

# GNSS Sky Visibility Planning and Dilution of Precision Analysis for EOS Ground Station Selection for Nigeria Space Programme

M. L. Ojigi\*<sup>1</sup>, J. D. Dodo<sup>3</sup> & Y. D. Opaluwa<sup>2</sup>

<sup>1</sup>*Mission Planning, IT and Data Management Department, National Space Research and Development Agency (NASRDA), Abuja, Nigeria*

<sup>2</sup>*Centre for Geodesy and Geodynamics, NASRDA, Toro, Nigeria*

<sup>3</sup>*Dept. of Surveying and Geoinformatics, FUT, Minna, Nigeria*

## Abstract

The establishment of Earth Observation Satellite (EOS) ground receiving stations in parts of Nigeria and other parts of the globe, similar to the Indian Remote Sensing (IRS) model will enhanced global tele-commands, precise EOS tracking, data transmission and distribution of NigeriaSat data, which will enhance global-scale data awareness, usage and higher financial returns for Nigeria. This study therefore attempts the application of Global Navigation Satellite System (GNSS) sky visibility planning and dilution of precision analysis technique to select optimal location for EOS ground station(s) in Nigeria. The Nigerian Geodetic Network (NigNet) GNSS Continuously Operating Reference Stations (CORS) RINEX data of February 2012 and Trimble Total Control (TTC) software were used for the determinations of the baselines and positions of the 11 available CORS. The technique of GNSS sky visibility planning and dilution of precision (DOP) was adopted because signals from satellites behave in similar pattern in the atmosphere, so poor visibility in GNSS signal in a particular observation window translates relatively to poor orbit definition signal for an EOS. Based on Jon's rating of DOP values [1= ideal; 2-3 = excellent; 4-6 =good; 7-8= moderate; 9-20=fair; 21-50= poor)], the DOP values for the stations across Nigeria can be adjudged to range between excellent and good for ground receiving stations. However, the overall results showed that, GEMB on ellipsoidal heights of 1795.7857m has the most suitable DOPs and sky visibility plan for ground receiving sites; followed by CGG Toro (916.7853m) and RAMPOLY Maiduguri (702m). The sky visibility analysis showed availability of an average of 9 GPS and 2 GLONASS constellation satellites to receivers at elevation angles of 10°-15° between 6:00hrs and 24:00hrs daily across Nigeria. The approach of EOS ground receiving station suitability analysis demonstrated in this study is recommended for the Nigerian

\*Email : [lazarus.ojigi@nasrda.gov.ng](mailto:lazarus.ojigi@nasrda.gov.ng)

Space programme in EOS ground-based antennae farm establishment. It is also relevant in the densification of GNSS reference stations by public-private organizations for geoinformation development, engineering infrastructure tracking and navigation at state and local government levels across the country.

**Keywords:** GNSS, Sky Visibility, Planning, DOP, EOS, Ground Station.

## Résumé

L'établissement des stations de réception des Satellites d'Observation de la terre (EOS) dans certaines parties du Nigeria et dans d'autres parties du globe, semblable au model indien de la Télédétection (IRS), améliorera les télécommandes globales et le système de tracking précis des EOS, la transmission et la distribution de données du satellite NigeriaSat, qui amélioreront la sensibilisation des consciences sur les données d'échelle globale, l'utilisation et des retours financiers plus importants pour le Nigeria. Par conséquent, cette étude essaie d'appliquer le Système de Satellite de Navigation Global (GNSS), la planification de visibilité du ciel et la dilution de technique d'analyse de précision pour choisir l'emplacement optimal de la station terrestre des EOS au Nigeria. Le Réseau Géodésique Nigérian (NigNet), les Stations de Référence permanentes du GNSS (CORS), les données RINEX de février 2012 et le logiciel de Contrôle de Total de Trimble (TTC) ont été utilisés pour la détermination des lignes de base et des positions de 11 CORS disponibles. La technique de la planification de visibilité du ciel et de la dilution de précision (DOP) a été adoptée parce que les signaux de satellites se comportent dans un modèle semblable dans l'atmosphère, donc la faible visibilité dans le signal du GNSS dans une fenêtre d'observation particulière se transforme relativement en un signal de définition d'orbite pauvre pour un EOS. Considérant l'évaluation de Jon sur les valeurs du DOP [1 = idéal; 2-3 = excellent; 4-6 = good; 7-8 = modéré; 9-20 = assez bien; 21-50 = pauvre)], les valeurs de DOP pour les stations à travers le Nigeria peuvent être considérées comme s'étendant entre excellent et bon pour des stations de réception terrestres. Cependant, les résultats globaux ont montré que le GEMB sur les hauteurs ellipsoïdales de 1795.7857m a des valeurs de DOPs les plus appropriées et le plan de visibilité de ciel pour des sites de réception terrestres, suivi du CGG Toro (916.7853m) et du RAMPOLY Maiduguri (702m). L'analyse de visibilité du ciel a montré la disponibilité d'une moyenne de 9 GPS et 2 satellites de constellation GLONASS aux récepteurs d'angles d'élévation de 10°-15° entre 6.00 et 24.00 heures quotidiennement à travers le Nigeria. L'approche d'analyse de suitabilité des stations de

réception terrestres (EOS) démontrée dans cette étude pour le Programme Spatial Nigérian dans l'établissement des sites d'antenne basés au sol pour les EOS. C'est aussi pertinent dans la densification des stations de référence de GNSS par des organisations publiques-privées pour le développement de la géoinformation, les infrastructures d'ingénierie de tracking et de navigation aux niveaux des états et des niveaux d'administration locale à travers le pays.

**Mots clés :** GNSS, Visibilité du Ciel, Planification, DOP, EOS, Station terrestre.

## Introduction

Ground receiving station network (GRSN) is the means by which satellites in space stay in contact with the Earth. Human operators at the ground stations send commands to correct the satellites' trajectories, maneuver them into different orbits, and operate their instruments. The satellite transmits back to earth not only the scientific data that it is gathering, but also the 'housekeeping' information needed by the operators to check the satellite's performance (ESA, 2008). The types of control necessary for earth observation satellites include those of orbit, attitude, pointing of observation instrument, thermal, telemetry, communication, command, and electric power (ERSDAC, 2010). With the rapid advancement in the technologies of Earth Observation Satellites in low Earth orbit, the ability to precisely predict the position and velocity of the satellite is extremely important.

The ground station of an Earth Observation Satellites (EOS) system consists of all communicating earth stations which access the operational satellite. The ground station's job is two-fold, transmitting and receiving. When transmitting, the terrestrial data in the form of baseband signals is passed through a baseband processor, an up-converter, a high-powered amplifier, and through a parabolic dish antenna up to an orbiting satellite. In the case of a receiving station, it works in the reverse fashion by converting signals received through the parabolic antenna to baseband signal. The mission data acquired by the ground station from a spacecraft are transferred to the data users along with any telemetry and tracking information the data users may need for general station keeping. The basic functions of GRSN include among others; *telemetry tracking and control support, satellite orbit determination and monitoring, general station keeping, satellite payload management and in-orbit test (IOT)*. One of the strategic ways of monitoring the Orbit of an EOS is the use of (TLE) for velocity, *orbit inclination, eccentricity and coefficient of drag*

variation analysis (Langer *et al*, 1994, 2002; Cox *et al*, 2000; Ojigi, 2012).

Obtaining a precise orbit with sparse tracking data and the ability to accurately propagate it so that it can be used for scheduling instruments and ground station operations are important procedures selection of the estimation algorithm and force modeling. When GNSS observables have to be incorporated in the software, those suited for batch estimators must be used. The option is to obtain the processed baseline and navigation results using double differences of ionospheric free carrier phase and double difference pseudorange. Dow *et al* (1994) suggested that, measurements with GPS observables should be implemented either for pairs of ground stations or for geodesy, and for orbiting receiver or ground station pairs, in order to obtain precise orbits of the satellite carrying the GPS receiver.

Most modern satellites utilize space-borne GNSS receivers as primary navigation sensors, which allow positioning accuracies to the decimeter level because of the high precision of GPS carrier-phase measurements (Hauschild, *undated*; Hauschild & Montenbruck, 2008). The determination of Two Line Element (TLE) sets are enhanced by GNSS observable and receivers on EOS, whose orbit attitudes are subsequently tracked, monitored, propagated and modeled. High accuracy in EOS telemetry tracking and control is guaranteed using the GNSS carrier phase observable, free of ionospheric errors when dual frequency data is used. The unsurpassed observability is provided by the high number of GPS satellites that can be simultaneously tracked by an orbiting receiver ([http://nng.esoc.esa.de/gps/onboard\\_gps.html](http://nng.esoc.esa.de/gps/onboard_gps.html); Cox *et al*, 2000).

### ***Satellite Visibility and Observation Planning***

GNSS planning software have been developed (Fruet *et al*, 1999; Sguerso & Zatelli, 1999; zatelli & D'Inca, 2004) and recently updated (Federici & Sguerso, 2009), and introduced as modules of most GNSS solution software (commercial, scientific and open source software). GNSS Planning allows the identification of optimal areas to perform a survey in a given temporal window, or the best time interval for a survey campaign in a certain area (Federici, *et al*, 2010), taking into account the realistic obstructions to satellite signals due to factors such as terrain morphology, building and communication structures, weather and atmospheric conditions, etc. A popular representation of satellite availability is the skyplot, which is a plot of satellite tracks on a zenithal projection centered at the ground station (Figure 1.1).

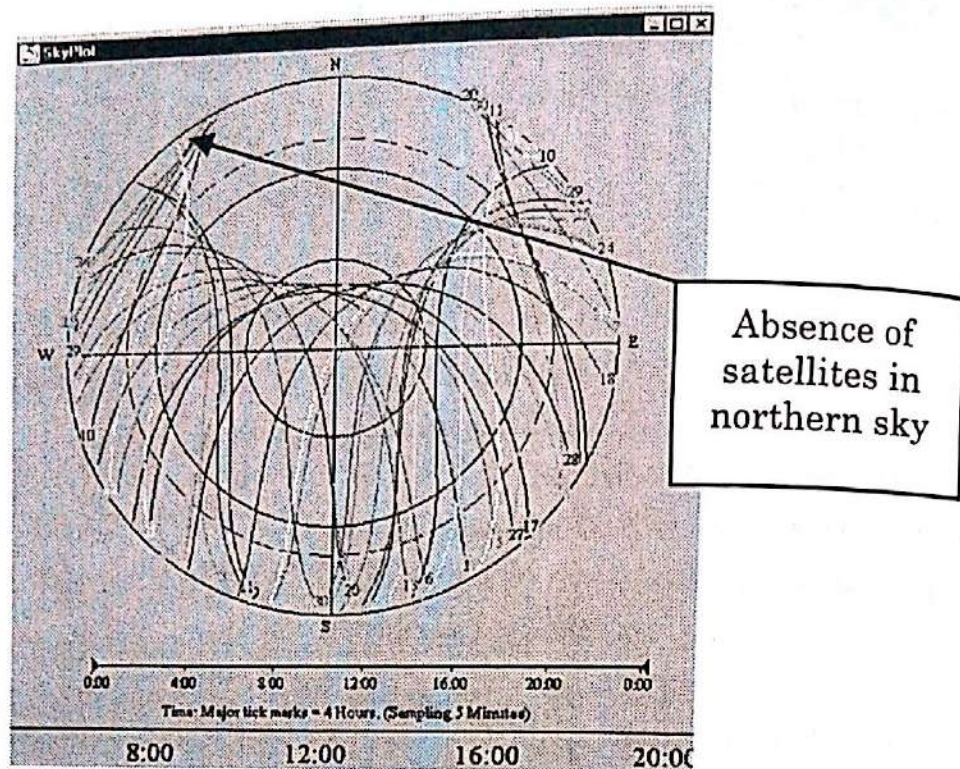


Figure 1.1: Skyplot showing absence of Satellites in Northern sky (Source: Oppliger, 2007)

### ***Dilution of Precision (DOP)***

The Dilution of Precision (DOP) is a measure of the geometrical strength of the observations model. DOP can also be a measure of the strength of the satellite-constellation geometry. The higher the number of satellites observed and used in the final solution, the better the solution. In mathematical terms, DOP is a scalar quantity used in an expression of a ratio of the positioning accuracy. It is the ratio of the standard deviation of one coordinate to the measurement accuracy. Therefore, since DOP (*Time DOP, Vertical DOP, Horizontal DOP and Geometric DOP*) can be used as a measure of geometrical strength, it can also be used to selectively choose four satellites in a particular constellation that will provide the best solution (U.S. Army Corps of Engineers, 1996; Strang *et al.*, 1997; Gladstone, 2006). In general, DOP values below 4 indicate excellent observation conditions (Oppliger, 2007). Jon's interpretation of DOP values (<http://www.developerfusion.com>) include: 1 = ideal; 2-3 = excellent; 4-6 = good; 7-8 = moderate; 9-20 = fair; 21-50 = poor.

The DOP factors used in satellite positioning are derived from the diagonal elements of the inverse of the normal matrix of the observation. The normal matrix is computed as part of standard GNSS navigation solutions during the post processing of observed data. The navigation solution is based on the measured Coarse Acquisition Code Pseudo

ranges and solves for the 3-D receiver coordinates (X, Y, Z) and the receivers clock offset (dT) using the least squares algorithm. In the least squares solutions, the inverse of the normal matrix is, of course, the variance matrix of the estimated parameters and therefore takes the form of equation (1) (Langley, 1999; Misra & Enge, 2001).

$$Q_{xx} = \begin{bmatrix} \sigma_X^2 & \sigma_{YX} & \sigma_{ZX} & \sigma_{TX} \\ \sigma_{XY} & \sigma_Y^2 & \sigma_{ZY} & \sigma_{TY} \\ \sigma_{XZ} & \sigma_{YZ} & \sigma_Z^2 & \sigma_{TZ} \\ \sigma_{XT} & \sigma_{YT} & \sigma_{ZT} & \sigma_T^2 \end{bmatrix} = \begin{bmatrix} \sigma_E^2 & \sigma_{EN} & \sigma_{Eh} & \sigma_{EdT} \\ \sigma_{EN} & \sigma_N^2 & \sigma_{Nh} & \sigma_{NdT} \\ \sigma_{Eh} & \sigma_{Nh} & \sigma_h^2 & \sigma_{hdT} \\ \sigma_{EdT} & \sigma_{NdT} & \sigma_{hdT} & \sigma_{dT}^2 \end{bmatrix} \quad (1)$$

Where,

$$TDOP = \sigma_{dT} \quad (2)$$

$$VDOP = \sigma_h \quad (3)$$

$$HDOP = (\sigma_E^2 + \sigma_N^2)^{1/2} \quad (4)$$

$$PDOP = (\sigma_E^2 + \sigma_N^2 + \sigma_h^2)^{1/2} = (\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2)^{1/2} \quad (5)$$

$$GDOP = (\sigma_E^2 + \sigma_N^2 + \sigma_h^2 + c\sigma_{dT}^2)^{1/2} = (\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2 + c\sigma_{dT}^2)^{1/2} \quad (6)$$

c = velocity of light ( $\approx 3.0 \times 10^8 \text{ m/s}^2$ )

### ***Statement of Problem***

The ground receiving station network (GRSN) allows for data access and provision of highly-accurate ephemerides earth-centered inertial (ECI) coordinates, satellite sub-point (latitude, longitude, and altitude for non-spherical earth), look angles (azimuth, elevation, range, and range rate), and right ascension and declination. One major outlet of satellite data distribution from the Indian Cartosat-1 Spacecraft is the Indian Remote Sensing (IRS) International Ground Stations operating in various parts of the World (<http://www.nrса.gov.in>). The establishment of ground receiving stations elsewhere in Nigeria and other parts of the globe, similar to the IRS model will enhance global tele-commands, data transmission and distribution of NigeriaSat imageries, and lead to global-scale data awareness, usage and higher financial returns.

GNSS technology plays strong role in the selection of suitable ground station location through sky visibility and DOP analysis, precise determination and monitoring of orbital elements of Low Earth Orbit Satellites (LEOS), determination of unpredictable spacecraft trajectories, leveraging on GNSS continuous coverage and great accuracy (*when spacecrafts are performing frequent maneuvers or flying at very low altitudes their flight modes may sometimes be so unpredictable*), and computation of the relative position of two spacecrafts (e.g. N-2 and N-X) using relative or differential modes of GNSS receivers. In view of this, it is therefore imperative to use the GNSS CORS infrastructure in Nigeria and associated International GNSS Service (IGS) facilities to plan and select the optimal ground stations for Nigeria space programme.

### ***Aim and Objectives of Study***

The study aims at applying the GNSS sky visibility planning and dilution of precision analysis for EOS ground station selection for Nigerian space programme. The objectives of the study are to:

- i. carry out the sky visibility analysis at elevation cutoff angles of  $10^\circ$ ,  $12^\circ$  and  $15^\circ$  using satellite visibility planning technique;
- ii. carry out the multiple and single station dilution of precisions (DOPs) analysis of eleven (11) Nigeria Geodetic Network (NigNet) GNSS COR stations in Nigeria at elevation cutoff angles of  $10^\circ$ ,  $12^\circ$  and  $15^\circ$  respectively;
- iii. use the DOPs and satellite visibility analysis to identify and select suitable locations for ground receiving antenna in Nigeria, in addition to the existing one at the National Space Research and Development Agency (NASRDA) in Abuja;

- iv. articulate strategies to mitigate signal obstruction and interferences in GRSN locations and operations for the Nigeria space programme.

### ***Nigeria's Ground Station Facility and Satellites in Orbit***

The NigeriaSat-2 and NigeriaSat-X have two common ground stations located in Surrey, UK and NASRDA, Abuja receptively. The satellites are routinely tracked by the two ground stations, with a satellite pass in about 3-4days for N-2 and N-X in 3-5 satellites days interval. The integrated Ground Station Telemetry Tracking and Control (TTC) also consists of GPS\_Receivers (*onboard N-2 and N-X*, and operated at the ground simultaneously) to create reference frame of the satellite, and the Inertial Reference Unit (IRU) to record attitude variations (*pitch, roll and yaw*) of the platform; required for satellite orbit's attitude corrections. Parameters involved in typical command links include changes and corrections in attitude control and orbital control, antenna pointing and control, transponder mode of operation and battery voltage control.

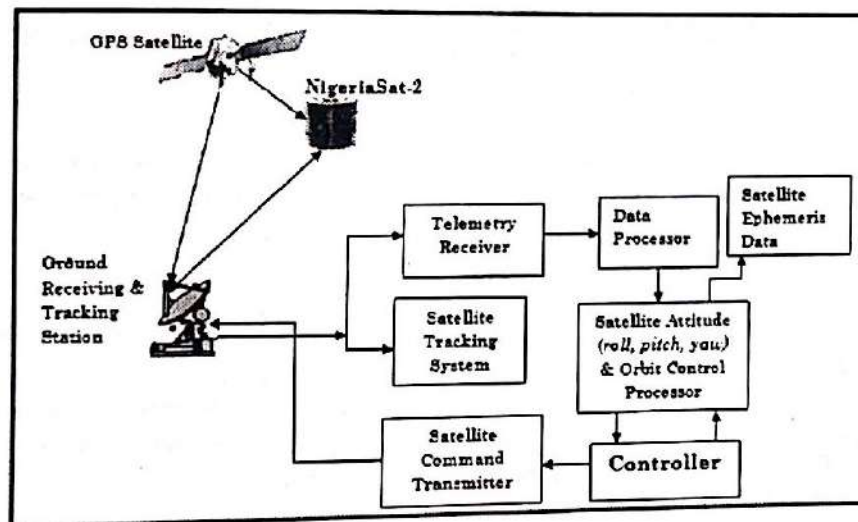


Figure 1.2: A Model of Tracking and Control Functional Elements for the NigeriaSat at NASRDA, Abuja, Nigeria (Source: Authors' Design).

### ***NigeriaSat Infrastructure***

The NigeriaSat infrastructure is comprised of the NigeriaSat-2 (N-2) and NigeriaSat-X (N-X) spacecrafts, Mission Control Centre [Mission Control Suite (MCS), Ground Station (GS) and the Mission Operations Centre (MOC)], Communication and Power Control Systems, etc. N-2 and N-X are polar orbiting, Low Earth Observation Satellites (LEOS) at an altitude of about 700km. The Payload of NigeriaSat-2 is Camera-based, comprising 2.5m ground sampling distance (GSD) panchromatic

(very high resolution); 5.0m GSD (high resolution) in four (4) spectral bands and 32m GSD also in 4 spectral bands (Red, Green, Blue and NIR) (medium resolution). On the other hand, the NigeriaSat-X is a multi-spectral system with sensors in three (3) spectral bands (Red, Green and Blue) with images of 22m GSD (<http://www.sstl.co.uk>; Chizea et al, undated; Tamunopekerebia et al, 2009).

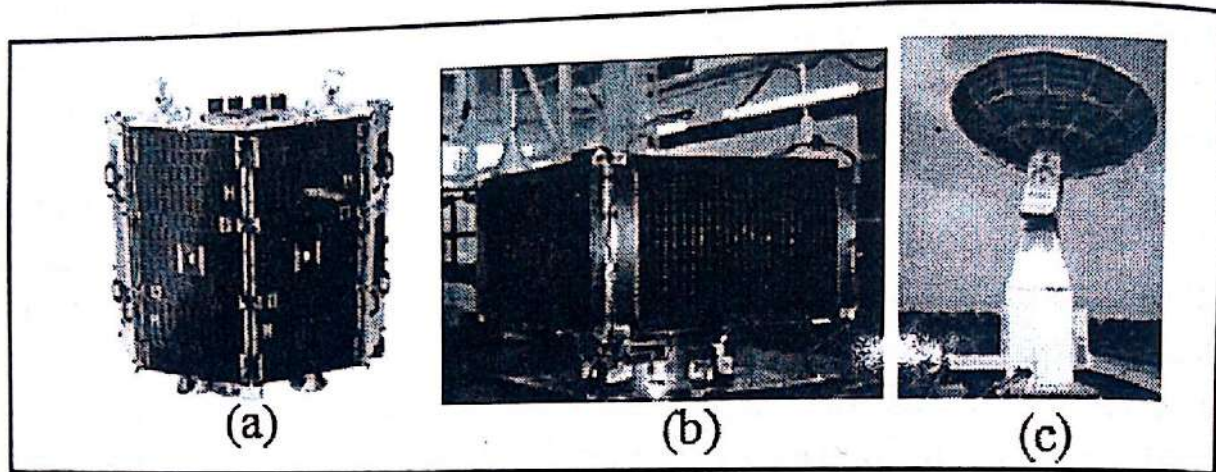


Figure 1.3(a, b and c): The NigeriaSat Spacecrafts and Ground Station Antenna [a, b: N-2, N-X (<http://www.sstl.co.uk>); c: GS Antenna at NASRDA, Abuja (source: Authors' field work)].

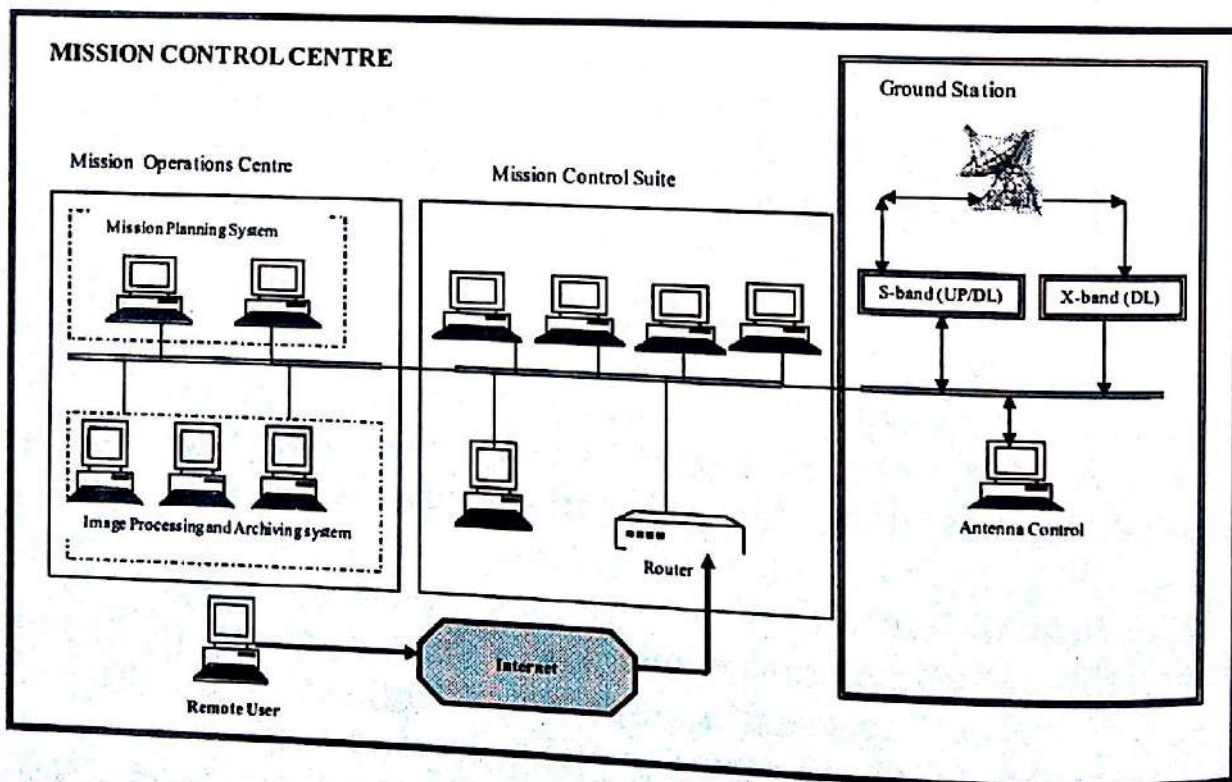


Figure 1. 4. Mission Control Centre (Source: Chizea et al, undated)

## **Materials and Methods**

### ***Data Collection and Sources***

The dataset used is a collection of NigNet RINEX data for nine (9) COR Stations observed in February 2012 and obtained from the Office of the Surveyor General of the Federation (OSGoF) Nigeria, and International GNSS Service (IGS) Navigation Data (<http://igs.org>; <http://igscb.jpl.nasa.gov/>).

### ***Description of NigNet CORS***

The NigNet CORS came into existence in 2008 and since then the number of stations have increased gradually to eleven (11) as of April 2011 (<http://www.nignet.net>). The CORS were established by the Office of the Surveyor General of the Federation (OSGF). The eleven (11) NigNet COR Stations already installed and operational are located in: Abuja (OSGoF), Port Harcourt (RUST), Gembu (GEMB), Lagos (ULAG), Kebbi ), Zaria (ABUZ), Yola (FUTY), Enugu (UNEC), Calabar (UCAL), Toro (CGGT) and Maiduguri (RAMPOLY).

### ***Ground Station Site Selection Procedure with GNSS***

Generally, the factors used for selecting ground receiving stations include geographic location, ground elevation, sky visibility, site's geology and structural stability, antenna diameter, power and communication facilities, security, Internet and data access, weather and climate, etc. The site selection was based on satellite sky visibility planning and dilution of precision. This is because signals from satellites behave in similar pattern in the atmosphere; so poor visibility in GNSS signal in a particular observation window translates relatively to poor orbit definition signal for the EOS. The ground elevation, geographical locations (coordinates) and local mean time (LMT) were used for generating the sky visibility and DOPs criteria for site selection procedure in this study.

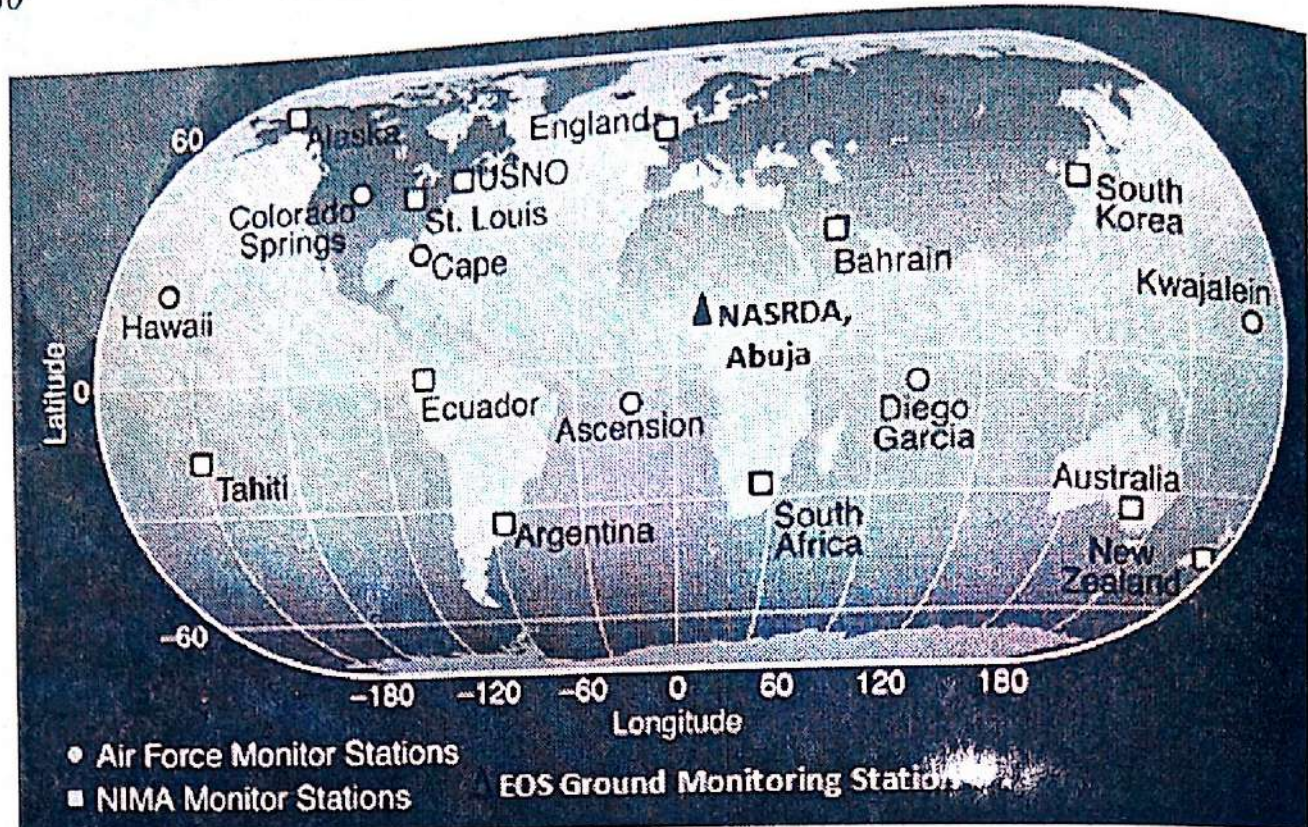


Figure 2.3: GPS Monitoring Stations, NIMA Tracking Stations across the globe and NigeriaSat Ground Monitoring Station (Modified after Langer et al, 2002)

To schedule GNSS operations for effective EOS operations and maintenance, the following factors, amongst others need to be considered:

- i. From the ground stations, satellites are not normally tracked below an elevation of  $10^\circ$  to  $20^\circ$  due to large atmospheric refraction and interference errors at lower elevation angles.
- ii. There is a 24 hour observation window for GNSS, but not possible for EOS
- iii. There are periods when many more satellites are visible than the other due to climatic factors.
- iv. The satellites' positions in the sky are predictable. They can be computed and output in a convenient graphical form, and taken out into the field during reconnaissance.

### ***Data Preparation and Processing***

The NigNet RINEX data for February 2010 were prepared and processed at intervals of 10seconds. Fixed solution, ionospheric free computations and biased adjustment of the baselines and station coordinates were carried out using Trimble Total Control Software.

### ***Sky Visibility and DOPs Computation***

The multistation sky visibility plots for the entire 11 selected points were carried out for three different elevation cutoff angles of  $10^\circ$ ,  $12^\circ$  and  $15^\circ$  respectively using Trimble Total Control software. This approach is to simulate the availability of the Global Navigation Satellites System during station and space craft tracking sessions. The input variables include the 3D spatial coordinates (latitude, longitude, and ellipsoidal height) of the stations, time and period of observation (06hr-24hrs/28 days of February 2012), and cutoff angles of 10, 12 and 15 degrees. Similarly, the mean DOPs values were computed for the same stations at elevation cutoff angles of  $10^\circ$ ,  $12^\circ$  and  $15^\circ$  respectively for the same period of observations. A popular representation of satellite availability is the skyplot, which is a plot of satellite tracks on a zenithal projection centered at the ground station. The satellite azimuth and elevation are functions of time.

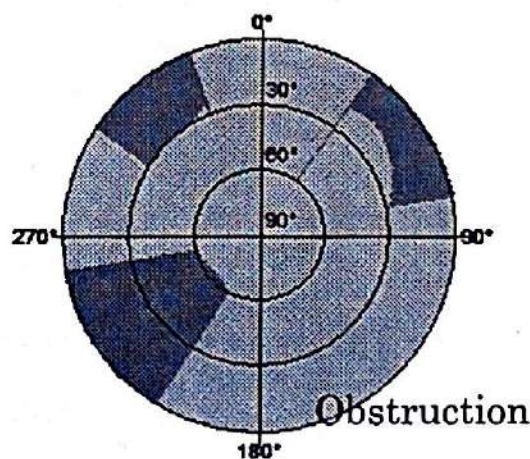


Figure 2.4: A sample of satellite signal obstructions (*shadow regions*) on a skyplot

## **Results and Discussion**

### ***Results***

Table 3.1 shows the post-processed curvilinear coordinates ( $\phi$ ,  $\lambda$ ,  $h$ ) of nine of the eleven NigNet reference controls in Nigeria. The relevance of these points to the selection of ground station is that they provide the frame work for baseline and spatial analysis in relation to the NASRDA Satellite Ground Stations in Abuja, Nigeria.

Table 3.1: The adjusted reference points in WGS84 (geographical coordinates and std. dev.)

| Point | Latitude( $\square$ )  | $\sigma$ (mm) | Longitude( $\lambda$ ) | $\sigma$ (mm) | Height (m) | $\sigma$ (mm) |
|-------|------------------------|---------------|------------------------|---------------|------------|---------------|
| ABUZ  | N 11° 09'<br>06.26225" | 0.0           | E 7° 38'<br>55.22929"  | 0.0           | 705.4601   | 0.0           |
| BKFP  | N 12° 28'<br>06.87297" | 2.7           | E 4° 13'<br>45.22956"  | 6.8           | 250.5099   | 8.5           |
| CGGT  | N 10° 07'<br>23.14085" | 1.2           | E 9° 07'<br>05.87589"  | 1.6           | 916.7853   | 5.2           |
| FUTY  | N 9° 20'<br>59.07440"  | 3.2           | E 12° 29'<br>52.02238" | 9.0           | 247.6116   | 9.9           |
| GEMB  | N 6° 55'<br>01.92069"  | 3.5           | E 11° 11'<br>02.13748" | 7.7           | 1795.7857  | 10.5          |
| OSGF  | N 9° 01'<br>39.59767"  | 1.6           | E 7° 29'<br>10.78586"  | 1.7           | 532.9498   | 6.1           |
| RUST  | N 4° 48'<br>06.61408"  | 5.4           | E 6° 58'<br>42.63372"  | 12.3          | 45.5320    | 17.0          |
| ULAG  | N 6° 31'<br>02.37835"  | 3.1           | E 3° 23'<br>51.40406"  | 8.0           | 44.7918    | 10.6          |
| UNEC  | N 6° 25'<br>29.30450"  | 3.1           | E 7° 30'<br>17.92300"  | 5.9           | 254.4941   | 10.5          |

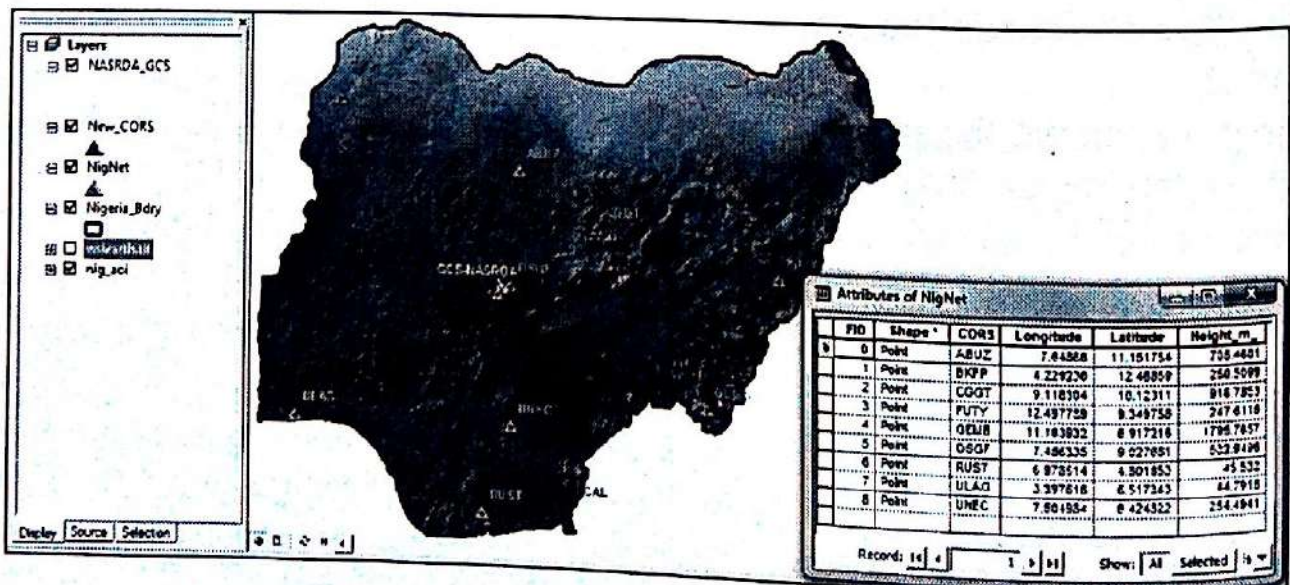


Figure 3.1: NigNet Stations and NigeriaSat Ground Station at NASRDA, Abuja

Figures 3.2a-c show the multistation sky visibility chart for the elevation cutoff angles  $15^\circ$ ,  $12^\circ$  and  $10^\circ$  respectively. On the other hand, figures 3.3a-b show the single station sky visibility plan for GEMB station at both  $15^\circ$  and  $10^\circ$  elevation cutoff angles.

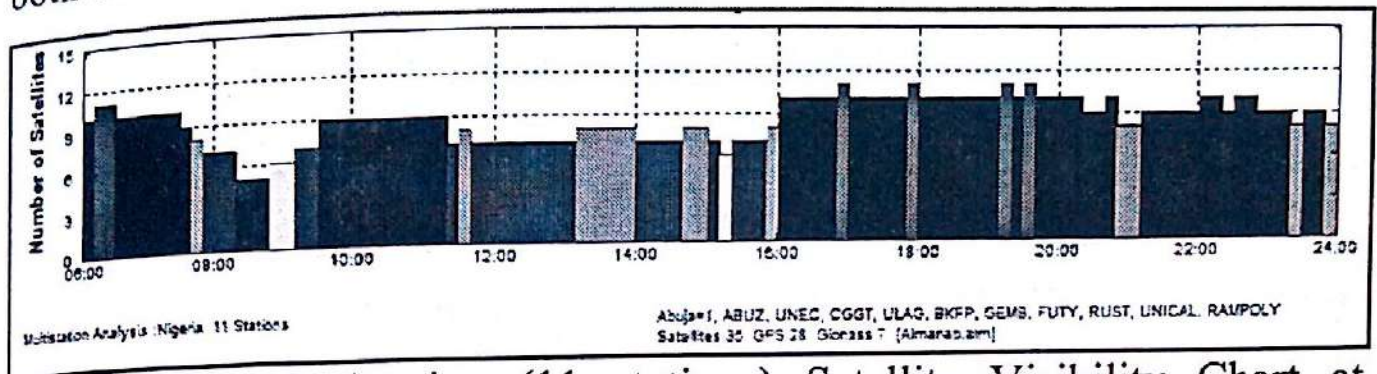


Figure 3.2a: Multistation (11 stations) Satellite Visibility Chart at Elevation Cutoff Angle of  $15^\circ$

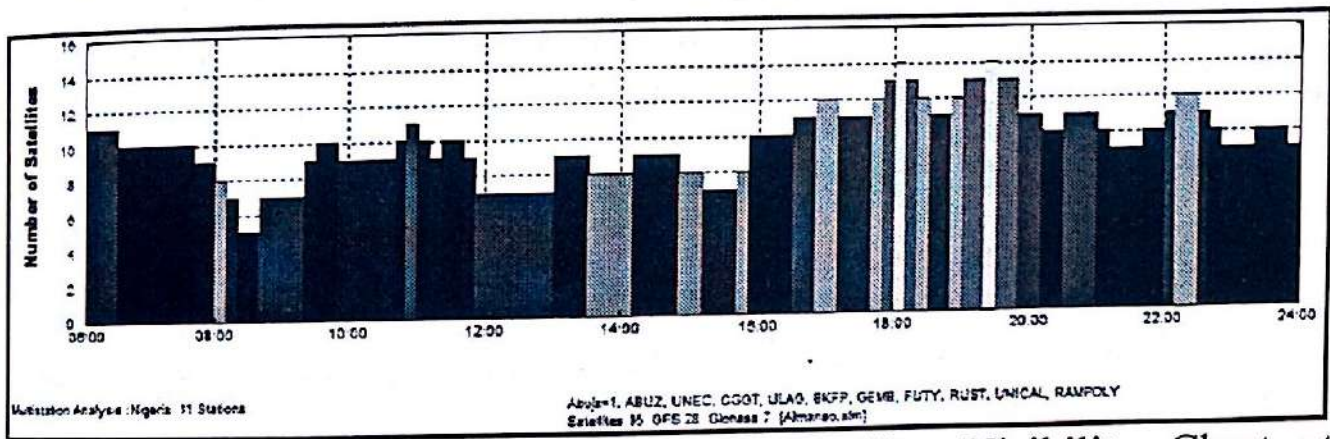


Figure 3.2b: Multistation (11 stations) Satellite Visibility Chart at Elevation Cutoff Angle of  $12^\circ$

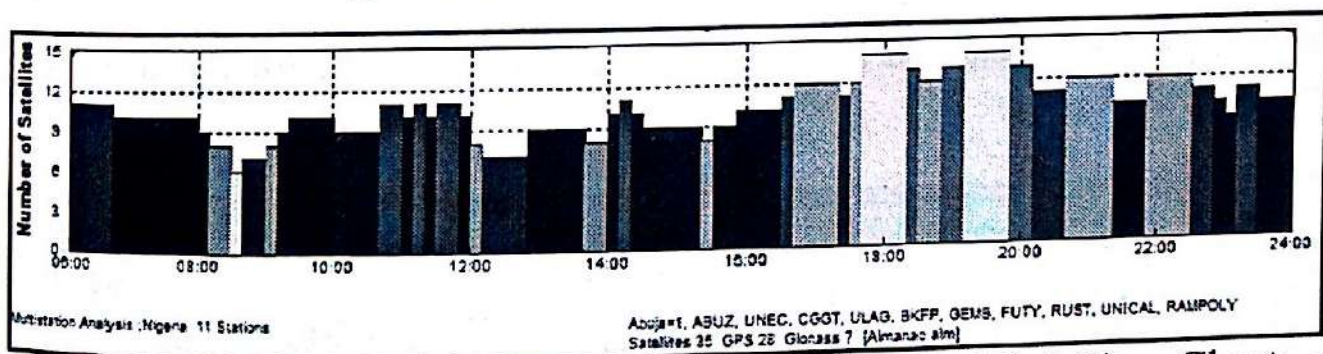


Figure 3.2c: Multistation (11 stations) Satellite Visibility Chart at Elevation Cutoff Angle of  $10^\circ$

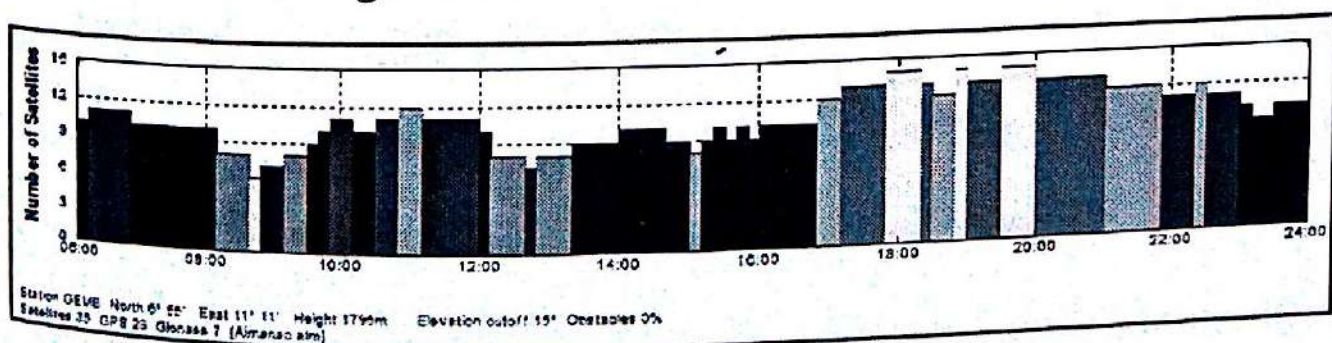


Figure 3.3a: GEMB (Single Station) Satellite Visibility Chart at Elevation Cutoff Angle of  $15^\circ$

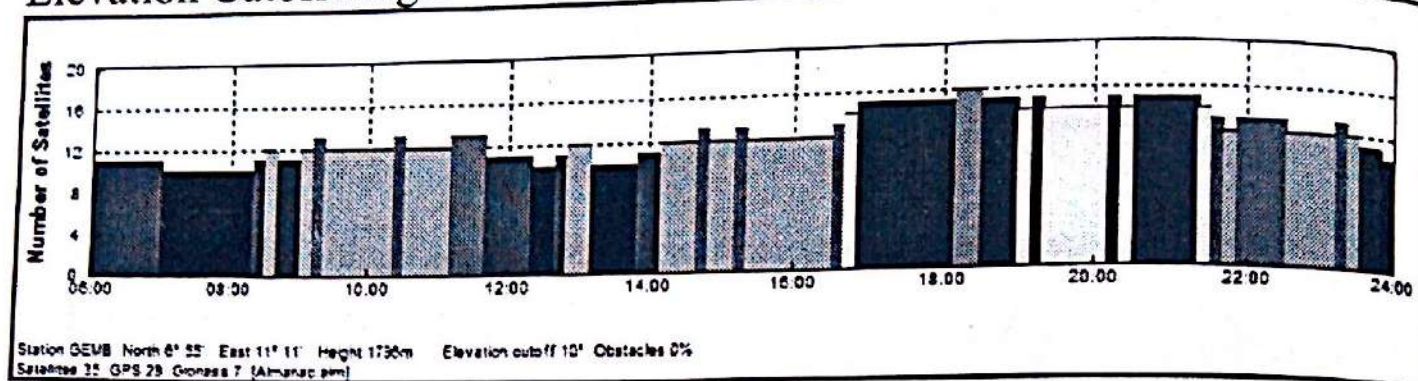


Figure 3.3b: GEMB (Single Station) Satellite Visibility Chart at Elevation Cutoff Angle of  $10^\circ$

Figures 3.4a-c show the multistation (11 stations) DOPs at elevation cutoff angles of  $15^\circ$ ,  $12^\circ$  and  $10^\circ$  respectively. The single station DOPs for each of the 11 stations in the network are shown in figures 3.5a-k.

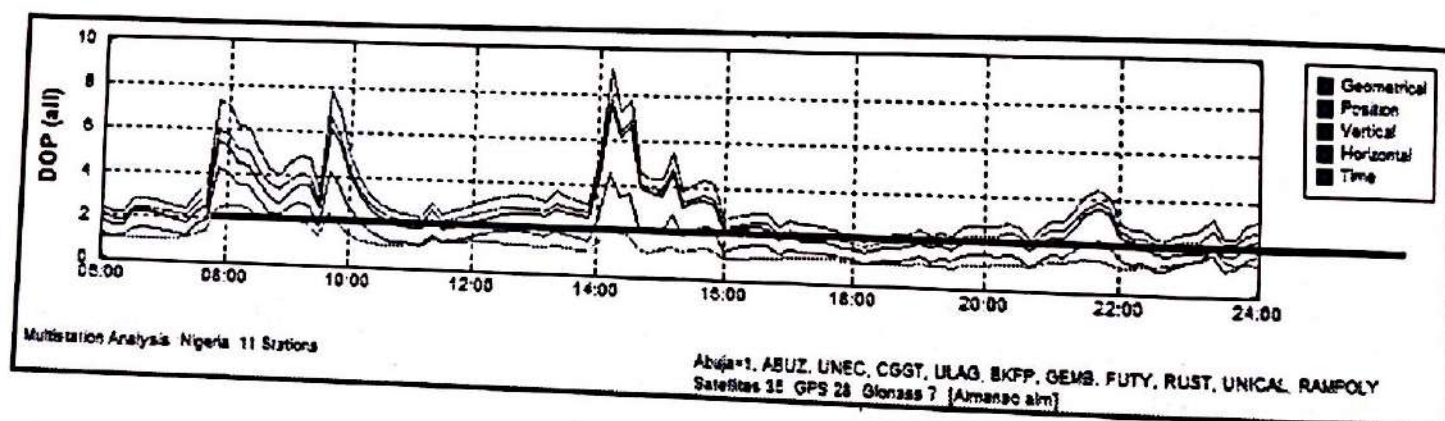


Figure 3.4a: Multistation (11 Stations) Mean DOPs at Elevation Cutoff Angle of  $15^\circ$

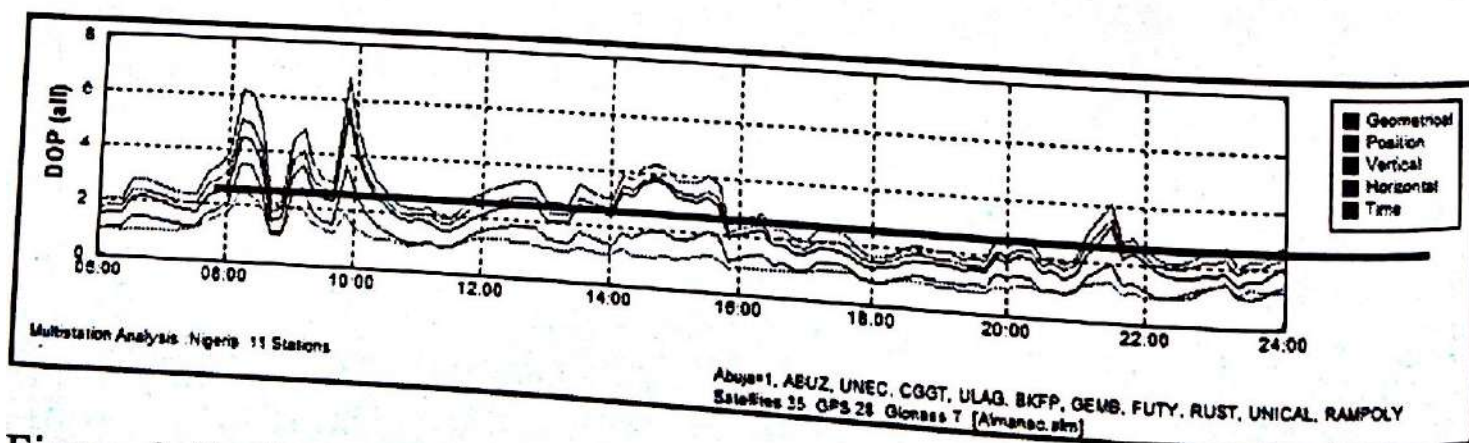


Figure 3.4b: Multistation (11 Stations) Mean DOPs at Elevation Cutoff Angle of  $12^\circ$

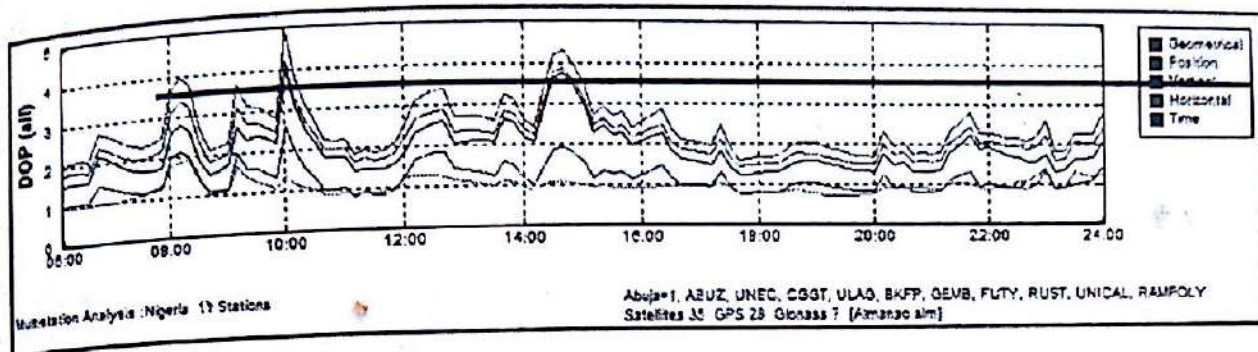


Figure 3.4c: Multistation (11 Stations) Mean DOPs at Elevation Cutoff Angle of  $10^\circ$

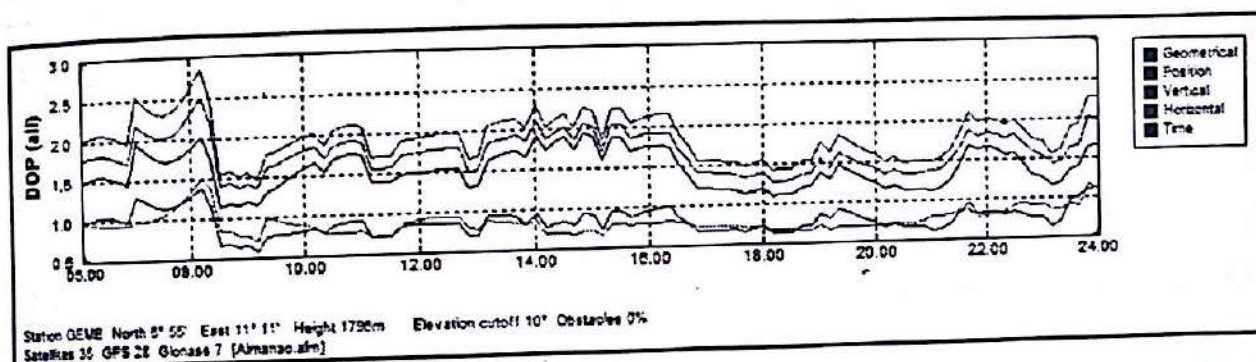


Figure 3.5a: GEMB (Single Station) DOP at Elevation Cutoff Angle of  $10^\circ$  [all round GDOP  $\leq 2.8$  (Overall Best DOPs)]

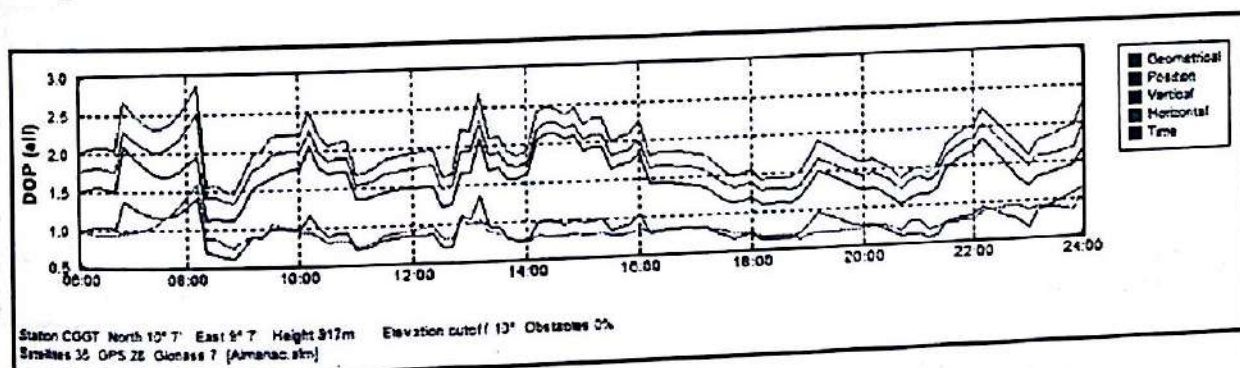


Figure 3.5b: CGGT (Single Station) DOP at Elevation Cutoff Angle of  $10^\circ$  [all round GDOP  $\leq 2.9$ ]

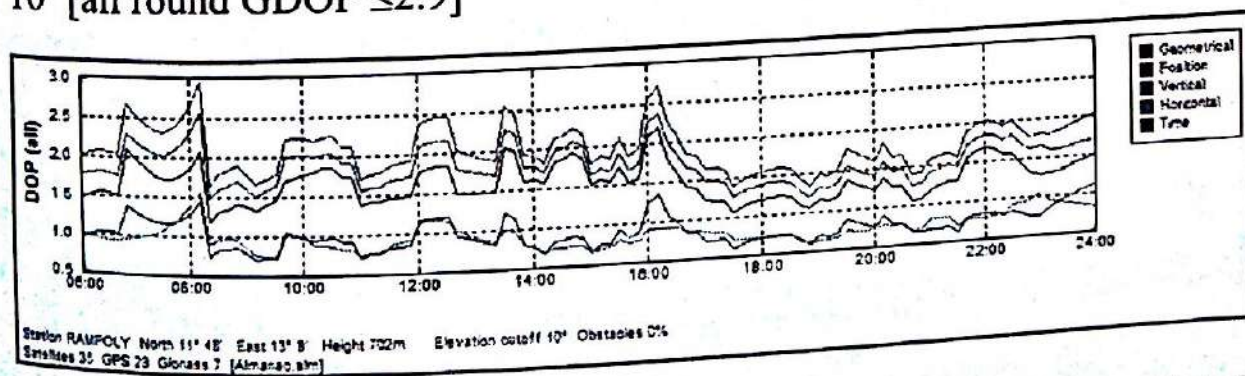


Figure 3.5c: RAMPOLY (Single Station) DOP at Elevation Cutoff Angle of  $10^\circ$  [all round GDOP  $\leq 2.9$ ]

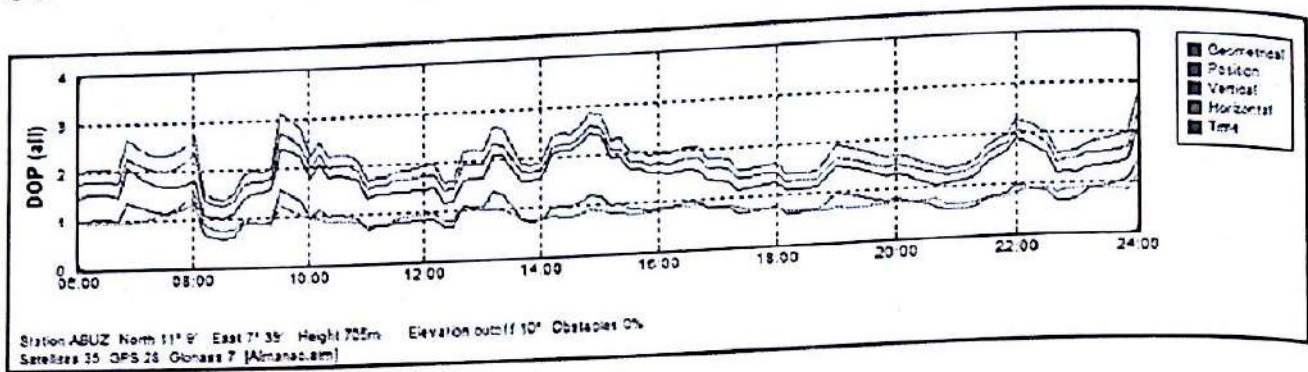


Figure 3.5d: ABUZ (Single Station) DOP at Elevation Cutoff Angle of  $10^\circ$  [all round GDOP  $\leq 3.0$ ]

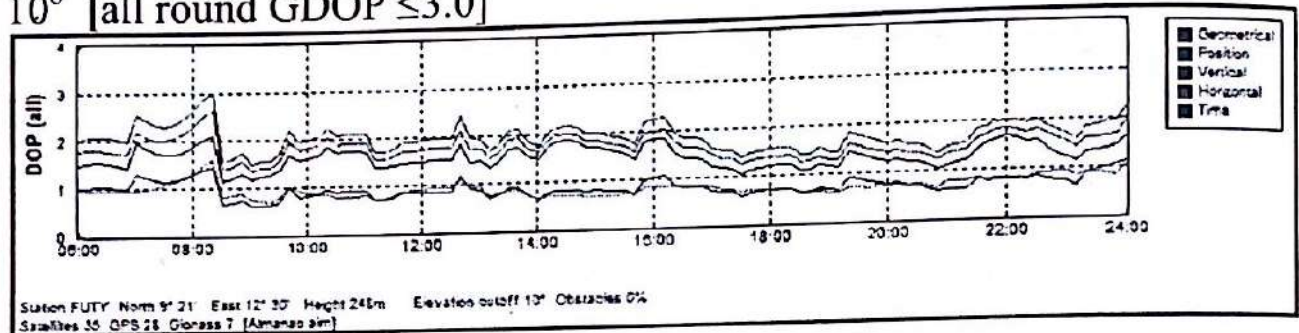


Figure 3.5e: FUTY (Single Station) DOP at Elevation Cutoff Angle of  $10^\circ$  [all round GDOP  $\leq 3.0$ ]

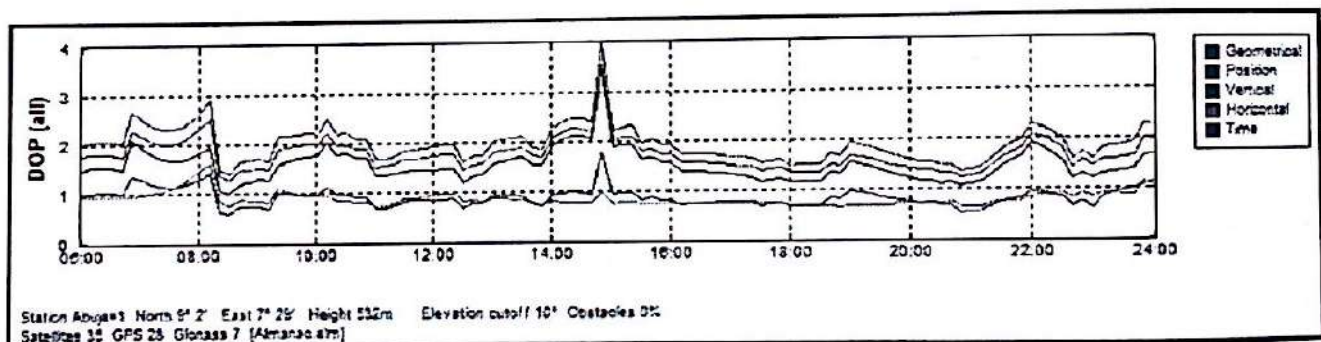


Figure 3.5f: ABUJA-1 (Single Station) DOP at Elevation Cutoff Angle of  $10^\circ$  [all round GDOP  $\leq 3.0$ , but GDOP  $\leq 4.0$  at 14:40-14:50hrs]

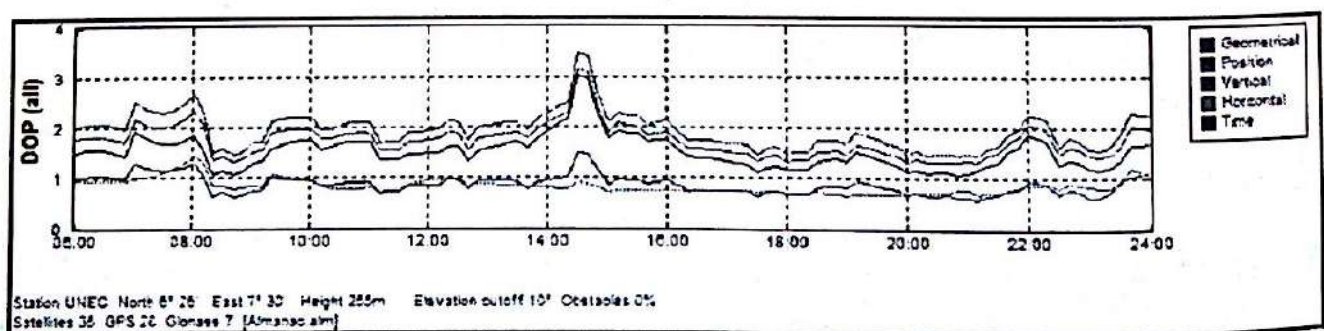


Figure 3.5g: UNEC (Single Station) DOP at Elevation Cutoff Angle of  $10^\circ$  [all round GDOP  $\leq 3.0$ , but GDOP  $\leq 3.4$  at 14:30-14:50hrs]

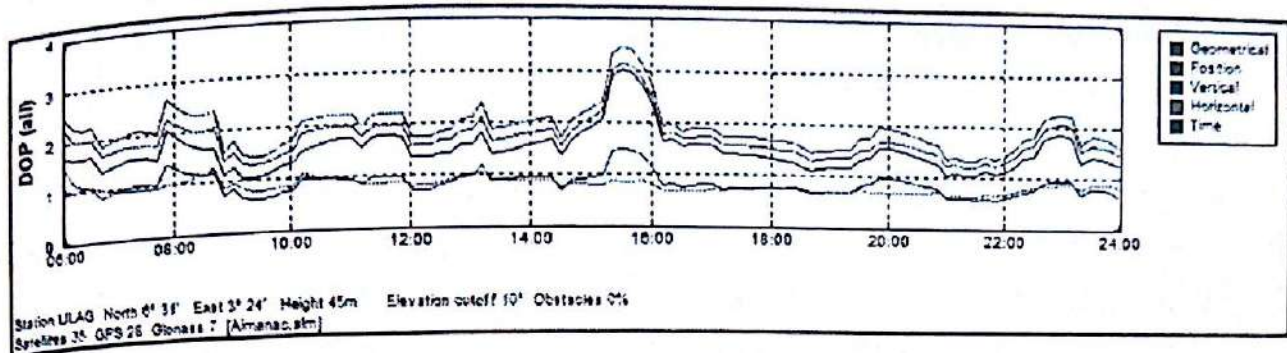


Figure 3.5h: ULAG (Single Station) DOP at Elevation Cutoff Angle of  $10^\circ$  [all round GDOP  $\leq 3.0$ , but GDOP  $\leq 3.3$  at 15:30-16:00hrs]

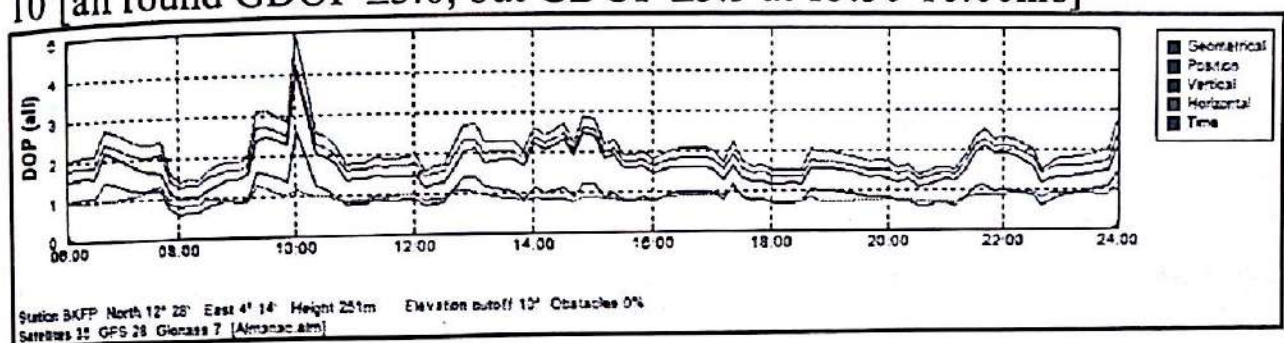


Figure 3.5i: BKFP (Single Station) DOP at Elevation Cutoff Angle of  $10^\circ$  [all round GDOP  $\leq 3.0$ , but GDOP  $\leq 5.0$  at 10:00hrs]

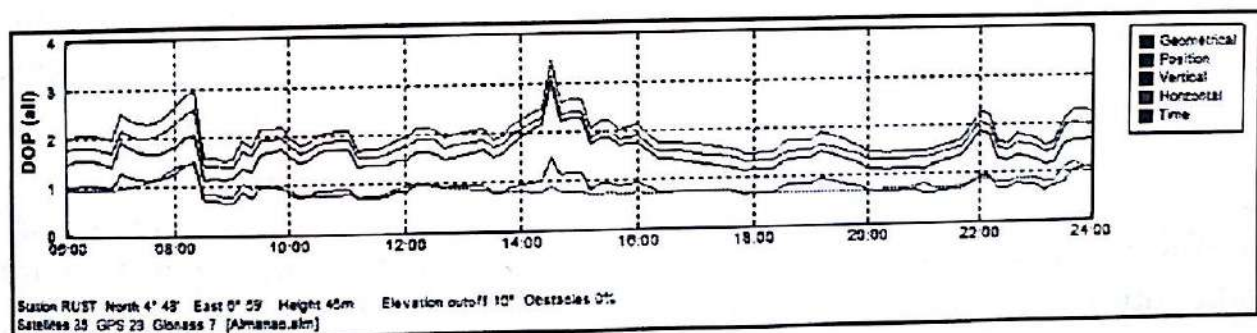


Figure 3.5j: RUST (Single Station) DOP at Elevation Cutoff Angle of  $10^\circ$  [all round GDOP  $\leq 3.0$ , but GDOP  $\leq 3.2$  at 14:40hrs]

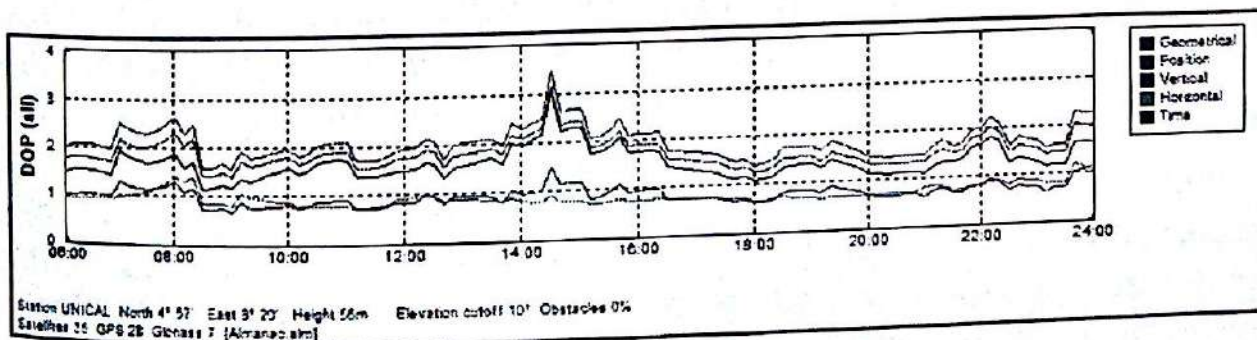


Figure 3.5k: UCAL (Single Station) DOP at Elevation Cutoff Angle of  $10^\circ$  [all round GDOP  $\leq 3.0$ , but GDOP  $\leq 3.2$  at 14:40hrs]

### *Discussion of results*

Table 3.1 shows the ionospheric-free, processed and adjusted WGS84 geographical coordinates with their corresponding standard deviations, while Figure 3.1 shows the geospatial locations of the 9 out of the 11 NigNet CORS on the ITRF-based global earth model (subset for Nigeria). These points provided the frame work for baseline and spatial analysis in relation to the NASRDA Satellite ground stations in Abuja, Nigeria.

The sky visibility planning with the multistation analysis showed that, more satellites are available at the elevation cutoff angle of  $10^\circ$  than those of  $12^\circ$  and  $15^\circ$  respectively. Similarly, the single station sky visibility planning for GEMB station as a test case also showed that, wider view of the sky is possible at elevation cutoff angle of  $10^\circ$  at the station than for higher elevation cutoff angle of  $15^\circ$ . Therefore, if a ground receiving antenna is to be established at Gembu, in Taraba State, it therefore implies that, longer session of satellite signal and telemetry tracking would be possible and enhanced at elevation cutoff angle of  $10^\circ$ , and with 0% obstruction, compared to elevation cutoff angle of  $15^\circ$ . The only potential drawback with low elevation cutoff angle may be the atmospheric refraction effect. From the sky visibility analysis, average of 9 GPS and 2 GLONASS satellites are visible daily to receivers at  $10^\circ$ - $15^\circ$  elevation angles between 6:00hrs and 24:00hrs across Nigeria. The advantage of the skyplots and visibility chart is that, in the actual satellite data tracking, information on possible percentage obstructions becomes useful. If the data quality is poor (usually indicated by the signal-to-noise ratio during operations), the possible source(s) of interference can be identified and appropriate actions taken to assist subsequent data processing.

From figures 3.4a-c, the multistation DOPs analysis for elevation cutoff angle of  $10^\circ$ , recorded excellent results ranging from 0-4, while those of  $12^\circ$  recorded similar results, but with slight decline between the hours of 8:00am and 10:00 am. For elevation cutoff angle of  $15^\circ$ , the DOP values declined to between 4-9 for the time period of 8:00am to 10:00am, and 14:00hrs to 16:00hrs, while other hours of the days recorded DOP values  $\leq 3.0$ . On a general note, the interpretations of the multistation of the DOP values indicated ideal to fair values. DOP is a measure of satellite fix geometry quality, which is a product of signal travel time, overhead satellite geometry and the ranged positions (horizontal and vertical).

The individual station DOP analysis showed that, GEMB in Gembu, Taraba State on ellipsoidal height of 1795.7857m has the best DOP values of  $\leq 2.8$ , followed by both CGGT in Toro, Bauchi State on ellipsoidal height of 916.7853, and RAMPOLY, Maiduguri, Borno State on ellipsoidal height of about 702m with DOP values  $\leq 2.9$  respectively. ABUZ in Zaria, Kaduna state and FUTY in Yola, Adamawa State, located on ellipsoidal heights of 705.4601m and 247.6116m respectively recorded DOP values of  $\leq 3.0$ . ABUJA-1 in Abuja, RUST in PortHarcourt, ULAG in Lagos, UNEC in Enugu, UCAL in Calabar and BKFP in Birnin Kebbi showed DOP values of  $\leq 3.0$  at all times, excluding hours of 10:00am and 14:00-16:00hrs with values ranging between 3.2 and 5.0.

For Earth observation satellite system, the quality of satellite signal or telemetry at a the ground receiving station may be significantly compromised by *permanent scene cloud cover, interferences from spectrum and signal propagation* activities near or around the site, which sometimes results in broken images and creation of artifacts. Therefore, the establishment of ground station based on excellent sky visibility and DOP will favour high telemetry signal reception and quality data access in Nigeria. In the case of ground stations in other countries of the world, bilateral agreements or scientific collaborations between the affected countries and Nigeria are necessary conditions, in addition to the geospatial and infrastructural criteria.

### **Summary of Findings**

The key findings from the study are summarised as follows:

1. Based on Jon's rating of DOP values [1= ideal; 2-3 = excellent; 4-6 =good; 7-8= moderate; 9-20=fair; 21-50= poor (<http://www.developerfusion.com>)], the DOP values for the stations across Nigeria can be adjudged to range between excellent and good for satellite ground receiving stations;
2. The DOP and sky visibility for satellite observations at elevation cutoff angles of  $10^\circ$  are better than those of  $12^\circ$  and  $15^\circ$  respectively;
3. GEMB on ellipsoidal heights of 1795.7857m has the most suitable DOPs and sky visibility chart for ground receiving sites; followed by CGG Toro (916.7853m) and RAMPOLY Maiduguri (702m). This is a strong indication that, ellipsoidal heights and geographical locations are key factors in achieving excellent DOP and sky visibility for very good satellite observations

4. From the sky visibility analysis, average of 9 GPS and 2 GLONASS satellites are visible daily to receivers at  $10^{\circ}$ - $15^{\circ}$  elevation angles between 6:00hrs and 24:00hrs across Nigeria;

### **Conclusion**

In this study, satellite observation planning technique was used to generate multiple and single stations sky visibility and dilution of precision analysis as vital criteria and preliminary decision support for satellite ground station site selection in Nigeria. The key datasets and materials used include the geographical coordinates, ground elevation, local mean time, elevation cutoff angles, GPS and GLONASS constellations for a period of one month. The technique therefore, produced excellent results, which were used to rank and select most suitable locations for ground receiving antenna in Nigeria, in addition to the existing one at the National Space Research and Development Agency (NASRDA) in Abuja.

However, it should be noted that, this approach of sky visibility and DOP analysis does not provide the final criteria for ground receiving antenna selection; hence other key factors such as the site's geology and structural stability, antenna diameter, power and communication facilities, security, Internet and data access, weather and climate variability, etc, must be considered in an integrated manner. In case of international ground stations, bilateral agreements and scientific collaborations between the affected countries and Nigeria are additional requirements.

### **Recommendations**

The following are hereby recommended:

- i. In order to avoid signal obstruction and interferences at GRS in Nigeria, the stations should be located on elevated ground outside city centres and regions free of telecommunication masts and tall building structures and towers;
- ii. Elevation cutoff angle of  $10^{\circ}$  from the horizon should be implemented in ground receiving station selection in Nigeria.
- iii. This approach should be adopted for the Nigerian space programme in EOS ground-based antennae farm establishment, and for the densification of GNSS reference stations by public-private organizations involved in geoinformation development, geodetic and atmospheric research, engineering infrastructure

tracking and navigation at state and local government levels across the country.

- iv. Before selecting an acceptable site and to be fixed with certainty for satellite tracking or ground station, several stations of interest should be sampled, as there may be many candidate locations with similar geospatial characteristics suitable for the desired station.
- v. Other key factors such as the ground stability, security, power and communication infrastructure in the phases of ground station site analysis and selection must not be compromised.

### Acknowledgements

We appreciate the Office of the Surveyor General of the Federation (OSGoF) for the implementation of the CORS infrastructure for Nigeria, and freely providing the RINEX data of the existing CORS on the NigNet website (<http://www.nignet.net>). Thanks to the International GNSS Service (IGS) for providing the orbit/navigation data used for the post processing of the CORS data. The authors wish to acknowledge NASRDA, Abuja for the Ground Station Infrastructure for NigeriaSat-2/X.

### References

- Dow, J.M., Martin Mur, T.J., Romay Merino, M.M., (1994).ESA's Precise Orbit Determination Facility, *ESA Bulletin* No. 78, May.
- Chizea, F. D. and J. I. Ejimanya, J. I., (undated). NigeriaSat-2: Technical Parameters, Operational Perspectives and Target Applications. [http://www.nasrda.net/Earth\\_Future/NigeriaSat\\_2\\_Paper3.doc](http://www.nasrda.net/Earth_Future/NigeriaSat_2_Paper3.doc)
- Cox, J., Chao, C. C., Stephens P. W., and Warner, L. F., (2000).Optical Tracker and S-Band Ranging Utility for Accurate Orbit Determination and Prediction. *Proceedings, AAS/AIAA Space Flight Mechanics Meeting*, Paper AAS 00-116 (January 23–26).
- ESA, (2008). Villafranca Ground Station. [http://www.esa.int/esaMI/ESAC/SEM\\_8FXNZCIE\\_0.html](http://www.esa.int/esaMI/ESAC/SEM_8FXNZCIE_0.html). European Space Agency.
- Earth Remote Sensing Data Analysis Center (ERSDAC) (2010). Earth Observation Satellites. Seminar Room.
- Federici, B., Giacomelli, D., Sguerso, D., Vitti, A., Zatelli, P. (2010) A Web Processing Service for GNSS Realistic Planning. [www.isprs.org/proceedings/xxxviii/4-W13/ID\\_10.pdf](http://www.isprs.org/proceedings/xxxviii/4-W13/ID_10.pdf). Comm. IV/5

- Federici, B. and Sguerso, D., (2009). Planning GNSS realistico per applicazioni statiche e cinematiche. Bollettino SIFET session scientifica, ISSN: 1721-971X 1(1), pp. 79-93.
- Fruet, G., Sguerso, D. and Zatelli, P., (1999). Planning GPS automatico con ostruzioni realistiche. In: Atti del convegno: a Conferenza nazionale delle Associazioni Scientifiche per le Informazioni Territoriali ed Ambientali, Napoli.
- Gladstone, P. (2006). *NAVSTAR GPS: Overview of GPS and Absolute Positioning*. Chapter 8.
- Hauschild André (Undated). Near-Real-Time Orbit Determination of LEO Satellites DLR/GSOC, Oberpfaffenhofen, Germany.
- Hauschild, A. and Montenbruck, O. (2008). Real-time Clock Estimation for Precise Orbit Determination of LEO Satellites, *ION GNSS*, Savannah, Georgia, USA,  
<http://www.developerfusion.com>  
<http://igs.org>  
<http://igscb.jpl.nasa.gov/>  
<http://www.nignet.net>. Nigeria CORS Network. Provided by the Office of the Surveyor-General of the Federation (OSGoF), Federal Republic of Nigeria.
- [http://nng.esoc.esa.de/gps/onboard\\_gps.html](http://nng.esoc.esa.de/gps/onboard_gps.html) On-board GPS  
[http://nng.esoc.esa.de/gps/onboard\\_gps.html](http://nng.esoc.esa.de/gps/onboard_gps.html)
- <http://www.nrsea.gov.in>. CartoSat-1: A Global IRS Mission for Large Scale Mapping and Terrain Modeling Applications. National Remote Sensing Agency (NRSA) of India. Pp. 1-8.
- <http://www.sstl.co.uk>. NigeriaSat-2 Mission Objectives. Surrey Satellite Technology Limited. Accessed on 10/08/2011
- Langer, J., Powell, T., and Cox, J., (2002). Orbit Determination and Satellite Navigation.  
<http://www.aero.org/publications/crosslink/summer2002/04.html>
- Langer, J. V., Feess, W. A., Harrington, K. M., Bacigalupi, M. R. Mach, R. G., Abusali, P. A. M. and Cardoza, M. A., (1994). RADCAL: Precision Orbit Determination with a Commercial-Grade GPS Receiver. *Proc. of the 1994 Institute of Navigation National Technical Meeting*, San Diego, Jan).
- Langley, B. R., (1999). Dilution of Precision. *GPS World*, May 1999.  
[www.gpsworld.com](http://www.gpsworld.com) Pp. 52-59
- Misra, P., and Enge, P. (2001). Global Positioning System, Signals, Measurements, and Performance.

- Ojigi, M. L., (2012). Orbit Stability Analysis of NigeriaSat-1 Spacecraft Using Predicted Two Line Element Sets Data for 2004-2010. *Nigerian Journal of Surveying & Geoinformatics*. 4/1, March 2012. A Technical Publication of Nigerian Institution of Surveyors (NIS). ISSN: 0189-8914.. 39-54.
- Oppliger, G. (2007). Differential and precision GPS surveying for sub-meter and centimeter accuracy. Feb. [crack.seismo.unr.edu/ftp/pub/louie/./GEOL493\\_Lec14\\_GPS\\_glo.ppt](http://crack.seismo.unr.edu/ftp/pub/louie/./GEOL493_Lec14_GPS_glo.ppt). (Accessed: 22-08-13)
- Sguerso, D. and Zatelli, P., (1999). Planning of kinematic GPS including realistic obstacles description. In: XXII General Assembly of IUGG, Birmingham, UK.
- Strang, G and Borre, K., (1997). *Linear Algebra, Geodesy, and GPS*, Wellesley-Cambridge Press, 1997.
- Tamunopekerebia, O., Chizea, F., Madalla, F., Lawal, A., Ezeoke, N., (2009). The NigeriaSat-X Project. A paper presented at the 2<sup>nd</sup> IAA Conference, Abuja, Nigeria. 10pp.
- U.S. Army Corps of Engineers (1996). NAVSTAR Global Positioning System Surveying, Department of the Army, Engineer Manual EM 1110-1-1003, Washington, DC 20314-1000
- Zatelli, P. and D'Inc'a, D., (2004). New modules for satellite surveying planning in GRASS. *Geomatics Workbooks* 3, pp. 1-14. ZOO Open WPS platform, 2010. <http://www.zoo-project.org/> (accessed 18 May 2010).