Chapter 6

Comparative Study of Some Online GNSS Post-Processing Services at Selected Permanent GNSS Sites in Nigeria

Olalekan Adekunle Isioye, Mefe Moses and
Lukman Abdulmumin

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79924

Abstract

Many applications in surveying and mapping have been made simpler and more precise due to the advent of GNSS, and thus, the demand for using cutting-edge GNSS techniques in surveying and mapping applications has become indispensable. Online GNSS post-processing services are now available to provide support for users in need of precise point positioning or conventional differential positioning services and without requiring a prior knowledge of GNSS processing software. This study evaluates the performance of some online GNSS facilities with emphasis on observation duration (i.e. 1hr, 2hr, 6hr 12hr and 24hr observations). Three of these online facilities (AUSPOS, GAPS and magic-GNSS) were chosen based on their mode of operation and were evaluated at the location of five permanent GNSS stations in Nigeria. The study cut across two epochs in the year 2014 (i.e. seven days each in the months of January and July). Results in this study indicate that users can expect reliable results from these online services and their accuracy is within allowable limits for mapping applications in Nigeria. The similarity of the results between all of the services used is amazing, thus further demonstrates the robustness of the algorithms and processes employed by the different online facilities.

Keywords: Global Navigation Satellite System (GNSS), continuously operating reference stations (CORS), precise point positioning (PPP), GNSS online processing, positioning accuracy

1. Introduction

Global Navigation Satellite Systems (GNSS) is generic term for a composition of different satellite navigation technologies such as American GPS (Global Positioning System); its Russian equivalent, GLONASS (GLObal Navigation Satellite System); the Chinese system, BeiDou; the Japanese regional system, QZSS; the Indian regional system IRNSS (Indian Regional Navigation Satellite System); finally, is the European Galileo system. The GPS and GLONASS has since attained full operational status. The BeiDou, is expected to achieve completion for worldwide service in 2020, although a limited version of its signal has already been available since December 2012. The QZSS, is at present providing a limited service in the form of an augmented signal for GPS, but should be progressively upgraded and achieve full impartiality in 2023. The IRNSS, is at a final point operation as well. The Galileo system is expected to attain full operational capability in 2020 [1, 2].

Global Navigation Satellite System (GNSS) is one of the most innovative and practical technology developed in recent times. Since its inception it has grown to provide not only world-wide, all weather navigation, but precise position determination capabilities to all manner of users especially for surveying and geodetic applications. In surveying and mapping, this represents a revolutionary departure from conventional surveying procedures, which relied on observed angles and distances for determining point positions [3, 4].

Traditionally, it was necessary to obtain positioning with GNSS using at least two receivers, and the collected data processed for high accurate positioning using the GNSS data processing software whether scientific or commercial. However, the usage of such software is also quite difficult because they generally require deep knowledge of the GNSS, experience in the processing and they mostly need a licencing fee [4–7].

A remarkable volume of information and resources on GNSS are available on the internet including GNSS raw data, precise GNSS satellite orbit and clock files (which are provided by the international GNSS Service (IGS) and many other organisations, as well as some GNSS processing software (e.g., see [8]). This software vary in terms availability for use (cost), accuracy, and their mode of operation which are often dependant on the technical know-how of the users. Some of the very accurate but complex to use software are GAMIT/GLOBK (from Department of Earth Atmospheric and Planetary Sciences, MIT), GIPSY/OASIS-II (from Jet Propulsion Laboratory, JPL), PAGES (from United States National Geodetic Survey, NGS). The BERNESE software (from the Astronomisches Institut der Universitat Bern, Switzerland), is a state-of-the-art GNSS processing software similar to GIPSY and GAMIT but available only commercially at a very high cost. There are also numerous MATLAB based GNSS processing system which are freely available online (e.g., see [8, 9]), however, users require requisite skills to use them. Numerous studies have explore and put forward improvements in GNSS processing system that will aid users confronted with challenges enumerated herein [5, 6, 10].

Regarding the improvements in GNSS data processing methodology, many new opportunities have been offered to the users. In this respect, many organisations have developed online

GNSS processing services. These services provide GNSS processing results to the user free of charge and with unlimited access. The user sends a Receiver Independent Exchange Format (RINEX) file to the service and within a short period of time, the estimated position of the receiver used to collect the RINEX data is sent back to the user. Organisations that provide these free services include: Geohazards Division of Geoscience Australia, the Geodetic Survey Division (GSD) in Canada, the United States' National Geodetic Survey (NGS), Scripps Orbit and Permanent Array Center (SOPAC) at the University of California and the Jet Propulsion Laboratory (JPL) at National Aeronautics and Space Administration (NASA) [7].

The only requirement for using these services is a computer having an internet connection and web browser. These services are designed to be as simple as possible for the user and with minimal input. Users of such systems have to perform uploading/sending of their collected data in RINEX format by using the web site of these services, e-mail or ftp sites to the system and selecting a few processing options. Some of these services process not only the GPS but also the data of other systems, particularly those of GLONASS, and provide resilience and a higher accurate positioning service in certain cases to their users [5].

Currently, there are several online GNSS post-processing services, and are best categorised base on their adopted approach of processing the RINEX files. Categorically, there are those that use the Precise Point Positioning (PPP) approach (see [11–13] for documentation). Those in this category include Canadian Spatial Reference System-Precise Point Positioning (CSRS-PPP), magicGNSS, (APPS) and GPS Analysis and Positioning Software (GAPS). PPP based services used the GNSS data collected with only a single receiver with precise satellite ephemerides and clock data by taking into account corrections like carrier phase wind-up, satellite antenna phase offset, solid and ocean tides. The category of the GNSS online processing services that adopted the conventional relative approach, where user's RINEX files are processed relative to other GNSS continuously operating reference stations (CORS). The Trimble RTX, Australian Surveying and Land Information Group Online GPS Processing Service (AUSPOS) and Online Positioning User Service (OPUS) are based on this approach [5].

The application/usage of these facilities are gaining global acceptance and numerous studies have evaluated the accuracy of different online GNSS processing in different part of the world (e.g. Australia, Egypt, etc.). The results of such studies have demonstrated inherent limitations, the accuracies, conveniences of online post processing of GNSS observations, and have also identified a wide range of uses within the surveying community (e.g., see [13–15]). This chapter is dedicated to the report on the accuracy of three online GNSS processing facilities (magic GNSS, GAPS, and AUSPOS) over the territory of Nigeria. The major objective of the study is to investigate the effects of the variation in the duration of GNSS observation sessions on the positional accuracy when using online processing facilities.

The structure of the paper is as follows: first a general description and status of the different online GNSS post-processing services is presented in Section 2. Section 3 explains the methods used in the data acquisition, processing and evaluation of results. Section 4 describes the results. Lastly, the concluding remarks were presented and additionally, the paper gives insight into possible future expansion of GNSS infrastructures in Nigeria.

2. Overview of GNSS data processing and online services

Currently, there exist several online facilities for GNSS post processing applications. The different facilities or services are provided by different organisations and thus their mode of processing, restrictions, processing options, and format/latency of results varies. **Table 1** gives a summary of the comparison of the different facilities.

Each of the above-mentioned organisations have different technical specifications with respect to service features such as membership requirement, storage limitation of the GPS/GNSS RINEX data to be uploaded, process in static/kinematic modes, evaluation the data collected by single/dual or multi frequency receiver, GPS/GNSS antenna type selection, etc. The basic requirements that the user needs to take advantage of these different services are almost the same: access to the Internet and a valid email address. The user sends a Receiver Independent Exchange Format (RINEX) file to the service and within a short period of time, the estimated position of the receiver used to collect the RINEX data is sent back to the user. Solution quality from the various processing services depends on the availability, proximity and quality of base station data, and the availability of precise satellite orbits and clock corrections.

3. Methodology

Three online GNSS processing software were selected for this study. The selection was based on their mode of processing. One out of the selected three used the relative solution approach (i.e. AUSPOS) and the remaining two utilises the PPP technique (i.e. magicGNSS and GAPS).

The study utilised data from the new Nigerian GNSS Network (NIGNET) [16, 17] for the evaluation of the selected online GNSS services. Daily GNSS data in Hatanaka-compressed ASCII format were downloaded from the NIGNET site at www.nignet.net. The files were uncompressed with the freely available CRX2RNX software. The GNSS data were downloaded at the location of five different stations in the NIGNET (see **Figure 1**) for the year 2014. These stations include: ABUZ (Zaria); BKFP (Birnin-Kebbi); CLBR (Calabar); FUTY (Yola); and UNEC (Enugu). The stations were selected based on the data available per day (data consistency) from each station as the NIGNET is often characterised by large data gaps [18].

The GNSS data were collected at two epochs corresponding to GPS weeks 1774 and 1800, respectively. The data were collected for all 7 days in each week, it cuts across two different seasons of the year (months of January and July). The reason for this was to identify possible seasonal variations in the estimated coordinates from the different online facilities. The daily (24 h) RINEX files (observation data files) at each station were then decimated into 2, 6 and 12 h using the TEQC analysis software. This was done in order to check the effect of the length of observation session on the output of the different online GNSS processing services. The 24 h files and the decimated files were submitted to the three GNSS online processing services (magicGNSS, GAPs, and AUSPOS). After submission, both the 24 h and decimated files were processed and all the results were received via e-mail.

Service short name	Organisation /company	Software	Supported constellations	Data transfer method	Restrictions of length of GPS data set	Available options	Coordinates (Datum)	Websites
AUSPOS	Geoscience Australia USA	Bernese	GPS	Web service (uploading), via anonymous FTP	Minimum of 1 h. Maximum of 7 days of data	Dual frequency, static observations, DGPS only	ITFR2008, GDA 2020, GDA94	http://wwwb.ga.gov.au/bin/gps.pl
CSRS-PPP	Natural Resources Canada	NRCanPPP	GPS, GLONASS	Web Service (uploading)	No minimum Maximum 6-day long Provided uncompressed RINEX file is less than 100 MB	Single and dual frequency in static and kinematic mode, uses velocity grid (NUVEL1-A model) to account for crustal motion, PPP only	IGS 2014, ITRF 2008, NAD83 (CSRS)	http://www.geod.nrcan.gc.ca/online_data_e.php
OPUS	National Geodetic Survey	PAGES	GPS	Web service (uploading)	Minimum 2 h. Maximum 24 h	Dual frequency, static observations. Services available only to central and north America	ITRF 2008	http://www.ngs.noaa.gov/OPUS/
GAPS	University of New Brunswick	GAPS v6.0.0 r587	GPS, Galileo, BeiDou	Uploading via web service (supports RINEX 2, 3, and raw data)	Minimum 2 h	Dual frequency pseudo-range and carrier phase static and kinematic observations, basic and advance mode of processing, PPP only	ITRF 2008, ETRF 2005 & earlier solutions	http://gaps.gge.unb.ca/
APPS	NASA Jet Propulsion Laboratory	AUTO-GIPSY 6.4	GPS, GLONASS, BeiDou	Uploading, FTP, email (RINEX 2, GIPSY TDP files)	Process multiple RINEX files in a single session, multi-day RINEX files	Dual and single frequency, four processing mode(static, kinematic, NRT, most accurate), user input pressure correction, PPP and DGNSS services	ITRF 2008	http://apps.gdgps.net/
Magic-GNSS	GMV Innovating Solutions	Magic PPP client (magicAPK)	GPS, GLONASS, Galileo, BeiDou, QZSS	Uploading and E-mail (RINEX-2, RINEX-3, RTCM 10403.2)	No restrictions	Dual frequency, static and kinematic observations, PPP only	ITRF 2008	http://magicgnss.gmv.com/ppp
Trimble RTX	Trimble Navigation Limited	Trimble office	GPS, GLONASS, Galileo, BeiDou, QZSS	Uploading (RINEX 2, RINEX 3)	Minimum of 1 h Maximum 24 h	Dual frequency pseudo-range and carrier phase observations, static observations, PPP	ITRF 2014 with options for other datum, option of plate model	http://www.trimblertx.com/UploadForm.aspx

Table 1. Overview of the structures, requirements, and processing options of the different online GNSS post-processing services.

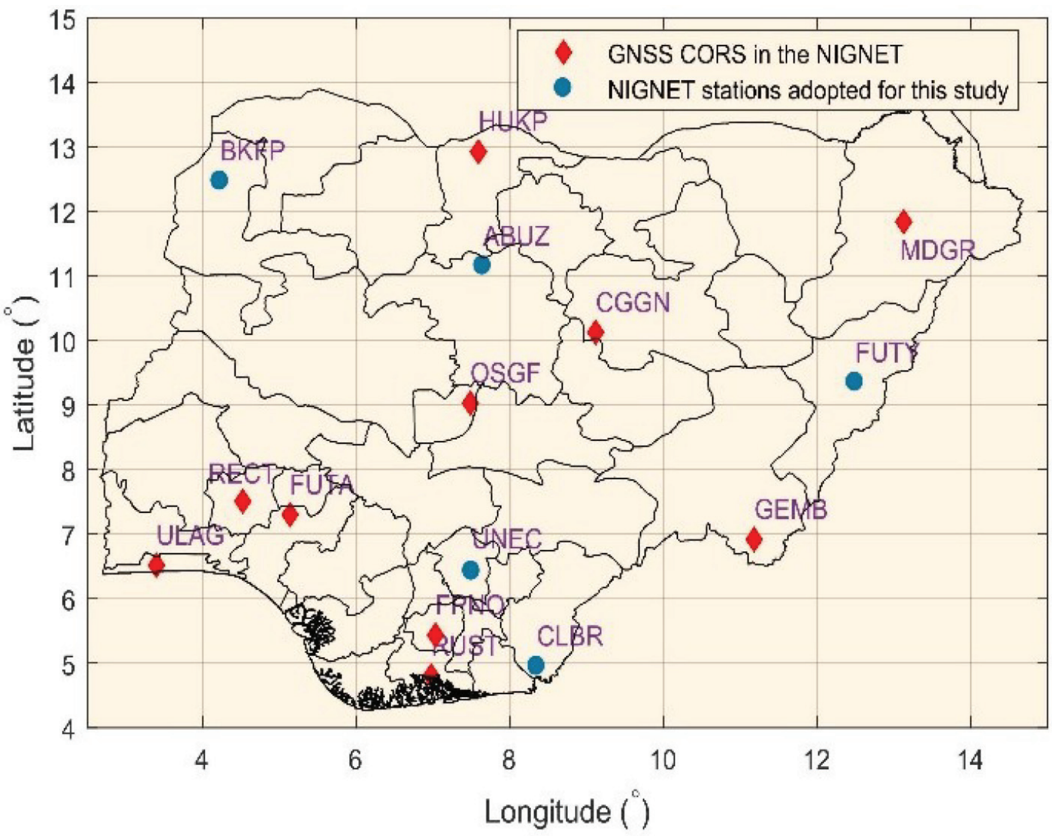

Figure 1. Location of permanent GNSS stations in the Nigerian GNSS network (NIGNET).

To compare the results from the online GNSS post processing facilities with known station coordinates which were originally obtained from long time station average using BERNESE software, the residuals (differences) in northing, easting and heights components were computed for all observations in the two epoch and were employed in subsequent analysis. Consequently, the root-mean-square error (RMSE) in both the vertical and horizontal directions were computed from the differences using Eqs. (1) and (2). Similarly, the Horizontal RMSE (HRMSE) and vertical RMSE (VRMSE) were calculated using Eqs. (3) and (4);

$$RMSE_{North} = \sqrt{\sum_{i=1}^{n} \frac{(P_{i,North} - O_{i,North})^2}{n}} \quad (1)$$

$$RMSE_{East} = \sqrt{\sum_{i=1}^{n} \frac{(P_{i,East} - O_{i,East})^2}{n}} \quad (2)$$

$$HRMSE = \sqrt{(RMSE_{North})^2 + (RMSE_{East})^2} \quad (3)$$

$$VRMSE = \sqrt{\sum_{i=1}^{n} \frac{(P_{i,Vertical} - O_{i,Vertical})^2}{n}} \quad (4)$$

In Eqs. (1), (2), and (4); P_i is the known station coordinates for the NIGNET stations and the estimated coordinates from the different online GNSS services are denote by O_i, and n is the total number of observations.

4. Results and discussions

The coordinate of the NIGNET stations were obtained in geographic unit and were converted to equivalent Universal Traverse Mercator (UTM) coordinate system with projection on the WGS 84 ellipsoid. The coordinates of the selected five NIGNET station for this study in UTM (Northing, Easting and Height) system is presented in **Table 2**. Similarly, all 3D coordinates obtained from the magicGNSS, GAPS, and AUSPOS were converted to UTM system for easy comparison. Appendices A.1–A.5 contain the average 3D coordinates of the stations at the 2, 6, 12, and 24 h observation sessions.

To compare accuracy of magicGNSS, AUSPOS, and GAPS online services, the coordinates of the selected permanent GNSS site which were originally computed using BERNESE software are taken as reference. The coordinate differences of each online services subtracted from reference coordinates of all the stations and RMSE, HRMSE, and VRMSE have been computed by Eqs. (1)–(4). The combined results of the performance measures (RMSE, HRMSE, and VRMSE) is presented in **Table 3** for observations at all the permanent GNSS stations in January 2014 (first epoch).

The RMSE values for the east and north components are typically less than 0.3 m for the magic GNSS and GAPS services; while those of the AUSPOS service were higher and greater than 0.3 m in all instances as seen in **Table 3**. Accordingly, the HRMSE values for the magicGNSS and GAPS were also less than those from AUSPOS; also, the VRMSE values for AUSPOS are higher than those of magicGNSS and GAPS which is an indication that AUSPOS results are less accurate when compared to magicGNSS and GAPS. **Figure 2** is a plot of the different performance measures, it very evident form **Figure 2** that AUSPOS performs less than the other two services. Also, it can be seen the 24 h file do not always give the best results. However, AUSPOS did gave some deterrent messages on the use of 2 h files for processing.

Again, the combined results of the performance measures (RMSE, HRMSE, and VRMSE) is presented in **Table 4** for observations at all the permanent GNSS stations in July 2014 (second epoch).

S/no	Stations	Easting (m)	Northing (m)	Height (m)
1.	ABUZ	352440.6939	1233094.064	705.0536
2.	BKFP	633587.9715	1378678.241	249.9995
3.	CLBR	428111.6667	547205.768	57.1295
4.	FUTY	884308.222	1035426.663	247.3917
5.	UNEC	334662.4162	710405.3358	254.3912

Table 2. The UTM coordinates of the selected GNSS stations from the NIGNET.

Duration (h)	RMSE (E)	RMSE (N)	HRMSE	VRMSE
magicGNSS				
2	0.10823	0.10840	0.04316	0.15318
6	0.09798	0.12607	0.04410	0.15967
12	0.10634	0.11150	0.04231	0.15408
24	0.10768	0.10840	0.04293	0.15280
AUSPOS				
2	0.37673	0.69649	0.34905	0.62703
6	0.36023	0.71277	0.41569	0.63781
12	0.34954	0.71344	0.41882	0.63118
24	0.38925	0.70973	0.42112	0.80946
GAPS				
2	0.22128	0.04342	0.03108	0.22550
6	0.19239	0.04253	0.03108	0.19703
12	0.20384	0.05975	0.03153	0.21242
24	0.22508	0.14803	0.02749	0.26940

Table 3. Performance of online GNSS services during the first epoch of observation.

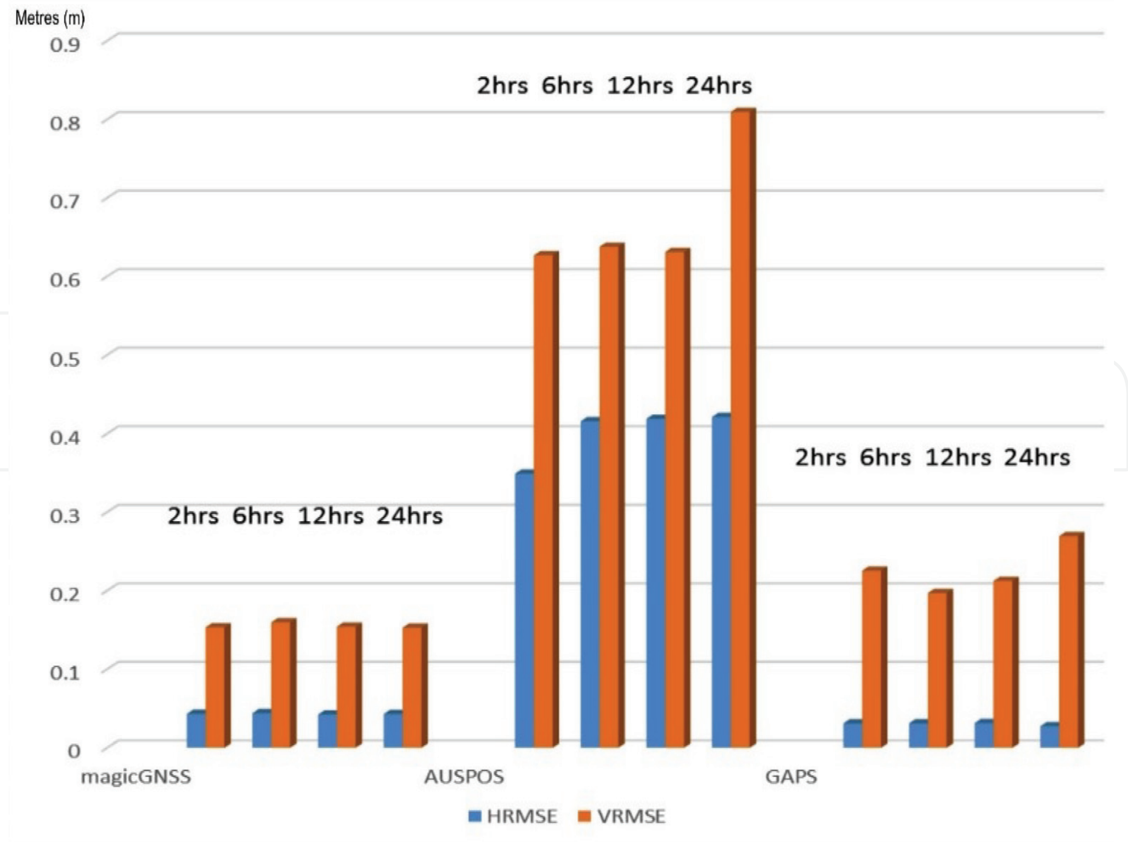

Figure 2. A plot of the HRMSE and VRMSE for the different online GNSS services during the first epoch of observations.

http://dx.doi.org/10.5772/intechopen.79924

The results from **Table 4** are in very good agreement with those in earlier discussed (**Table 3** for the first epoch of observations). **Figure 3** is a plot of the different performance measures for the second epoch of observation.

From **Figure 3** it is evident that the 24 h observation files and the decimated files (2, 6 and 12 h), produce results with millimetre (mm) to a centimetre (cm) level of accuracy when processed with magicGNSS and GAPS. It is again evident from **Figure 3** that magicGNSS produces the best results, followed by GAPS and then AUSPOS. This is the same for the two epochs.

The AUSPOS is the only one of the three facilities that utilises the relative approach, its results were not pleasing, the poor performances of AUSPOS is attributed long baselines in the processing because of non-availability of nearby IGS stations for the processing. Thus, baselines of shorter lengths will increase the quality of data, the reliability and dependability of the online AUSPOS facilities. As earlier stated, AUSPOS again gave a warning message in processing the 2 h files indicating that the precision of estimated coordinates are outside the confidence level but the situation was different with magicGNSS and GAPS.

All the three services investigated in this study return results to users via email. Time delay on receiving the results depends on several factors including the traffic on the Internet and the number of users accessing the service at the same time. The displayed times in **Table 5** are only a rough estimates in order to compare the speed of each of the services and were obtained by submitting the same 24 h data set to each of the service.

The AUSPOS is the fastest to return results, followed by GAPS and then magicGNSS; again it was found to be more user friendly, followed by magicGNSS (e-mail version) and then GAPS.

Duration (h)	RMSE (E)	RMSE (N)	HRMSE	VRMSE
Magic GNSS				
2	0.12714	0.12379	0.03169	0.17745
6	0.10241	0.11328	0.02096	0.15271
12	0.07737	0.11046	0.02095	0.13486
24	0.10147	0.10527	0.02583	0.14622
AUSPOS				
2	0.58026	0.11122	0.44654	0.59082
6	0.56693	0.11216	0.44207	0.57792
12	0.57561	0.11502	0.43894	0.58699
24	0.68495	0.30499	0.44182	0.74979
GAPS				
2	0.03041	0.00040	0.03958	0.03041
6	0.06927	0.00434	0.04003	0.06941
12	0.11972	0.45249	0.03421	0.46806
24	0.26515	0.45061	0.03841	0.52284

Table 4. Performance of online GNSS services during the second epoch of observation.

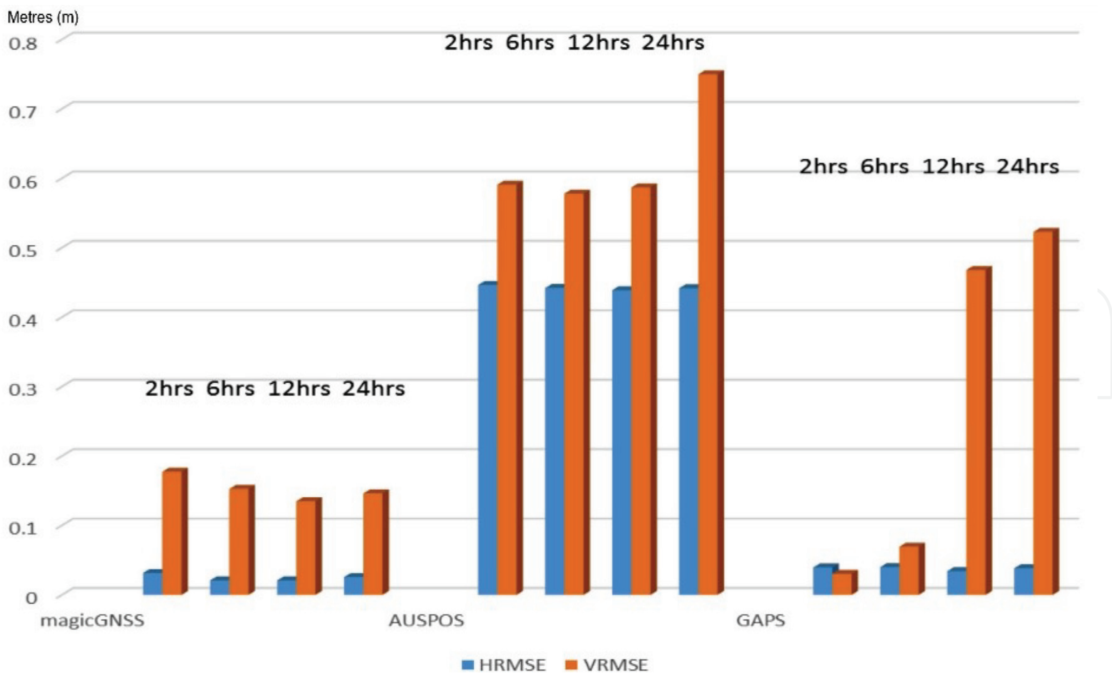

Figure 3. A plot of the HRMSE and VRMSE for the different online GNSS services during the second epoch of observations.

Elapsed time (min)	MagicGNSS		AUSPOS		GAPS	
	Min	Max	Min	Max	Min	Max
	2	1440	1	2	2	3

Table 5. Latency results from magicGNSS, AUSPOS, and GAPS online GNSS post-processing services.

The GAPS facilities has some security features which sometimes exasperate the process of submitting files for processing. Also, the advanced mode of processing in GAPS gives room to decimate files automatically by just giving the range of observation without going into the tedious processes of doing it with TEQC software.

5. Concluding remarks

In this work, a comparative analysis of some online GNSS post-processing services at locations of permanent GNSS stations in Nigeria has been made. Online GNSS processing services can help users either using precise point positioning (PPP) or differential method, and without requiring a prior knowledge of GNSS processing software. Results in this project indicate that users can expect reliable results from these online services. The similarity of the results between all of the services used is amazing. That they differ only by a few millimetre (mm) or centimetre (cm) demonstrates the robustness of the algorithms and processes they employ in processing GNSS observations. Results for decimated daily RINEX files also show that users can process data sets of less than 24 h observation period and expect almost the same results (or better results in some cases) when compared to the 24 h data set. Among the three online facilities examined in this study, the AUSPOS seems to have the most flexible and user friendly interface, followed by magicGNSS and then GAPS. As mentioned earlier, magicGNSS produces the best result, followed by GAPS and then AUSPOS. When selecting a faster means of obtaining result from these software, AUSPOS is the fastest, followed by GAPS and then magicGNSS. The reason why AUSPOS did not perform as GAPS and magicGNSS is due to the effect of long baselines in the processing and this again affirm the advantage of the PPP techniques. Regardless of the problem that might be encountered in the return of results (processed coordinate values), magicGNSS is undoubtedly the best of the three. Undoubtedly, the online GNSS facilities have brought a paradigm shift in GNSS positioning applications, in view of the accuracy and efficiency (saving cost of buying and operating a second receiver) they offer to users. It is therefore necessary that if any of these facilities (including those not considered in this study) is to be used for processing, the need for reliability and accuracy must first be considered. Finally, creating awareness among surveyors and other professionals on the functionality and dependability of online GNSS post-processing services is needed so that they can fully explore the potential of these facilities in mapping and possibly cadastral applications in Nigeria and other parts of the world.

Acknowledgements

The authors would wish to express their profound gratitude to the numerous reviewers for their productive observations that helped to perk up this chapter. We wish to thank the office of the Surveyor General of the federal republic of Nigeria (OSGOF) for the GNSS data used in the study.

Conflict of interest

The authors avow that there no conflicts of interest regarding the publication of this manuscript.

Authors' contribution

OAI conceived the idea of the paper, MM and LA downloaded, prepared and processed all dataset used in the report, manuscript was drafted by OAI. All authors read and approved the final draft.

Appendices and nomenclature

The mean station coordinates for ABUZ, BKFP, CLBR, FUTY, and UNEC for the two epochs of study are presented in Appendices A.1–A.5, respectively.

A.1. Mean station coordinates for ABUZ in the two epochs of observation

	Duration (h)	Station coordinate		
		Easting (m)	Northing (m)	Height (m)
		Epoch 1		
MagicGNSS	2	352440.7181	1233094.105	705.054
	6	352440.718	1233094.108	705.051
	12	352440.7182	1233094.103	705.053
	24	352440.7185	1233094.104	705.054
AUSPOS	2	352441.0593	1233094.676	705.234
	6	352441.0581	1233094.679	705.232
	12	352441.0592	1233094.679	705.236
	24	352441.056	1233094.676	705.234
GAPS	2	352440.8165	1233094.156	705.073
	6	352440.8493	1233094.155	705.071
	12	352440.8274	1233094.149	705.07
	24	352440.8165	1233094.154	705.073
		Epoch 2		
MagicGNSS	2	352440.7617	1233094.105	705.053
	6	352440.7508	1233094.103	705.054
	12	352440.7398	1233094.1	705.053
	24	352440.718	1233094.102	705.053
AUSPOS	2	352440.7509	1233094.126	705.237
	6	352440.729	1233094.127	705.239
	12	352440.7508	1233094.122	705.24
	24	352440.7507	1233094.132	705.236
GAPS	2	352440.7302	1233094.15	705.064
	6	352440.7304	1233094.146	705.065
	12	352440.7305	1233094.148	705.063
	24	352440.7299	1233094.148	705.064

A.2. Mean station coordinates for BKFP in the two epochs of observation

	Duration (h)	Coordinates		
		Easting (m)	Northing (m)	Height (m)
		Epoch 1		
MagicGNSS	2	633588.0497	1378678.305	250.049
	6	633588.0494	1378678.302	250.048
	12	633588.0496	1378678.306	250.05
	24	633588.0495	1378678.305	250.048
AUSPOS	2	633588.0703	1378678.9	250.184
	6	633588.07	1378678.902	250.18
	12	633588.0701	1378678.903	250.183
	24	633588.0702	1378678.901	250.184
GAPS	2	633588.0933	1378678.284	250.001
	6	633588.093	1378678.286	250.003
	12	633588.0933	1378678.284	250.004
	24	633588.0932	1378678.285	249.999
		EPOCH 2		
MagicGNSS	2	633588.047	1378678.302	250.012
	6	633588.0472	1378678.303	249.999
	12	633588.047	1378678.303	250
	24	633588.0471	1378678.301	250.013
AUSPOS	2	633588.0402	1378678.778	250.19
	6	633588.0404	1378678.777	250.189
	12	633588.0407	1378678.775	250.19
	24	633588.0402	1378678.777	250.192
GAPS	2	633588.0417	1378678.341	250.012
	6	633588.0418	1378678.342	250.01
	12	633588.042	1378678.34	250.009
	24	633588.0417	1378678.34	250.008

A.3. Mean station coordinates for CLBR in the two epochs of observation

	Duration (h)	Coordinates		
		Easting (m)	Northing (m)	Height (m)
		EPOCH 1		
MagicGNSS	2	428111.7174	547205.8302	57.183
	6	428111.7173	547205.8324	57.184
	12	428111.717	547205.8335	57.183
	24	428111.7171	547205.8314	57.183
AUSPOS	2	428111.8034	547205.8643	57.344
	6	428111.7912	547205.8645	57.343
	12	428111.769	547205.8644	57.344
	24	428111.7468	547205.8649	57.343
GAPS	2	428111.7848	547205.83	57.167
	6	428111.7845	547205.8296	57.17
	12	428111.7846	547205.8293	57.171
	24	428111.7848	547205.8317	57.167
		EPOCH 2		
MagicGNSS	2	428111.7213	547205.8316	57.188
	6	428111.7202	547205.8319	57.185
	12	428111.7191	547205.8312	57.181
	24	428111.718	547205.8316	57.182
AUSPOS	2	428111.7158	547204.7951	57.357
	6	428111.7147	547204.7918	57.358
	12	428111.7158	547204.7929	57.357
	24	428111.9527	547204.3555	57.356
GAPS	2	428111.3121	547204.4158	57.178
	6	428111.2899	547204.4192	57.18
	12	428111.2566	547204.417	57.172
	24	428111.2613	547204.4157	57.178

A.4. Mean station coordinates for FUTY in the two epochs of observation

	Duration (h)	Coordinates		
		Easting (m)	Northing (m)	Height (m)
		EPOCH 1		
MagicGNSS	2	884308.2235	1035426.664	247.393
	6	884308.2133	1035426.701	247.401
	12	884308.2334	1035426.668	247.39
	24	884308.2224	1035426.663	247.393
AUSPOS	2	884308.4531	1035426.813	247.572
	6	884308.3431	1035426.81	247.57
	12	884307.1331	1035426.798	247.571
	24	884308.4532	1035426.802	247.572
GAPS	2	884308.2816	1035426.356	247.4
	6	884308.1815	1035426.466	247.404
	12	884308.2246	1035426.555	247.401
	24	884308.2812	1035426.733	247.399
		EPOCH 2		
MagicGNSS	2	884308.2342	1035426.7	247.4
	6	884308.1904	1035426.677	247.395
	12	884308.1464	1035426.675	247.4
	24	884308.2225	1035426.662	247.392
AUSPOS	2	884308.2779	1035426.726	247.58
	6	884308.2713	1035426.726	247.578
	12	884308.2669	1035426.725	247.572
	24	884308.2757	1035426.727	247.579
GAPS	2	884307.4646	1035426.76	247.4
	6	884307.5736	1035426.75	247.401
	12	884307.6836	1035426.749	247.401
	24	884307.8574	1035426.754	247.402

A.5. Mean station coordinates for UNEC in the two epochs of observation

	Duration (h)	Coordinates		
		Easting (m)	Northing (m)	Height (m)
		EPOCH 1		
MagicGNSS	2	334662.5036	710405.410	254.383
	6	334662.4914	710405.413	254.380
	12	334662.4899	710405.416	254.384
	24	334662.5036	710405.418	254.383
AUSPOS	2	334662.5126	710405.410	254.573
	6	334662.5134	710405.411	254.570
	12	334662.5105	710405.417	254.569
	24	334662.5145	710405.415	254.573
GAPS	2	334662.4889	710,405. 429	254.394
	6	334662.4919	710405.433	254.389
	12	334662.4962	710405.388	254.390
	24	334662.4979	710405.391	254.390
		EPOCH 2		
magicGNSS	2	334662.4904	710405.4100	254.383
	6	334662.4907	710405.4102	254.380
	12	334662.491	710405.4096	254.378
	24	334662.4916	710405.4106	254.383
AUSPOS	2	334662.483	710405.398	254.6
	6	334662.4826	710405.3992	254.59
	12	334662.4832	710405.3997	254.588
	24	334662.4826	710405.3983	254.588
GAPS	2	334662.4897	710405.4041	254.4
	6	334662.4895	710405.4049	254.399
	12	334662.4899	710405.406	254.397
	24	334662.4871	710405.405	254.399

Author details

Olalekan Adekunle Isioye*, Mefe Moses and Lukman Abdulmumin

*Address all correspondence to: lekkyside4u@yahoo.com

Department of Geomatics, Ahmadu Bello University, Zaria, Kaduna, Nigeria

References

[1] Hoffmann-Wellenhof B, Litchtenegger H, Wasle E. GNSS—Global Navigation Satellite Systems: GPS, GLONASS, Galileo and More. Vienna: Springer-Verlag; 2008. ISBN: 987-3-211-73012-6(print)

[2] Shaw M. GPS Modernization: On the Road to the Future GPS IIR/IIR-M and GPS III.UN/UAE/US Workshop on GNSS Applications, Session 1: Trends in Satellite-Based Navigation Systems; Dubai, UAE. 2011

[3] Awange JL. Environmental Monitoring Using GNSS: Global Navigation Satellite Systems. New York: Springer-Verlag; 2012. ISBN: 978-3-540-88255-8(Print)

[4] Ocalan T. Accuracy assessment of GPS precise point positioning (PPP) technique using different web-based online Services in a forest environment. Sumarski List. 2016;**7-8**: 357-368

[5] Alkan RM, Ozulu M, Ilci V. Web-based GNSS data processing services as an alternative to conventional processing technique. In: FIG Working Week 2016; New Zealand. pp. 1-35

[6] Satirapod C, Wong K, Rizos C. A web-based automated GPS processing system. In: The Proceedings of the 2nd Trans-Tasman Surveyors Congress, Queenstown; 20–26 August 2000; New Zealand. Available from: https://www.researchgate.net/publication/250222229_A_WEB-BASED_AUTOMATED_GPS_PROCESSING_SYSTEM. [Accessed: 2018-05-12]

[7] El-Mowafy A. Analysis of web-based GNSS post-processing services for static and kinematic positioning using short data spans. Survey Review. 2013;**43**(323):535-549. DOI: 10.1179/003962611X13117748892074

[8] On-line Geodesy Resources: GPS. 2018. Available from: http://www3.sympatico.ca/craymer/geodesy/gps.html [Accessed: 2018-05-12]

[9] Strang G, Borre K. Linear Algebra, Geodesy, and GPS. Wellesley: Wellesley-Cambridge Press; 1997. 624 p

[10] Isioye OA, Enebeli I, Shebe MW, Mefe M. Near real time processing solution of differential GPS positioning using internet technology. Asian Journal of Engineering Science and Technology. 2011;**1**(2):58-66. A publication of the Faculty of Engineering, Sciences and

Technology, Iqra University, Karachi, Pakistan, September 2011. Available from: http://ajest.iqra.edu.pk/journal.php. ISSN: 2007-1142

[11] Rizos C, Janssen V, Roberts C, Ve Grinter T. Precise point positioning: Is the era of differential GNSS positioning drawing to an end? In: The Proceedings FIG Working Week; 6-10 May 2012; Rome, Italy. 2012

[12] Zumberge JF. Automated GPS data analysis service. GPS Solutions. 1999;**2**(3):76-78

[13] Zumberge JF, Heflin MB, Jefferson DC, Watkins MM, Webb FH. Precise point positioning for the efficient and robust analysis of GPS data from large networks. Journal of Geophysical Research. 1997;**102**(B3):5005-5017

[14] Ghoddousi-Fard R, Dare P. Online GPS processing services: An initial study. GPS Solutions. 2006;**10**:12-20

[15] Ebner R, Featherstone W. How well can on-line GPS PPP post processing services be used to establish geodetic survey control networks. Journal of Geodesy. 2008;**2**:149-157

[16] Jatau B, Fernandes RMS, Adebomehin A, Goncalves N. NIGNET-the new permanent GNSS network of Nigeria. In: FIG Congress 2010 Facing the Challenges—Building the Capacity Sydney; 11-16 April 2010; Australia

[17] Naibbi AI, Ibrahim SS. An assessment of the existing continuously operating reference stations (CORS) in Nigeria: An exploration using geographical information system (GIS). American Journal of Geographic Information System. 2014;**3**(4):147-157. DOI: 10.5923/j.ajgis.20140304.01

[18] Isioye OA, Combrinck L, Botai J. Evaluation of spatial and temporal characteristics of GNSS-derived ZTD estimates in Nigeria. Theoretical and Applied Climatology. 2017;**132**: 1099. DOI: doi.org/10.1007/s00704-017-2124-7