007	630377.142	690533.554	187.114	
Day 23-05-2007	630377.145	690533.560	187.016	
Difference	0.003	0.006	-0.098	
Ratio	$= [(0.003)^2 + (0.006)^2 + (-0.098)^2]^{1/2} /112086.898 = 1:1,141,100$			
Day 22-05-2007	630377.142	690533.554	187.114	
Day 24-05-2007	630377.144	690533.549	187.071	112,086.898
Difference	0.002	-0.005	-0.043	
Ratio	$= [(0.002)^2 + (-0.005)^2 + (-0.043)^2]^{1/2} /112086.898 = 1:2,586,500$			
Day 23-05-2007	630377.145	690533.560	187.016	
Day 24-05-2007	630377.144	690533.549	187.071	112,086.898
Difference	-0.001	-0.011	0.055	
Ratio	$= [(0.001)^2 + (-0.011)^2 + (0.055)^2]^{1/2} /112086.898 = 1:1,998,100$			

Accra Baseline	**N(m)**	**E(m)**	**U(m)**	**Baseline (m)**
Date:				
Day 23-05-2007	618716.670	812167.213	86.903	
Day 24-05-2007	618716.664	812167.204	86.941	194,308.030
Difference	-0.006	-0.009	0.038	
Ratio	$= [(-0.006)^2 + (-0.009)^2 + (0.038)^2]^{1/2} /194308.030 = 1:4,918,000$			
Day 22-05-2007	618716.663	812167.207	87.006	
Day 23-05-2007	618716.670	812167.213	86.903	194,308.030
Difference	0.007	0.006	-0.103	
Ratio	$= [(0.007)^2 + (-0.006)^2 + (-0.103)^2]^{1/2} /194308.030 = 1:1,879,000$			
Day 22-05-2007	618716.663	812167.207	87.006	
Day 24-05-2007	618716.664	812167.204	86.941	194,308.030
Difference	0.001	-0.003	-0.065	
Ratio	$= [(0.001)^2 + (-0.003)^2 + (-0.065)^2]^{1/2} /194308.030 = 1:2,985,800$			

In order to compute the accuracy of the positions for each sub-session the true position coordinates were compared with positions from the sub-sessions as presented in table 4. RMSE values were computed from the differences as shown in column-8 of table 4 (a), (b) and (c).

Table 4. Mean Coordinate Differences and Root Mean Squared Errors from Partitioned Data

(a)

ACCRA STATION						BASELINE LENGTH = 194.308km	
SESSION	MEAN COORDINATES (m)			MEAN COORD. DIFFERENCE (m)			
DURATION (min)	N[m]	E[m]	U[m]	dN[m]	dE[m]	dU[m]	RMSE
5	618716.682	812167.322	87.104	0.016	0.114	0.154	0.111
10	618716.629	812167.279	86.985	-0.037	0.071	0.035	0.050
15	618716.575	812167.035	87.060	-0.091	-0.173	0.110	0.130
20	618716.644	812167.24	86.990	-0.022	0.032	0.040	0.032
30	618716.632	812167.217	87.042	-0.034	0.009	0.092	0.057
40	618716.635	812167.182	87.003	-0.031	-0.026	0.053	0.039
50	618716.67	812167.198	87.027	0.004	-0.010	0.040	0.045
60	618716.669	812167.2	87.021	0.003	-0.008	0.071	0.041
90	618716.668	812167.202	87.012	0.002	-0.006	0.062	0.036
120	618716.663	812167.205	86.979	-0.003	-0.003	0.029	0.017
150	618716.663	812167.203	86.984	-0.003	-0.005	0.034	0.020
180	618716.664	812167.203	86.976	-0.002	-0.005	0.026	0.015
210	618716.664	812167.205	86.984	-0.002	-0.003	0.034	0.019

(b)

ASSIN FOSU STATION						BASELINE LENGTH = 112.087km	
SESSION	MEAN COORDINATES (m)			MEAN COORD. DIFFERENCE (m)			
DURATION (min)	N[m]	E[m]	U[m]	dN[m]	dE[m]	dU[m]	RMSE
5	630377.452	690533.628	187.288	0.308	0.074	0.221	0.223
10	630377.121	690533.090	187.212	-0.023	-0.464	0.145	0.281
15	630377.059	690533.279	187.071	-0.085	-0.275	0.004	0.166
20	630377.104	690533.527	187.049	-0.040	-0.027	-0.017	0.030
30	630377.104	690533.582	187.091	-0.040	0.028	0.025	0.031
40	630377.110	690533.551	187.095	-0.034	-0.003	0.028	0.025
50	630377.146	690533.569	187.127	0.002	0.015	0.060	0.036
60	630377.147	690533.575	187.127	0.003	0.021	0.060	0.037
90	630377.149	690533.555	187.092	0.005	0.001	0.025	0.015
120	630377.144	690533.556	187.103	0.000	0.002	0.036	0.021
150	630377.141	690533.565	187.128	-0.003	0.011	0.061	0.036
180	630377.138	690533.552	187.108	-0.006	-0.002	0.041	0.024
210	630377.138	690533.551	187.115	-0.006	-0.003	0.048	0.028

(c)

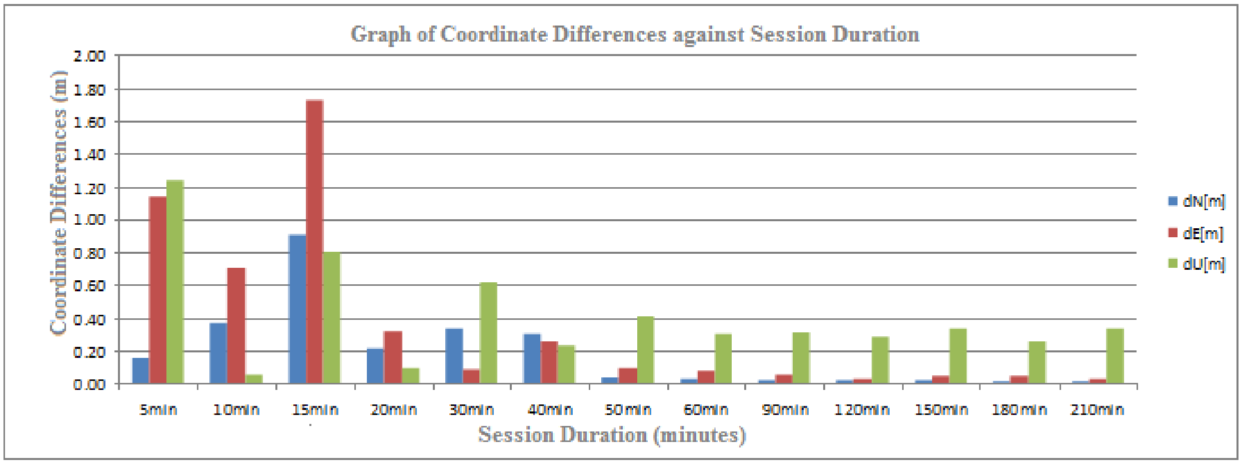
SUNYANI STATION						BASELINE LENGTH = 112.068km	
SESSION	MEAN COORDINATES (m)			MEAN COORD. DIFFERENCE (m)			
DURATION (min)	N[m]	E[m]	U[m]	dN[m]	dE[m]	dU[m]	RMSE
5	811323.982	573279.416	330.741	-0.356	0.510	0.437	0.439
10	811324.061	573277.6	331.135	-0.277	-1.306	0.831	0.908
15	811324.038	573278.693	330.007	-0.300	-0.213	-0.297	0.273
20	811324.076	573279.047	329.116	-0.262	0.141	-1.188	0.707
30	811324.361	573278.264	330.197	0.023	-0.642	-0.107	0.376
40	811324.184	573278.794	330.176	-0.154	-0.112	-0.128	0.132
50	811324.232	573279.014	330.171	-0.106	0.108	-0.134	0.117
60	811324.229	573279.01	330.195	-0.109	0.104	-0.109	0.108
90	811324.255	573279.007	330.154	-0.083	0.101	-0.150	0.115
120	811324.254	573279.005	330.280	-0.084	0.099	-0.024	0.076
150	811324.298	573278.994	330.281	-0.040	0.088	-0.023	0.058
180	811324.309	573278.933	330.269	-0.029	0.027	-0.035	0.031
210	811324.319	573278.907	330.266	-0.019	0.001	-0.038	0.024

4. Discussion

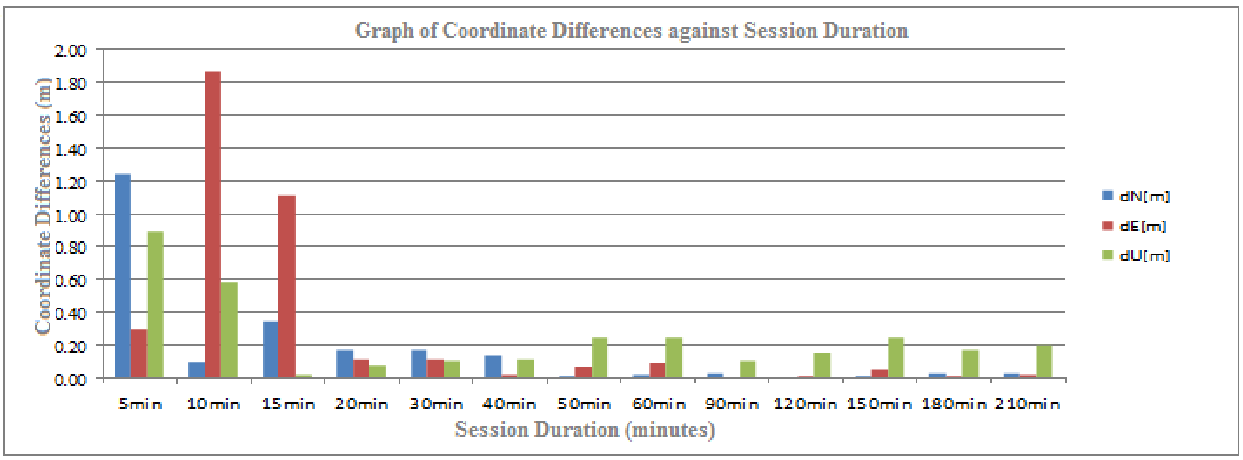
In their research papers Creager and Maggio (1998)**;** Eckl *et al*. (2001); Shen *et al*. (2009) and Wieser (2004) worked on longer baselines up to 300km or more and selected data with observation duration of (4-24)-hours in their analyses. They showed that longer observation durations produced better positional accuracies and concluded that accuracy is slightly affected by length of baseline but greatly affected by observation durations. Thus, GNSS is capable of producing different accuracies for different observation durations. However, accuracy requirements depend on project type and purpose. It is therefore cost effective and time-saving if the observation duration required (optimum time) to produce the desired accuracy in a given GNSS project is known.

In order to determine the optimum time for fixing positions by GNSS, accuracy (in the form of coordinate differences) was plotted against observation duration for different baselines as presented in figure 2 (a), (b) and (c).

(a)



(b)



(c)

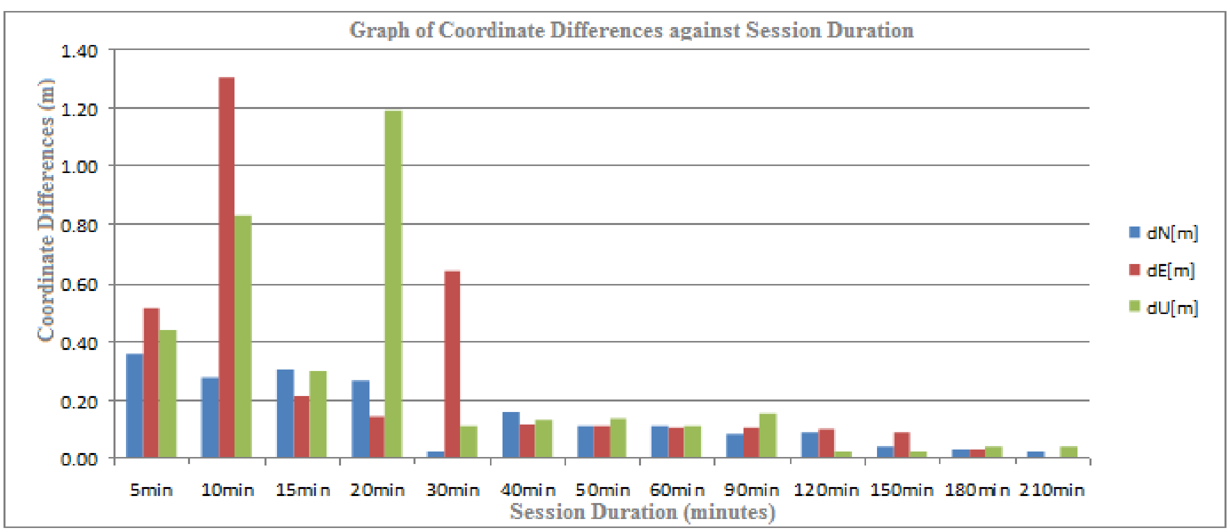


Figure 2. Bar chart of accuracy against session duration for Accra, Assin Fosu and Sunyani baselines.

Accuracy often improved sharply between 5 and 20 minutes time span in all the three figures. The accuracy then continued to improve steadily between 20 and 50 minutes sessions. After 50 minutes of logging, no significant improvement of accuracy is recorded. This means that after 50 minutes of observation, any additional time spent on a point will not necessarily refine position results. Since the baseline was up to 195 km, the results pointed to the fact that 50 minutes could serve as the optimum observation duration.

In table 2 (a) with baseline of 194.3km the coordinate differences in the ENU directions in the order of [maximum, minimum] are respectively E[0.173, 0.003], N[0.091, 0.002] and U[0.154,0.026] meters. The coordinate differences continued to decrease in all directions of ENU as observation duration increased signifying improvement of accuracy. These coordinate differences were compared with the permissible coordinate differences of ± 0.210 m for 100km baseline and ± 0.410 m for 200km baseline as published by the United States Army Corps of Engineers (USACE) in 2003, No. 1110-1-1003. It could be confirmed that all positions were fixed within the acceptable accuracy limit of the USACE. This trend was seen in table 2(b) and (c) as well.

Figure 3 relates RMSE to observation duration such that RMSE values continued to decline as session duration increased thereby confirming the reports of earlier studies: Creager and Maggio (1998) and Eckl et al. (2001).

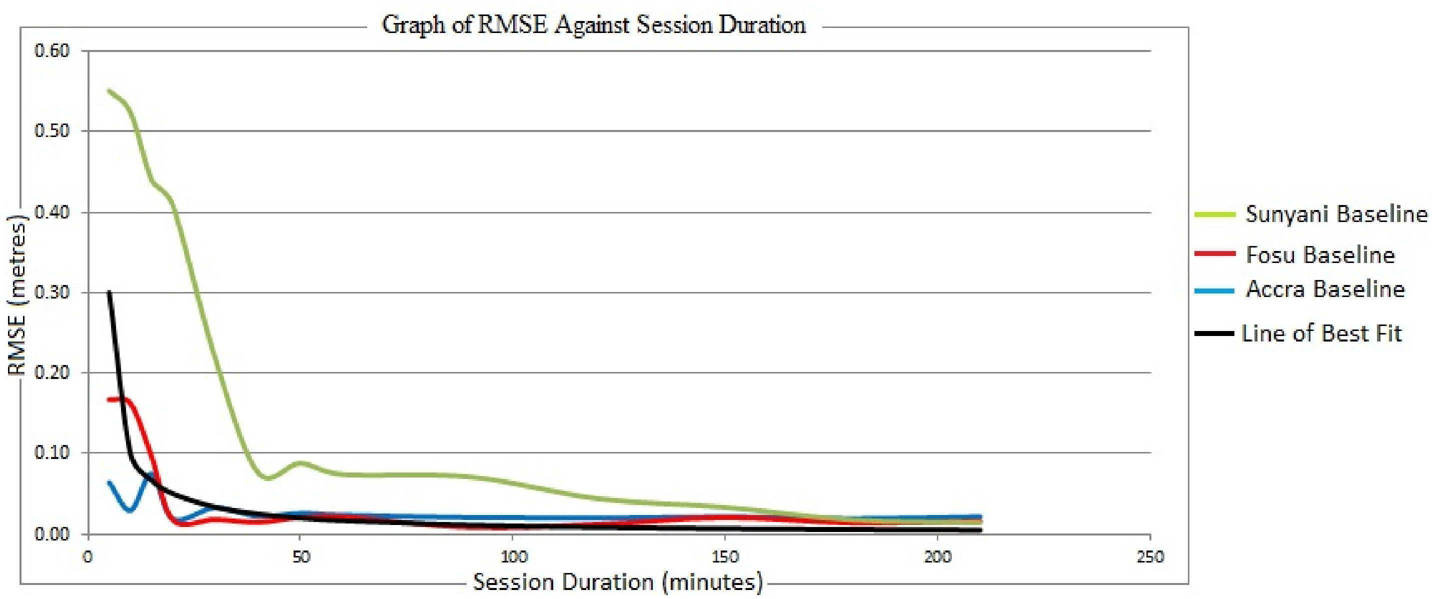


Figure 3. Combined graph of RMSE against session duration for Accra, Sunyani and Assin Fosu baselines.

According to Hoehn and Niven (1985) RMSE values measure the scatter among a set of positions from several sub-session data for the same rover stations. Thus, RMSE values indicate the precision of the position coordinates for each of the sub-session data. Thus, precision improved with time. The graphs also fit perfectly on an exponential curve indicating that RMSE values could be predicted for given session duration between 5 minutes and 4 hours in this study. This information will help the surveyor to select observation duration to be spent on each point if the positional accuracy is specified. The predictive curve is expressed in a mathematical equation below:

$$RMSE = \frac{c}{\sqrt{T}} \qquad [1]$$

Where T is the duration in hours and c is a quantity in units of km root hour.

The effect of baseline length on accuracy was measured using three categories of baseline**:** Kumasi – Accra (193.7km)**;** Kumasi – Assin Fosu (115.0km) and Kumasi – Sunyani (112.6km).

5. Conclusions

The study was set to determine how much time (optimum duration) to be spent on rover positions in order to obtain the desired accuracy using GNSS data observed locally from Ghana for baseline length up to 195km. This goal was achieved by analysing accuracies for observation durations spanning from 5 minutes to 4-hrs. After 50 minutes of observation, coordinate differences became insignificant yielding values of 0.003m, 0.002m and 0.026m in the ENU directions respectively. These coordinate differences were within the accuracy threshold for baselines up to 200km as published by the USACE in 2003. The study therefore set 50 minutes as the optimum observation duration when fixing ground control points at baseline length up to 195km.

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