**ARDHI UNIVERSITY**

# VALIDATION OF BEIDOU NAVIGATION SATELLITE SYSTEM IN POINT POSITIONING USING GPS

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**BSc Geomatics**

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# VALIDATION OF BEIDOU NAVIGATION SATELLITE SYSTEM IN POINT POSITIONING USING GPS

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A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Science in Geomatics (BSc. GM) of Ardhi University

## CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University dissertation titled "**Validation of beidou navigation satellite system in point positioning using gps**" in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics at Ardhi University.

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| Date ……………………… | Date……………………… |

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I, MLANZI RAFIH R hereby declare that, the contents of this dissertation are the results of my own findings through my study and investigation, and to the best of my knowledge they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of higher learning.

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**MLANZI, RAFIH R**

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# DEDICATION

*I dedicate this Dissertation to my beloved mother Mrs. Fatma Yusuf Ngayama and my late dear father Mr. Ramadhani Seif Mlanzi I still keep praying for you dear father may almighty God keep resting your soul in eternal peace. Also, my beloved family members. I appreciate their support so much.*

## ABSTRACT

Global Navigation Satellite System (GNSS) is a general term describing any satellite constellation that provides positioning, navigation and timing (PNT) services on a global or regional basis. The GNSS comprises different satellites that can be used in positioning which are GPS (Global Positioning System) operated by USA, GLONASS (Global Navigation Satellite System) operated by Russia, BeiDou operated by China, Galileo operated Europe and the Japan Quasi-Zenith (QZSS). Through the development of these constellations which are now in full operation. One of them is BeiDou which became globally used in 2020 and its accuracy is about 10cm but will reach a millimeter level after post processing, due to the fact that its accuracy of positioning is not known here in Tanzania. Validation has to be done based on GPS satellites and act as a base. The GNSS observation for both GPS and BeiDou was done at a time using a CHC NAV receiver with observation time of 24 hours. Then data were separated to different combined solutions independently using Efix Geomatics Office, so there were three rinex data which one contain BDS only, GPS only and the other contain BDS+GPS. The rinex data were processed using Trimble Business Center sepatately, after baseline processing the results obtained were adjusted grid coordinates, adjusted geodetic coordinates and error ellipse components for both BDS only, GPS only and BDS+GPS. The results were compered using coordinates difference between GPS and BDS, also using GPS and BDS+GPS and analysed using positional accuracy on which the accuracy of BDS+GPS was about less than 6mm better than BDS only which was less than 3cm. The major conclusion of this study is that the BDS+GPS provides better results that can be used on different surveying such as control establishment since it has minimum coordinate difference in both directions which are less than 6mm. The BDS during observation had a greater number of satellites that were tracked by receivers at a time especially in station BNG12 tracks many number of beidou satellites. So, in Tanzania it is easy to track satellites from GPS and BDS systems.


**Keywords**: Global Positioning System (GPS), Beidou

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| GNSS | Global Navigation Satellite System |
| GPS | Global positioning system |
| GLONASS | Russia Global Navigation Satellite System |
| BDS | Chinese BeiDou System |
| GEO | Geostationary Orbit |
| IGSO | Inclined Geosynchronous Satellite Orbit |
| MEO | Medium Earth Orbit |
| SBAS | Satellite Based Augmentation System |
| RINEX | Receiver Independent Exchange |
| UTM | Universal Transverse Mercator |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background

Global Navigation Satellite System (GNSS) refers to a global, satellite-based, all-weather, 24 hour operational radio-navigation and time transfer system which is designed to provide positioning, timing and navigation (PNT) services primarily for military as well as civilian applications. GNSS is the collective name for the US Navigation Satellite System with Timing and Ranging (NAVSTAR), Global Positioning System (GPS), the Russian Global Navigation Satellite System (GLONASS), European Galileo, Chinese BeiDou and the Japan Quasi-Zenith (QZSS) (Bayram, 2016). Table 1.1 shows full constellation satellite numbers of these systems at the time of writing.

*Table 1.1: Number of satellites in each system (Library, n.d.)*

| System | Origin | Full Constellation |
|---|---|---|
| GPS | USA | 31 |
| GLONASS | Russia | 24 |
| Galileo | European Union | 30 |
| BeiDou | China | 35 |

### 1.1.1 Overview of GPS

In satellite surveying, the satellites become the reference or control stations, and the ranges (distances) to these satellites are used to compute the positions of the receiver. Conceptually, this is equivalent to resection in traditional ground surveying work where distances and/or angles are observed from an unknown ground station to control points of known position. The global positioning system can be arbitrarily broken into three parts: (a) the space segment, (b) the control segment, and (c) the user segment.

The space segment consists nominally of 24 satellites operating in six orbital planes spaced at 60° intervals around the equator. Four additional satellites are held in reserve as spares. The orbital planes are inclined to the equator at 55°. This configuration provides 24-hr satellite coverage between the latitudes of 80°N and 80°S. The satellites travel in near-circular orbits that have a mean altitude of 20,200 km above the Earth and an orbital period of 12 sidereal hours.1 The individual satellites are normally identified by their Pseudorandom Noise (PRN) number, but can also be identified by their satellite vehicle number (SVN) or orbital position (Ghilani & Wolf, 2014). Figure 1.1 shows the arrangement of satellites in space segment.

*Figure 1.1: Arrangement of satellites in space segment (Library, n.d.)*

The control segment consists of monitoring stations, which monitor the signals and track the positions of the satellites over time. The initial GPS monitoring stations are at Colorado Springs, and on the islands of Hawaii, Ascension, Diego Garcia, and Kwajalein. The DoD has since added several more tracking stations to its control network. The tracking information is relayed to the master control station, the master control station uses this data to make precise, near-future predictions of the satellite orbits, and their clock correction parameters. This information is uploaded to the satellites, and, in turn, transmitted by them as part of their broadcast message to be used by receivers to predict satellite positions and their clock biases (systematic errors) (Ghilani & Wolf, 2014).

The user segment in GPS consists of two categories of receivers that are classified by their access to two services that the system provides. These services are referred to as Standard Position Service (SPS) and the Precise Positioning Service (PPS). The SPS is provided on the L1 broadcast frequency and more recently the L2 at no cost to the user. This service was initially intended to provide accuracies of 100 m in horizontal positions, and 156 m in vertical positions at the 95% error level. However, improvements in the system and the processing software have substantially reduced these error estimates. The PPS is broadcast on both the L1 and L2 frequencies, and is only available to receivers having valid cryptographic keys, which are reserved for military and authorized users only. This message provides a published accuracy of 18 m in the horizontal, and 28 m in the vertical at the 95% error level (Ghilani & Wolf, 2014).

### 1.1.2 Overview of BDS

The development of the Chinese BeiDou Navigation Satellite System (BDS) follows the three-step strategy, that is the installation of the demonstration system (BDS-1), the regional system (BDS-2), and the global system (BDS-3) (Yang *et al.*, 2011). The construction of BeiDou-1 was started in 1994 and the operation was started in 2000 with the successful launch of two first generation experimental satellites in Geostationary Earth Orbit (GEO), Unlike the American GPS, Russian GLONASS, and European Galileo systems, which use medium Earth orbit satellites, BeiDou-1 used satellites in geostationary orbit. This means that the system does not require a large constellation of satellites, but it also limits the coverage to areas on BeiDou-1 Coverage polygon of BeiDou-1 Earth where the satellites are visible. The area that can be serviced is from longitude 70° E to 140° E and from latitude 5° N to 55° N. A frequency of the system is 2491.75 MHz the third GEO satellite was launched in 2003 to further enhance the system's performance (SCIO, 2016). The operation of BeiDou-2 was started with the successful launch of one Medium Earth Orbit (MEO) and one GEO experimental satellite in 2007 and 2009, respectively. By the end of 2012, BeiDou-2 has reached regional operational status to provide positioning and navigation services for users over the whole Asian–Pacific region with a constellation of five satellites in

GEO, five satellites in Inclined Geosynchronous Satellite Orbit (IGSO), and four satellites in MEO (Shi *et al.*, 2013).

The BeiDou global navigation satellite system, (BDS-3) is the third step of China's satellite navigation system construction. In addition to the positioning, navigation and timing (PNT) service provided by all GNSSs, also provides regional message communication (1000 Chinese characters per time) and global short message communication (40 Chinese characters per time), global search and rescue service (SAR), regional precise point positioning (PPP) service, embedded satellite-based augmentation service (BDSBAS), and space environment monitoring function. By the end of 2019, 28 BDS satellites had been successfully launched, including 24 medium circular orbit (MEO) satellites, 3 inclined geostationary orbit (IGSO) satellites and 1 geostationary orbit (GEO) satellite. However, only 18 MEO satellites can provide services thus far, and other satellites are in the test phase (Bijiao *et al.*, 2020).

### 1.1.3 Beidou satellite system constellation

The regional BeiDou-1 system was decommissioned at the end of 2012. The first satellite of the second-generation system, Compass-M1 was launched in 2007. It was followed by further nine satellites during 2009–2011, achieving functional regional coverage. A total of 16 satellites were launched during this phase.

In 2015, the system began its transition towards global coverage with the first launch of a new generation of satellites, and the 17th one within the new system. On 25 July 2015, the 18th and 19th satellites were successfully launched from the Xichang Satellite Launch Center, marking the first time for China to launch two satellites at once on top of a Long March 3B/Expedition 1 carrier rocket. The Expedition-1 is an independent upper stage capable of delivering one or more spacecraft into different orbits. On 29 September 2015, the 20th satellite was launched, carrying a hydrogen maser for the first time within the system.

In 2016, the 21st, 22nd and 23rd satellites were launched from Xichang Satellite Launch Center, the last two of which entered into service on 5 August 2016 and 30 November 2016, respectively. Table 1.2 shows number of the beidou satellites launches and current health.

*Table 1.2: Number of the beidou satellites launches and current health (Management, n.d.)*

| **Block** | **Launch period** | **Satellite Launches** | **Current in Orbit and Health** |
|---|---|---|---|
| 1 | 2000-2006 | 4 | 0 |
| 2 | 2007-2019 | 20 | 12 |
| 3 | 2015-present | 35 | 30 |
| Total | | 59 | 42 |

The determination of position the GNSS receiver calculates position based on data received from Satellites, where by the accuracy of positioning from a GNSS survey will generally depend on 4 (four) factors, namely: the accuracy of the data used, the observation geometry, the observation strategy used, and the data processing strategy. The observation geometry includes the observer geometry (network) and satellite geometry that depends on the number of satellites, locations, and distribution of satellites received. Theoretically, the more satellites received, the better satellite geometry. With the use of more satellites, it will get more data which is expected to increase the accuracy of GNSS surveys.

**Previous researches**

A test study conducted in Indonesia about Accuracy analysis of GNSS (GPS, GLONASS and BeiDou) observations for positioning. The study used GNSS receiver Hi-Target V30 to observe the baseline from base to other points (rovers). The GNSS observation in this case was carried out by static positioning and radial methods which were tied at the BM ITS – 01 as a reference point. The GNSS data processing used Hi-Target Geomatics Office (HGO) software to convert format data from HI Target format to RINEX (Receiver Independence Exchange) format and Topcon Tools 8.2.3 software to perform a baseline (differential positioning) processing. Involved different strategy as GPS, GLONASS and BeiDou signals were processed simultaneously and 2nd strategy both of GPS and GLONASS signal were processed simultaneously and 3rd strategy both of GPS and BeiDou signals were processed simultaneously, 4th strategy both of GLONASS and BeiDou signals were processed simultaneously and 5th strategy only GPS signal is processed and 6th strategy only GLONASS satellite signal is processed. In this research, the GNSS observation was divided into five categories of length of baselines: 1 km, 5 km, 10 km, 15 km and 20 km from the base station. Came up with the results that the 1st observation (GPS + GLONASS + BeiDou) and 2nd observation (GPS + GLONASS) strategy have the same horizontal and vertical accuracies for all categories (1 – 20 km) whereas horizontal accuracies are less than 2 cm and vertical accuracies are less than 2.5 cm. Also stated that all strategies have horizontal accuracies less than or equal 1 cm and vertical accuracies less than 2 cm for baseline less than 5 km (Khomsin *et al.*, 2019).

A test study was conducted in China about Preliminary assessment of the navigation and positioning performance of BeiDou regional navigation satellite system. In this research, its basic navigation and positioning performance are evaluated preliminarily by the real data collected in Beijing, including satellite visibility, Position Dilution of Precision (PDOP) value, and the precision of code and carrier phase measurements, the accuracy of single point positioning and differential positioning and ambiguity resolution (AR) performance, which are also compared with those of GPS. It was shown that the precision of BDS code and carrier phase measurements were about 33 cm and 2 mm, respectively, which were comparable to those of GPS. The accuracy of BDS carrier phase differential positioning is better than 1 cm for a very short baseline of 4.2 m and 3 cm for a short baseline of 8.2 km, which is on the same level with that of GPS. The accuracy of BDS/GPS carrier phase differential positioning is about 35 and 20 % better than that of GPS for two short baseline tests in this study. The accuracy of BDS code differential positioning is better than 2.5 m. (Yang *et al*., 2014).

**Current research**

In the current research, four points at Nyamisati in coastal region were observed in static method for 24 hours. The receiver used in the observation is CHCNAV. The observation baseline was about 7km. Then rinex data were separated to different combined solutions independently using Efix Geomatics Office. The rinex data were processed using Trimble Business Center sepatately, after baseline processing the results obtained were adjusted grid coordinates, adjusted geodetic coordinates and error ellipse components for both BDS only, GPS only and BDS+GPS. The results were compered using coordinates difference between GPS and BDS, also using GPS and BDS+GPS and analysed using positional accuracy on which the accuracy of BDS+GPS was about less than 6mm better than BDS only which was less than 3cm.

## 1.2 Problem statement

GPS positioning has been one of the commonly utilized positioning systems across the world. Over the past years in Tanzania we have been using GPS for positioning. In 1994, China started the construction of the BeiDou navigation satellite demonstration system and took over many years to make it operational. Finally, the BeiDou navigation satellite system has been fully operational as of now and due to be fully operational its accuracy has not been known. So, the aim of this study is to validate the performance of the BeiDou navigation satellite system in point positioning using GPS.

## 1.3 Research objective

### 1.3.1 Main objective

The main objective of this research is to validate the performance of the BeiDou navigation satellite system in point positioning based on the GPS using static observation.

### 1.3.2 Specific objectives

I. To compare the coordinate difference between the GPS system to that of BeiDou.
II. To analyze the BeiDou system to GPS system.
III. To investigate BeiDou position accuracy for GNSS data in control establishment.

## 1.4 Significance of the research

This research can provide important insights into the performance and accuracy of BDS compared to other global navigation satellite systems. This research can help to provide reliability and efficiency of BDS, enhance its compatibility with other systems, and promote its wider adoption in various applications such as transportation, agriculture and emergency response. Additionally, the research can also contribute to the advancement of satellite navigation technology and the development of a more global navigation system.

## 1.5 Scope of the research

The study of this research was at Nyamisati, Pwani region, Comprise of four control stations where by known control was TR40 and the other three controls were established.

### 1.6 Thesis structure

This dissertation consist of five chapters, chapter one had introduced main concept regarding positioning using BDS and GPS and its significance. It gives summary on similar researches regarding GNSS positioning and stating the research problem together with research objectives. Chapter two discusses important concept regarding GNSS positioning, error causing low accuracy in positioning from different literatures related to this research. Chapter three gives detailed methodology to process the data in order to obtain results in this research. Chapter four presents the results and discussion of obtained results and finally chapter five provides the conclusion and recommendations regarding to findings of this research.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Previous researches

There are several studies conducted on the performance of GNSS in positioning that have been published for example A test study was conducted in China about Preliminary assessment of the navigation and positioning performance of BeiDou regional navigation satellite system. In this research, its basic navigation and positioning performance are evaluated preliminarily by the real data collected in Beijing, including satellite visibility, Position Dilution of Precision (PDOP) value, and the precision of code and carrier phase measurements, the accuracy of single point positioning and differential positioning and ambiguity resolution (AR) performance, which are also compared with those of GPS. It was shown that the precision of BDS code and carrier phase measurements were about 33 cm and 2 mm, respectively, which were comparable to those of GPS. The accuracy of BDS carrier phase differential positioning is better than 1 cm for a very short baseline of 4.2 m and 3 cm for a short baseline of 8.2 km, which is on the same level with that of GPS. The accuracy of BDS/GPS carrier phase differential positioning is about 35 and 20 % better than that of GPS for two short baseline tests in this study. The accuracy of BDS code differential positioning is better than 2.5 m. (Yang *et al*., 2014).

Another test study was conducted in China about Performance assessment of single- and dual-frequency BeiDou/ GPS single-epoch kinematic positioning. In this research, the performance of the BeiDou/GPS single-epoch positioning was demonstrated in both static and kinematic modes and compared with corresponding GPS-only performance. It was shown that the availability and reliability of the single-frequency BeiDou/GPS and dual-frequency BeiDou single-epoch kinematic positioning were comparable to those of the dual-frequency GPS. For positioning accuracy with fixed ambiguities, the BeiDou/GPS single epoch solutions are improved by 23 and 4 % relative to the GPS-only case for two short baseline tests of 8 km, respectively. These results reveal that dual-frequency BeiDou real-time kinematic (RTK) is already applicable in Asia–Pacific areas and that single-frequency BeiDou/GPS RTK is also achievable but only with initialization of several seconds. (Haibo *et al*., 2013).

Another study was about Precise Point Positioning with the BeiDou Navigation Satellite System conducted in China. By the end of 2012, In order to assess the navigation and positioning performance of the BeiDou-2 system, Wuhan University has built up a network of BeiDou Experimental Tracking Stations (BETS) around the World. The Position and Navigation Data Analyst (PANDA) software was modified to determine the orbits of BeiDou satellites and provide precise orbit and satellite clock bias products from the BeiDou satellite system for user applications. This article uses the BeiDou/GPS observations of the BeiDou Experimental Tracking Stations to realize the BeiDou and BeiDou/GPS static and kinematic precise point positioning (PPP). The result indicates that the precision of BeiDou static and kinematic PPP reaches centimeter level. The precision of BeiDou/GPS kinematic PPP solutions is improved significantly compared to that of BeiDou-only or GPS-only kinematic PPP solutions. The PPP convergence time also decreases with the use of combined BeiDou/GPS systems (Min *et al*., 2014).

A test study conducted in Indonesia about Accuracy analysis of GNSS (GPS, GLONASS and BeiDou) observations for positioning. The study area of this research was Surabaya City, East Java. The study used GNSS receiver Hi-Target V30 to observe the baseline from base to other points (rovers). The GNSS observation in this case was carried out by static positioning and radial methods which were tied at the BM ITS – 01 as a reference point. The GNSS data processing used Hi-Target Geomatics Office (HGO) software to convert format data from HI Target format to RINEX (Receiver Independence Exchange) format and Topcon Tools 8.2.3 software to perform a baseline (differential positioning) processing. Involved different strategy as GPS, GLONASS and BeiDou signals were processed simultaneously and 2nd strategy both of GPS and GLONASS signal were processed simultaneously and 3rd strategy both of GPS and BeiDou signals were processed simultaneously, 4th strategy both of GLONASS and BeiDou signals were processed simultaneously and 5th strategy only GPS signal is processed and 6th strategy only GLONASS satellite signal is processed. In this research, the GNSS observation was divided into five categories of length of baselines: 1 km, 5 km, 10 km, 15 km and 20 km from the base station. Came up with the results that the 1$^{st}$ observation (GPS + GLONASS + BeiDou) and 2$^{nd}$ observation (GPS + GLONASS) strategy have the same horizontal and vertical accuracies for all categories (1 – 20 km) whereas horizontal accuracies are less than 2 cm and vertical accuracies are less than 2.5 cm. Also stated that all strategies have horizontal accuracies less than or equal 1 cm and vertical accuracies less than 2 cm for baseline less than 5 km (Khomsin *et al*., 2019).

## 2.2 Static positioning

This method is used to give high precision over long baselines such as are used in geodetic control surveys. One receiver is set up over a station of known X, Y, Z coordinates, preferably in the WGS 84 reference system, whilst a second receiver occupies the station whose coordinates are required. Observation times may vary from 45 min to several hours. This long observational time is necessary to allow a change in the relative receiver/satellite geometry in order to calculate the initial integer ambiguity terms. Accuracies in the order of 5 mm ± 1 ppm of the baseline are achievable as the majority of errors in GPS, such as clock, orbital, atmospheric error and SA, are eliminated or substantially reduced by the differential process. The use of permanent active GPS networks established by a government agency or private company could result in a further increase in accuracy for static positioning. Apart from establishing high precision control networks, it is used in control densification using a leap-frog technique; measuring plate movement in crustal dynamics and oil rig monitoring ( Schofield & Breach, 2007).

## 2.3 The GNSS constellation overview

### 2.3.1 Global Positioning System

GPS is operated and maintained by the U.S. Air Force. The nominal constellation of GPS consists of 31 satellites in six evenly spaced orbital planes with 55° inclination to the equator. Each plane contains four satellites, launched into a near-circular orbit with the altitude of about 20200 km above the earth and the orbital period of 11 hours 58 minutes. This nominal constellation provides global convergence with at least four satellites at any time of day.

There are many types of GPS satellites. These are Block I, Block II, Block IIA, Block IIR, Block IIR-M, Block IIF, and Block III satellites. Eleven Block I satellites were launched between 1978 and 1985. The lifetime of these satellites is about 4.5 years and they can only provide the positioning services for 3 or 4 days without any contact with the control segment. They transmit a civil code called as C/A code on the L1 frequency and a military code called as P code on both L1 and L2 frequencies. L1 and L2 frequencies are 1575.42 MHz and 1227.60 MHz, respectively. The first Block II satellite was launched on February 14, 1989. The lifetime of these satellites is about 7.5 years and they can provide the positioning services for 14 days without any contact with the control segment. The first Block IIA satellite was launched on November 26, 1990 (A denotes advanced). They are able to provide positioning services for 180 days without any contact with the control segment. The first Block IIR satellite was successfully launched on July 23, 1997 (R denotes replacement). The lifetime of these satellites is about 10 years and they can provide the positioning services for about half a year without any contact with the control segment without any degradation in orbit accuracy thanks to the capability to autonomously determine their orbits and generate their own navigation messages (Dunn & DISL, 2012).

They are able to measure the distances between them and to transmit observations to other satellites or to the control segment. The first Block IIR-M satellite was launched on September 25, 2005 (M denotes modernized). Compared to the previous satellite types, Block IIR-M satellites transmit a new civil code called as L2C code on L2 frequency, which allows for mitigating of the ionospheric effects, and also a new military code called as M code on both L1 and L2 frequencies for improved accuracy, enhanced encryption and anti-jamming capabilities. The GPS modernization process started with the Block IIR-M satellite. The first Block IIF satellite was launched on May 28 2010 (F denotes follow on). Compared to the previous satellite types, Block IIF satellites transmit a new civil code known as L5C on a new L5 frequency, which is 1176.45 MHz protected for the safety-of-life applications. The lifetime of these satellites is about 15 years. Block-III satellites are the future phase of the GPS modernization. Block-III satellites will transmit a fourth civil code called L1C code on L1 in order to interoperate with international GNSS. Its lifetime will also be longer (Dunn & DISL, 2012).

The GPS time (GPST) is on a continuous atomic time scale without the leap second corrections, which increments from a reference epoch starting at midnight on the night of 5th January 1980 and morning of 6th January 1980 in the universal Time Coordinated as maintained by the U.S. Naval Observatory (UTC (USNO)). In other words, the start epoch of GPST was at 00.00.00 on 6th January 1980 in UTC (USNO). The GPST is maintained by the Master Control Station (MCS) (Dunn & DISL, 2012). GPS uses the World Geodetic System-84 (WGS-84) reference system for the position of satellite antenna phase centers. At the time of writing this thesis, there were 30 operational GPS satellites, a combination of old and new satellites. This constellation was made up of 2 Block IIA, 12 Block IIR, 7 Block IIR M and 9 Block IIF GPS satellites.

### 2.3.2 Russian Global Navigation Satellite System

GLONASS is operated and maintained by the Russian Military Space Forces. The nominal constellation of GLONASS consists of 27 operational in three evenly spaced orbital planes with 64.8° inclination to the equator. Each plane contains eight satellites launched into a near-circular orbit with an altitude of about 19100 km above the earth and an orbital period of 11 hours, 15 minutes and 44 seconds (kumar, Srivastava, & Tiwari, 2021).

The first prototype satellite of GLONASS was launched in 1982 and the number of the launched satellites reached 18 in 1985. All these satellites transmit the navigation signals on two frequency bands. Since GLONASS uses the FDMA (Frequency Division Multiple Access) technique, each satellite transmits on the different frequencies by the frequency channel number as follows:

*L1 = 1,602 + 0.5625 k (MHz)* *Equation 1*

*L2 = 1,246 + 0.4375 k (MHz) where k indicates a channel number (k = -7…, +6)* *Equation 2*

Between 1985 and 1990, the first generation GLONASS satellites with longer lifetime and improved time and frequency standards were launched.

The number of GLONASS satellites decreased to seven in 2001 due to insufficient funds. Russian government approved a Federal GLONASS Program to modernize and rebuild the system for the period of 2002-2011 (Hedeker & Gibbons, 2006). The second generation GLONASS satellites called as GLONASS- M where M denotes modernized, were launched in 2001. The lifetime of these satellites was increased to about 7.5 years. These satellites transmit a new civil code on the L2 frequency band.

The first third generation GLONASS satellites known as GLONASS-K was launched on 26 February 2011 with an increased lifetime. GLONASS- K satellites transmit a new civil code on the new L3 frequency band. GLONASS-K signal follows the Code Division Multiple Access (CDMA) technique in which each satellite transmits a different code on the same frequency similarly to GPS and Galileo. The GLONASS constellation reached its full orbit capacity (FOC) on 8 December 2011. The GLONASS time (GLONASST) is not on a continuous atomic time scale. It requires the leap second corrections simultaneously with the UTC. It is synchronized with the Universal Time Coordinated as maintained by the National Time Scale of Russian Federation (UTC (SU)) which is a local UTC and kept by an ensemble of cesium standards and hydrogen masers with a difference to the UTC in the order of some nanoseconds. Its difference to the UTC is in the order of a few microseconds.

The GLONASS system time is maintained by the GLONASS Central Synchronizer (CS) time. There is a constant offset of three hours between the GLONASS time and UTC (SU) due to the difference between Moscow time and Greenwich Time. In addition to the leap second corrections and the 3-hour offset, the difference between GPST and GLONASST is usually 100 or several 100 ns level. GLONASS uses the PZ-90.11 reference system for the position of satellite antenna phase centers. At the time of writing this thesis, there were 27 operational GLONASS satellites, a combination of old and new satellites. This constellation was made up of 24 GLONASS- M and 2 GLONASS- K satellites (kumar *et al.*, 2021).

### 2.3.3 Chinese system BeiDou

BeiDou is developed by the Chinese Academy of Space Technology for primarily military missions. The nominal constellation of Galileo consists of 35 satellites including 5 Geostationary (GEO) satellites, 3 Inclined Geosynchronous Orbit (IGSO) satellites and 27 medium orbit (MEO) satellites.

The GEO satellites are positioned at 58.75° E, 80° E, 110.5° E, 140° E and 160° E respectively at an altitude of 35,786 km. The IGSO satellites are located in orbit at an altitude of 35,786 km at an inclination of 55°. The MEO BeiDou satellite orbits are at an altitude of 21,528 km with an inclination of 45° and have an orbital period of 12 hours and 53 minutes (Leick et al., 2015). Frequencies for BeiDou are allocated in three bands, which are 1575.42 MHz (B1), 1191.795 MHz (B2) and 1268.52 MHz (B3). Both Open Service (OS) and Authorization Service (AS) are provided in the B1 band, while only OS in the B2 band and AS in the B3 band (BeiDou Navigation , 2020).

BeiDou Time (BDT) which is on a continuous atomic time scale without leap second corrections. The BDT is related to the Universal Time Coordinated through UTC (NTSC) which is a UTC time maintained by National Time Service Center, China Academy of Science. The start epoch of BDT was at 00:00:00 on 1st January 2006 UTC (NTSC). BeiDou uses the China Geodetic Coordinate System 2000 (CGCS2000) for the position of satellite antenna phase centers.

### 2.3.4 European Galileo

Galileo is operated and maintained by the European Space Agency. The nominal constellation of Galileo consists of 27 operational and 3 spare satellites in three evenly spaced orbital planes with 56° inclination to the equator. Each plane contains ten satellites launched into a near-circular orbit with an altitude of about 23222 km above the earth and the orbital period of 14 hours 4 minutes and 45 seconds. This nominal constellation provides global convergence with at least six satellites in view from anywhere (almost) on the Earth at any time of day.

Galileo system development plan can be divided into three phases which are Galileo In-Orbit Validation Experiment (GIOVE) phase, Galileo In-Orbit Validation (IOV) phase and Galileo Full-Operational-Capability (FOC) phase. GIOVE phase has been completed with two experimental satellites, GIOVE-A and GIOVE-B, were launched on 28 December 2005 and on 27 April 2008, respectively. The purposes of launching these satellites were to secure the frequencies with the International Telecommunication Union (ITU) and to validate the technologies used in the nominal constellation. The IOV phase was completed with four IOV satellites launched as pairs on 21 October 2011 and 12 October 2012. The purpose of this phase was to make extensive orbit and control segment tests (GMV, 2011).

Now, the Galileo system is in the FOC phase in which the nominal Galileo constellation will be provided by 2019-2020. At the time of writing this thesis, the total number of the launched FOC satellites was four. The first two FOC satellites were launched on 22 August 2014, but unfortunately to the wrong orbits. The next two FOC satellites were launched on 27 March 2015. IOV and FOC satellites are fully representative of each other. In other words, they are the same type of satellites although their roles are different in the development process of the Galileo system (eoportal, 2014).

They transmit the navigation signals on E1 (1575.42 MHz), E5a (1176.45 MHz), E5b (1207.14 MHz) and E6 (1278.75 MHz) frequencies. Galileo system provides Open Service (OS), Public Regulated Service (PRS), Commercial Service (CS), Search and Rescue (SAR) and Safety-of- Life (SoL) services using the navigation signals on these bands. OS is provided on E1 (1575.42 MHz), E5a (1176.45 MHz) and E5b (1207.14 MHz) frequencies. Galileo System Time (GST) is on a continuous atomic time scale without the leap second corrections, which increments from a reference epoch starting at midnight on the night of 21st August 1999 and morning of 22nd August 1999 in UTC. It is maintained by the Precise Timing Facility (PTF) at the Galileo Control Centre in Italy (ESA 2013b, Inside GNSS 2013). At the start epoch, the GST was ahead of UTC by 13 seconds (Galileo ICD 2010). The GST is aligned to GPST except for the 1024 weeks difference of the time system origin and a small-time offset. Galileo uses the Galileo terrestrial reference frame (GTRF) for the position of satellite antenna phase centers (eoportal, 2014).

### 2.3.5 Satellite-based Augmentation systems

There are also satellite based augmentation systems (SBAS) such as the Wide Area Augmentation System (WAAS), the European Geostationary Navigation Overlay Service (EGNOS) and GPS Aided Geo Augmentation Navigation (GAGAN) system implemented by the Indian government. They are used to maintain high positioning accuracy by providing additional information such as an ephemeris correction and localized ionospheric delay information. This additional information is calculated using the GNSS satellite data collected from the ground stations. Then, the correction data is broadcast to users through the three geostationary satellite communication links.

WAAS consists of two geostationary satellites and a network of 38 ground stations across the US. EGNOS infrastructure comprises a ground network of 44 stations in Europe and 3 geostationary satellites. The signal coverage area includes most European countries. GAGAN consists of three geostationary satellites and a network of 15 ground stations across India.

The SBAS helps provide integrity messages and differential corrections such as ionospheric information which can be used by GNSS/SBAS receivers to improve the accuracy of GNSS receivers.The use of SBAS helps to improve User Equivalent Range Error (UERE) which is an indication of ranging accuracy for each satellite signal. SBAS plays an essential role in safety-critical application as well as applications where accuracy and integrity are crucial; examples include the guidance of agricultural machinery, and on-road vehicle fleet management.

## 2.4 The common sources of error

### 2.4.1 Ionospheric delay

The ionosphere is the layer of the atmosphere at a height of 50 km to 1000 km above the earth. It contains free electrons due to the sun’s radiation, the solar activity and geomagnetic disturbances. In normal atmospheric conditions, its delay is about 1-3 m at night and about 5-15 m in the mid- afternoon at mid-latitudes. Furthermore, its magnitude increases at the equator (Misra & Enge, 2006). The ionosphere advances the carrier- phase measurements and delays the pseudo-range measurements as they travel through the ionosphere. Therefore, the carrier-phase measurements are measured longer and the pseudo-range measurements are measured shorter.

The ionospheric delays for the pseudorange and carrier-phase measurements depend on the total electron content (TEC) along the propagation path of a signal and the frequencies of the measurements due to the dispersive medium property of the ionosphere. TEC depends on the geographic location of the receiver (well behaved in the mid-latitude), time (active at noon and quiet at night) and the solar activities. In DGPS, for the short baselines (5-10 km), the ionospheric error is mitigated by differencing techniques due to the fact that the reference and the rover stations are most likely affected by the same magnitude ionospheric delay. For the long baselines, the ionospheric error can be mitigated through a linear combination of the 1 and 2 frequencies, known as an ionosphere-free linear combination (Misra & Enge, 2006).

### 2.4.4 Multipath and Noise

The multipath is the phenomenon that occurs due to obstruction signals from the satellite reaching a GNSS antenna of a receiver via two or more paths. Figure 2.1 shows the multipath error.

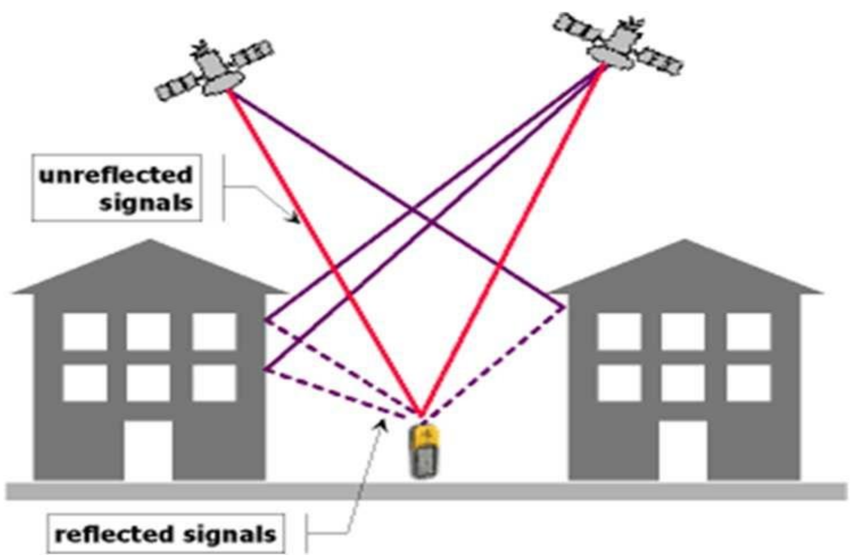


*Figure 2.1: Multipath effect (kumar m. , 2014)*

Un-reflected signals (red) are the desired ones. However, reflected signals (purple) being reflected from buildings cause the receiver to calculate the distance between satellite and itself incorrectly since the reflected signals (purple) travel longer than the un- reflected signals (red) which is desired. This unwanted effect is known as multipath. The effects of multipath cannot be removed through modeling or by differencing techniques. However, its effect may be decreased by using a choke ring antenna which can decrease the multipath error and setting up this antenna away from reflecting objects. In addition, the satellites at low elevations angles could be discarded by setting an elevation cutoff angle.

### 2.4.5 Receiver clock error

The receivers are generally equipped with the inexpensive crystal clocks which are not set exactly to GNSS reference time and also, they can drift easily over time. This offset between the GNSS reference time and the receiver time is called the receiver clock error. In PPP, it can be mitigated by estimating as an unknown parameter, while in DGPS, it can be eliminated by the between satellite differences techniques without depending on the separation between the reference and rover stations (Hofmann *et al.*, 2001).

### 2.4.6 Satellite Orbit and Clock error

These satellite orbits can be obtained from the broadcast orbits or the precise orbits. The broadcast orbits can be computed in a system-related Earth-Centered, Earth- Fixed (ECEF) coordinate system using the orbital parameters transmitted by the satellites in real-time as a part of their navigation messages in the accuracy range of about 1-6 meters while the precise orbits can be obtained in International Terrestrial Reference Frame (ITRF) coordinate system from International GNSS Service (IGS) via Internet free of charge in different latencies and accuracies, but generally in the range of about 5 centimeters (Hofmann *et al.*, 2001).

The satellite orbit error is the difference between its actual and predicted orbits. In DGPS, the satellite orbit errors are significantly mitigated by differencing techniques. However, the mitigation success depends on the separation between the reference and rover stations. In PPP, the satellite orbit errors are mitigated using the precise orbits to be able to provide high positioning accuracy. Note that the precise orbits can also be used for DGPS to increase the positioning accuracy.

The satellite clock error refers to the offset between GNSS reference time and satellite clock time due to a lack of synchronization of the satellite clock with respect to GNSS reference time. The satellite clock error can be mitigated using the broadcast clock corrections in the navigation messages with the precision of 7 nanoseconds, or precise clock corrections with precision of about 0.1 nanoseconds depending on the latency from IGS. Note that 1 nanosecond clock error causes a range error of about 30 cm. In DGPS, these satellite clock errors are eliminated completely by differencing techniques without depending on the separation between the reference and rover stations. However, in PPP, it should be mitigated using the precise clock products of IGS.

# CHAPTER THREE

# METHODOLOGY

This chapter presents the methods and procedures that were used for data collection, quality check, experiment setup and data processing to obtain the final output.

## 3.1 Data search and reconnaissance

This process involved physical survey and gathering of initial information of the area to be researched. During reconnaissance various resources to be used are likely to be analyzed. Including data search to identify the presence and existence of coordinates for control points to be used, understanding the nature of the environment, to identify if they met the requirements. In this study the reconnaissance is divided into two parts namely office and field reconnaissance. In office reconnaissance involved searching necessary information and data availability including acquired coordinates of existing control. In field reconnaissance, it involves familiarization with the projected area and nature of the terrain, whereby all the control stations were found on the stable ground. The control point used was TR40 in UTM (WGS84) as shown in table 3.1.

*Table 3.1: Available control point in UTM (WGS84)*

| Point Id | Easting (m) | Northing (m) | Elevation (m) |
|---|---|---|---|
| TR40 | 516406.751 | 9153296.387 | 167.679 |

## 3.2 Network design

Control Network is a network, often of triangles which are measured exactly by techniques of terrestrial surveying or by space techniques (i.e GNSS, VLBI, SLR and LLR). Control networks provide a reference framework of points for topographical mapping, deformation surveys of all manner of structures, construction works, as well as extension and densification of existing control network.

Classification of control networks are of three groups which are; a) primary or First order control network which is used to establish geodetic points, Determine the size, shape, and movement of earth. b) Secondary or Second order control network which is used for network densification in urban areas, Precise engineering projects. c) Tertiary or third order control network which is used for surveying and mapping projects, for network densification in non-urban areas.

There are two methods of establishment of control point, which are a) Conventional surveying consisting of Triangulation, Trilateration, Traverse, Resection. Conventional surveying performed using traditional precise surveying techniques and instruments, it needs intervisibility between adjacent stations. b) Space technique which consists of Static and rapid static for HZ and VT (GNSS surveying) in GNSS surveying relative technique mostly preferred and it needs visibility to sky.

Some criteria for network design are as follows; Network density: The network should be designed with a sufficient number of control points to ensure that the required accuracy is achieved. The number and distribution of control points should be based on the size and complexity of the survey area, Control point selection: The control points should be selected carefully, taking into consideration the location, accessibility, and stability of the ground. The points should be located on stable terrain and away from any areas that may be subject to significant movement or deformation, Observation methods: The observation methods used for establishing the control points should be appropriate for the level of accuracy required. Third-order control networks typically require high-precision geodetic surveying techniques, such as GPS (Global Positioning System). In this research the network was designed due to the mentioned criteria as shown in figure 3.1.

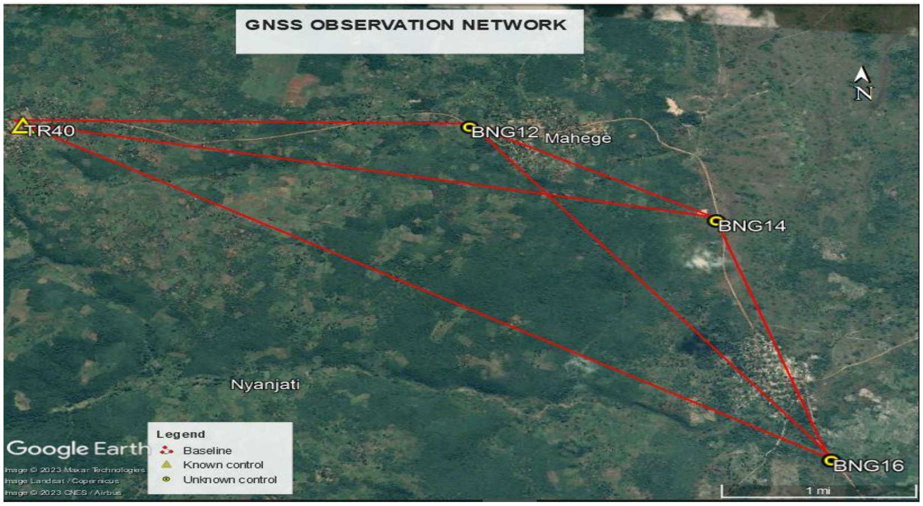


*Figure 3.1: The designed network*

### 3.4 Mission planning

Mission planning is the method used by surveyors to determine the number of satellites and their arrangement within a certain time, which is required for conducting a survey within a specified time. For a surveyor to get a better accuracy it is important to know the availability of satellites and time which gives a good observation. Good satellite geometry also plays a great role in GNSS observation, it's expressed as the dilution of precision (DOP). The mission planning was carried out by using online software known as Trimble GNSS planning online. In a Figure 3.2 shows the number of satellite active with respect to their arrangement within a period of time in which the BeiDou has many number of satellites.and figure 3.3 shows dilution of precision in observation.

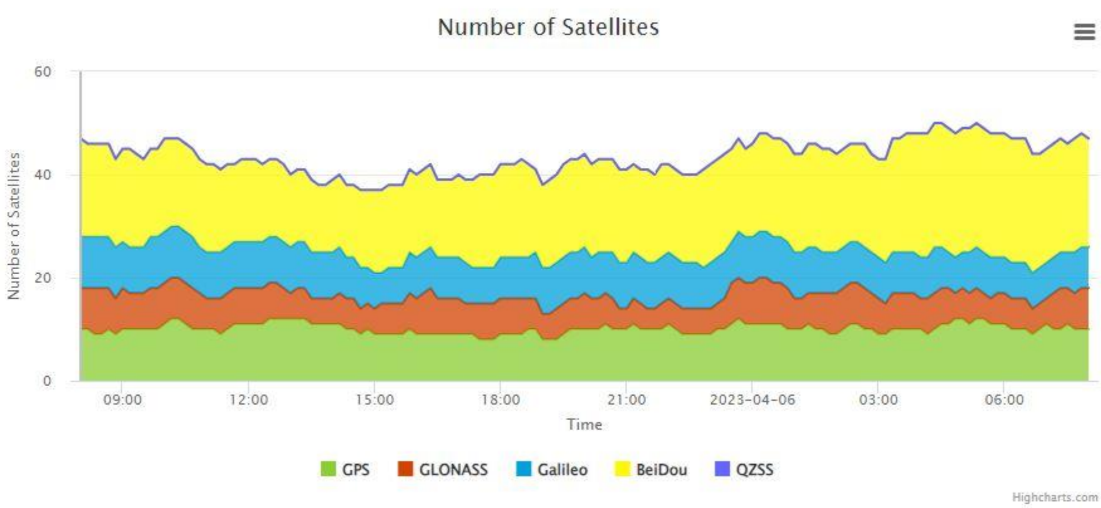


*Figure 3.2: Number of satellite available*

Figure 3.3 shows the dilution of precision in the area of interest in which the horizontal positioning has the minimum value which indicate higher accuracy.

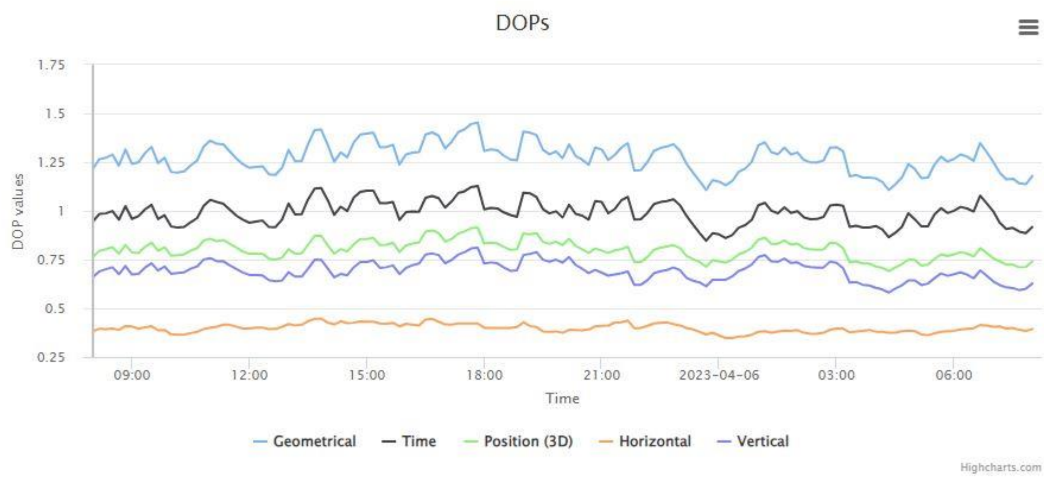


*Figure 3.3DOPs of each satellite*

### 3.5 GNSS observation

The surveying techniques used in this research study was by static positioning with duration of 24 hours observation. Static surveying using four CHC receivers were conducted where the one receiver was set at TR40 and the other receivers were set on stations with unknown coordinates which are BNG12, BNG14 and BNG16 simultaneously. These receivers were kept stationary and simultaneously tracking the same satellites at a time on which all of them were tracking only GPS and BEIDOU satellites.

### 3.6 Data Format

Data was exported from the receiver with the data format was HCN format. These data were translated to mixed Receiver Independent Exchange (RINEX) version 3.02 using Efix Geomatics Office (eoffice) software. Since RINEX data can be processed using Trimble Business Center (TBC) software that involves baseline processing. Also, the RINEX data were separated in different systems independent which involves GPS only and BDS only this was done using the eoffice software.

### 3.7 Data Quality check

The quality of RINEX files were checked using Efix Geomatics Office (eoffice) software. Eoffice is a software provided by China. The data quality check is important as it compares the actual observed data versus standard for observed data. The data were collected at open sky and minimum sky obstruction which indicates the quality for data processing. The data quality was assessed in percentage whereby the percentage below 60% indicated poor observation, between

60% and 80% indicated good observation and above 80% indicated excellent observation. Figure 3.4 shows the quality check for gps observations while figure 3.5 shows the quality chek for beidou observations.

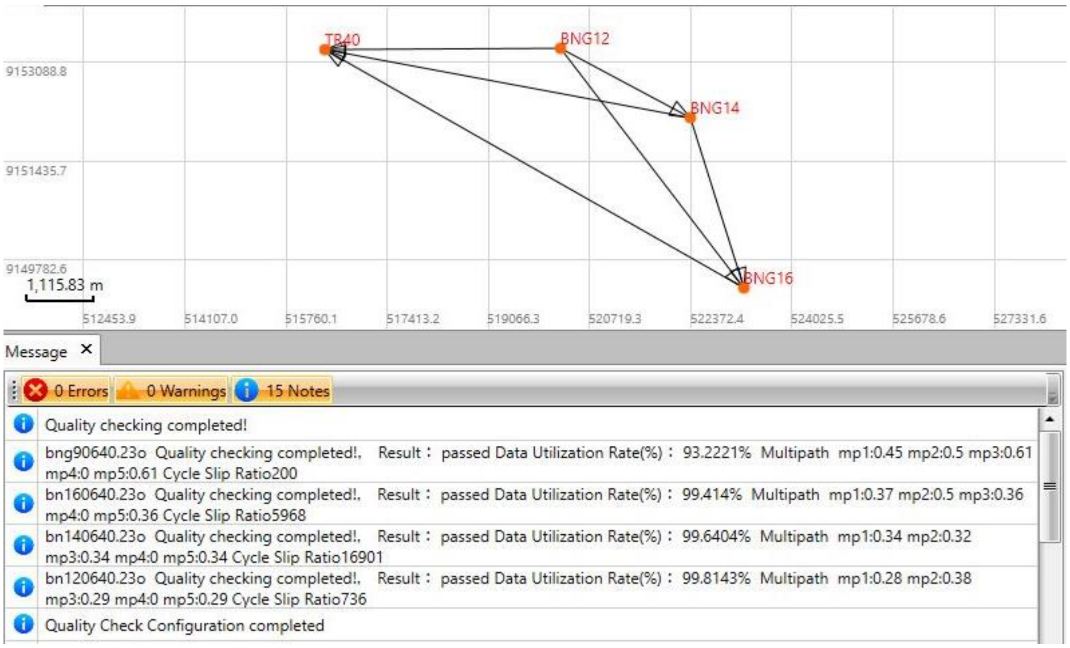


*Figure 3.4: Quality check results for gps*

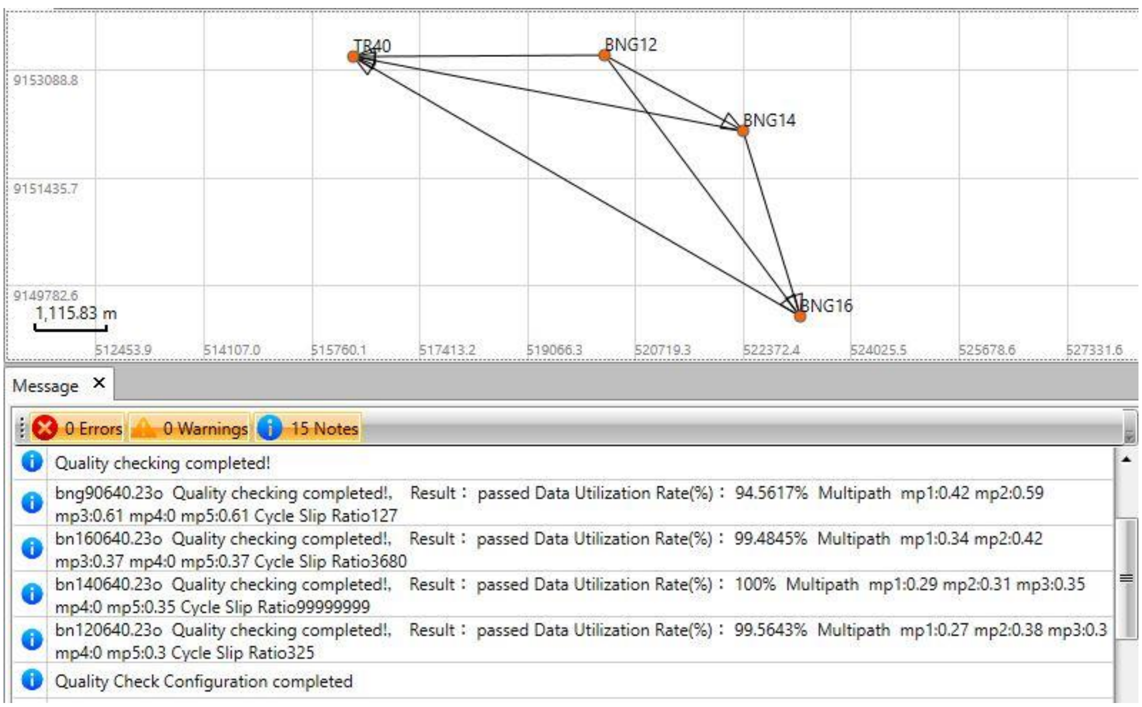


*Figure 3.5: Quality check results for beidou*

### 3.8 Data processing

The observation data in RINEX format were processed using TBC software in two separate systems which were GPS only and BEIDOU only to produce the final coordinates of a position. In order to obtain the final coordinates the RINEX files were imported and baseline were formed and finally the network was adjusted. Figure 3.6 shows the baseline processing network

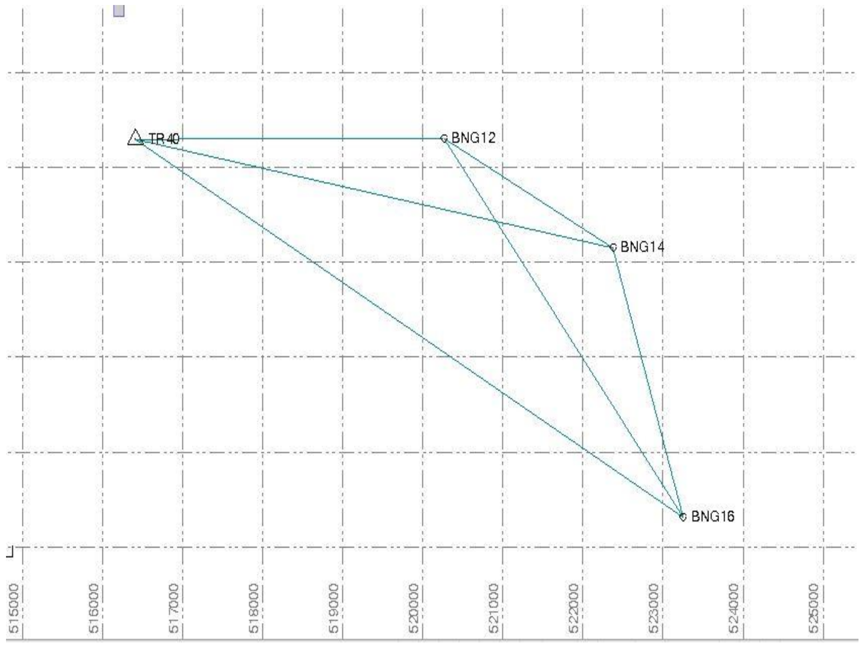


*Figure 3.6: Baseline processing network*

GPS were processed separately and after baseline processing the network was adjusted to produce the final adjusted coordinates which were used as the base coordinates in this research. The control station fixed was regarded as errorless and its error was distributed among the observations. One control point which is TR40 was used as fixed station to adjust the network.

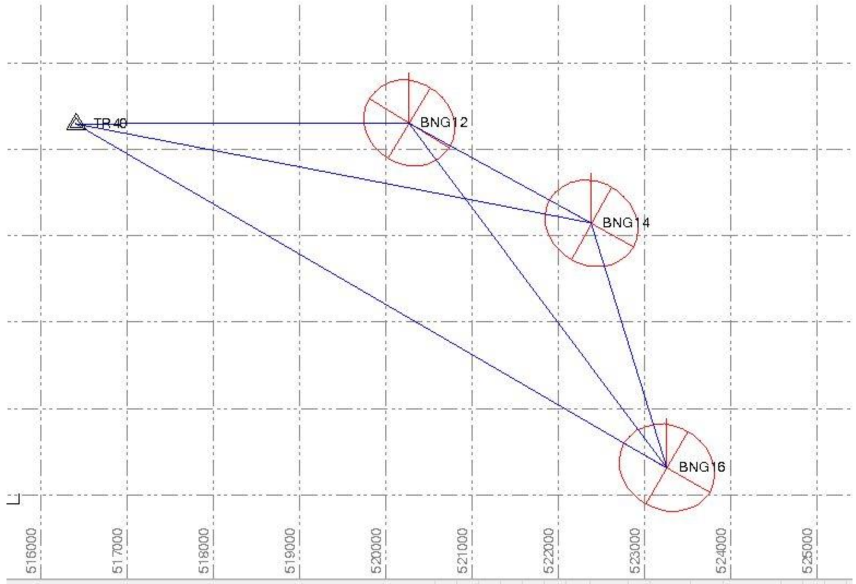


*Figure 3.7: Adjusted network for gps*

Beidou were processed separately and after baseline processing the network was adjusted to produce the final adjusted coordinates which were used to assess the agreement between beidou results based on gps.

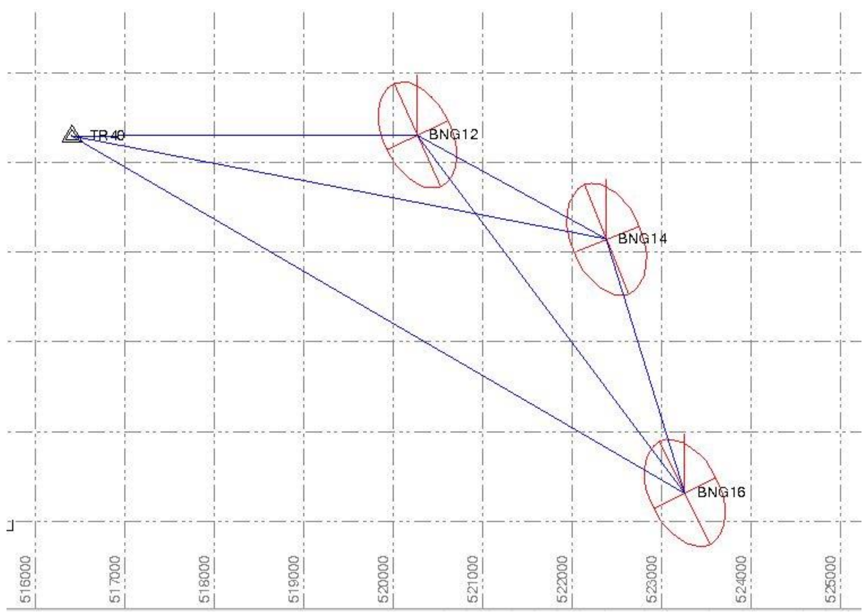


*Figure 3.8: Adjusted network for beidou*

# CHAPTER FOUR

## RESULTS, ANALYSIS AND DISCUSSION

This chapter presents the final results obtained after processing GNSS data using Trimble Business Center (TBC) software and analysis of the results will be thoroughly discussed, and statistically displaying the final results.

## 4.1 BASELINE PROCESSING

### 4.1.1 GPS

GPS satellite data were processed and the final results were obtained, which include adjusted grid coordinates, adjusted geodetic coordinates and the error ellipse as shown in tables 4.1, 4.2 and 4.3.

*Table 4.1: Adjusted grid coordinates for GPS in UTM (WGS84)*

| Point ID | Easting (m) | Easting Error (m) | Northing (m) | Northing Error (m) | Elevation (m) | Elevation Error (m) | Constraint |
|---|---|---|---|---|---|---|---|
| BNG12 | 520262.765 | 0.002 | 9153306.782 | 0.002 | 126.156 | 0.010 | |
| BNG14 | 522375.407 | 0.002 | 9152149.171 | 0.002 | 73.623 | 0.012 | |
| BNG16 | 523254.751 | 0.002 | 9149308.413 | 0.002 | 61.429 | 0.012 | |
| TR40 | 516406.751 | Fixed | 9153296.387 | Fixed | 167.679 | Fixed | EN |

*Table 4.2: Adjusted geodetic coordinates for GPS in UTM (WGS84)*

| Point ID | Latitude | Longitude | Height (m) | Height Error (m) | Constraint |
|---|---|---|---|---|---|
| BNG12 | S7°39'35.29200 | E39°11'01.40856" | 98.865 | 0.010 | |
| BNG14 | S7°40'12.95785" | E39°12'10.38609" | 46.260 | 0.012 | |
| BNG16 | S7°41'45.45123" | E39°12'39.13547" | 34.032 | 0.012 | |
| TR40 | S7°39'35.67906" | E39°08'55.54264" | 140.517 | Fixed | EN |

*Table 4.3: Error ellipse components for GPS*

| Point ID | Semi-major axis | Semi-minor axis | Azimuth |
|---|---|---|---|
| BNG12 | 0.002 | 0.002 | 121° |
| BNG14 | 0.003 | 0.002 | 120° |
| BNG16 | 0.003 | 0.002 | 120° |

### 4.1.2 BEIDOU

BEIDOU satellite data were processed and the final results were obtained, which include adjusted grid coordinates, adjusted geodetic coordinates and the error ellipse as shown in tables 4.4, 4.5 and 4.6.

*Table 4.4: Adjusted grid coordinates for BEIDOU in UTM (WGS84)*

| Point ID | Easting (m) | Easting Error (m) | Northing (m) | Northing Error (m) | Elevation (m) | Elevation Error (m) | Constraint |
|---|---|---|---|---|---|---|---|
| BNG12 | 520262.766 | 0.004 | 9153306.782 | 0.005 | 126.119 | 0.025 | |
| BNG14 | 522375.412 | 0.004 | 9152149.162 | 0.006 | 73.621 | 0.026 | |
| BNG16 | 523254.754 | 0.004 | 9149308.405 | 0.006 | 61.431 | 0.026 | |
| TR40 | 516406.751 | Fixed | 9153296.387 | Fixed | 167.679 | Fixed | EN |

*Table 4.5: Adjusted geodetic coordinates for BEIDOU in UTM (WGS84)*

| Point ID | Latitude | Longitude | Height (m) | Height Error (m) | Constraint |
|---|---|---|---|---|---|
| DCC1 | S7°39'35.29200" | E39°11'01.40862" | 98.828 | 0.025 | |
| DCC2 | S7°40'12.95814" | E39°12'10.38627" | 46.259 | 0.026 | |
| DCC3 | S7°41'45.45150" | E39°12'39.13557" | 34.034 | 0.026 | |
| W. TANK | S7°39'35.67906" | E39°08'55.54264" | 140.517 | Fixed | EN |

*Table 4.6: Error ellipse components for BEIDOU*

| Point ID | Semi-major axis (m) | Semi-minor axis (m) | Azimuth |
|---|---|---|---|
| DCC1 | 0.007 | 0.004 | 155° |
| DCC2 | 0.008 | 0.005 | 157° |
| DCC3 | 0.008 | 0.005 | 153° |

### 4.1.3 BEIDOU + GPS

BEIDOU and GPS satellite data were processed simultaneously and the final results were obtained, which include adjusted grid coordinates, adjusted geodetic coordinates and the error ellipse as shown in tables 4.7, 4.8 and 4.9.

*Table 4.7: Adjusted grid coordinates for BEIDOU + GPS in UTM (WGS84)*

| Point ID | Easting (m) | Easting Error (m) | Northing (m) | Northing Error (m) | Elevation (m) | Elevation Error (m) | Constraint |
|---|---|---|---|---|---|---|---|
| BNG12 | 520262.766 | 0.002 | 9153306.781 | 0.002 | 126.150 | 0.010 | |
| BNG14 | 522375.408 | 0.002 | 9152149.170 | 0.002 | 73.622 | 0.011 | |
| BNG16 | 523254.752 | 0.002 | 9149308.412 | 0.002 | 61.430 | 0.011 | |
| TR40 | 516406.751 | Fixed | 9153296.387 | Fixed | 167.679 | Fixed | EN |

*Table 4.8: Adjusted geodetic coordinates for BEIDOU + GPS in UTM (WGS84)*

| Point ID | Latitude | Longitude | Height (m) | Height Error (m) | Constraint |
|---|---|---|---|---|---|
| BNG12 | S7°39'35.29201" | E39°11'01.40859" | 98.860 | 0.010 | |
| BNG14 | S7°40'12.95789" | E39°12'10.38614" | 46.259 | 0.011 | |
| BNG16 | S7°41'45.45127" | E39°12'39.13550" | 34.033 | 0.011 | |
| TR40 | S7°39'35.67906" | E39°08'55.54264" | 140.517 | Fixed | EN |

*Table 4.9: Error ellipse components for BEIDOU + GPS*

| Point ID | Semi-major axis (m) | Semi-minor axis (m) | Azimuth |
|---|---|---|---|
| BNG12 | 0.002 | 0.002 | 144° |
| BNG14 | 0.003 | 0.002 | 153° |
| BNG16 | 0.003 | 0.002 | 139° |

## 4.2 ANALYSIS OF THE RESULTS

The obtained grid coordinates for the four stations have been computed from Trimble Business Center (TBC) software with static technique. The GPS only coordinates were taken as the true coordinates and used as the base.

### 4.2.1 Analysis of the coordinate difference for all the position solution

The coordinate difference and positional accuracy are obtained from the difference between the GPS solution and BEIDOU solution.

*Position difference = GPS solution – BEIDOU solution* *Equation 3*

*Horizontal position accuracy* = $\sqrt{\Delta E^2 + \Delta N^2}$ *Equation 4*

*Position accuracy* = $\sqrt{\Delta E^2 + \Delta N^2 + \Delta h^2}$ *Equation 5*

The following is the table 4.7 showing the coordinate differences between GPS solution and BEIDOU solution in Easting, Northing and elevation together with horizontal position accuracy of each control station.

*Table 4.10: Position accuracy and coordinates difference of all stations between GPS and BEIDOU*

| Station | ΔE | ΔN | Δh | Horizontal position accuracy | Position accuracy |
|---|---|---|---|---|---|
| BNG12 | -0.001 | 0 | 0.037 | 0.001 | 0.037 |
| BNG14 | -0.005 | 0.009 | 0.002 | 0.01 | 0.01 |
| BNG16 | -0.003 | 0.008 | -0.002 | 0.008 | 0.008 |

*Table 4.11: Position accuracy and coordinates difference of all stations between GPS only and BEIDOU + GPS*

| Station | ΔE | ΔN | Δh | Horizontal position accuracy | Position accuracy |
|---|---|---|---|---|---|
| BNG12 | -0.001 | 0.001 | 0.006 | 0.001 | 0.006 |
| BNG14 | -0.001 | 0.001 | 0.001 | 0.001 | 0.002 |
| BNG16 | -0.001 | 0.001 | -0.001 | 0.001 | 0.002 |

**4.2.2 Analysis of position solution in direction of ΔE, ΔN and Δh**

GPS only and BEIDOU only

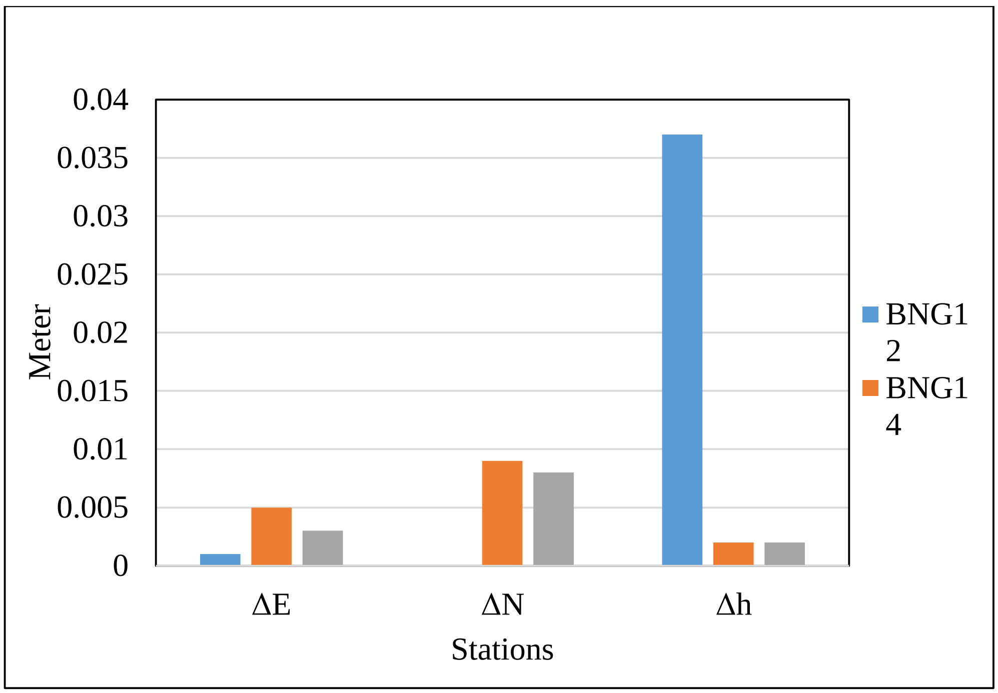


*Figure 4.1: Absolute coordinates difference between GPS and BEIDOU solution*

GPS only and BEIDOU+GPS

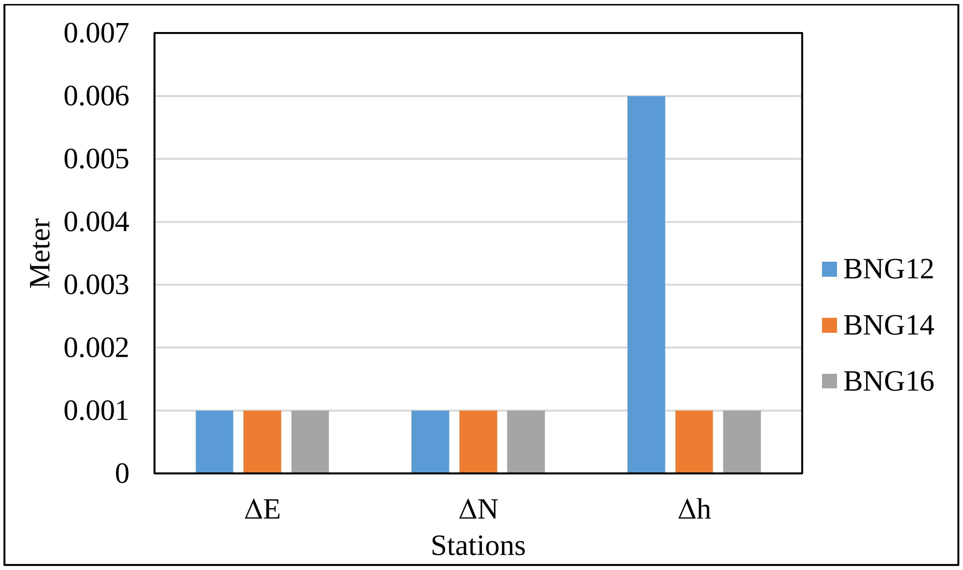


*Figure 4.2: Absolute coordinates difference between GPS only and BEIDOU+GPS solution*

### 4.2.3 Analysis of position solution for position accuracy

GPS only and BEIDOU only

The figure 4.2 shows the horizontal and vertical position accuracy of BEIDOU, and the result lays in millimeter level. This indicates that in Tanzania we can track BEIDOU satellites.

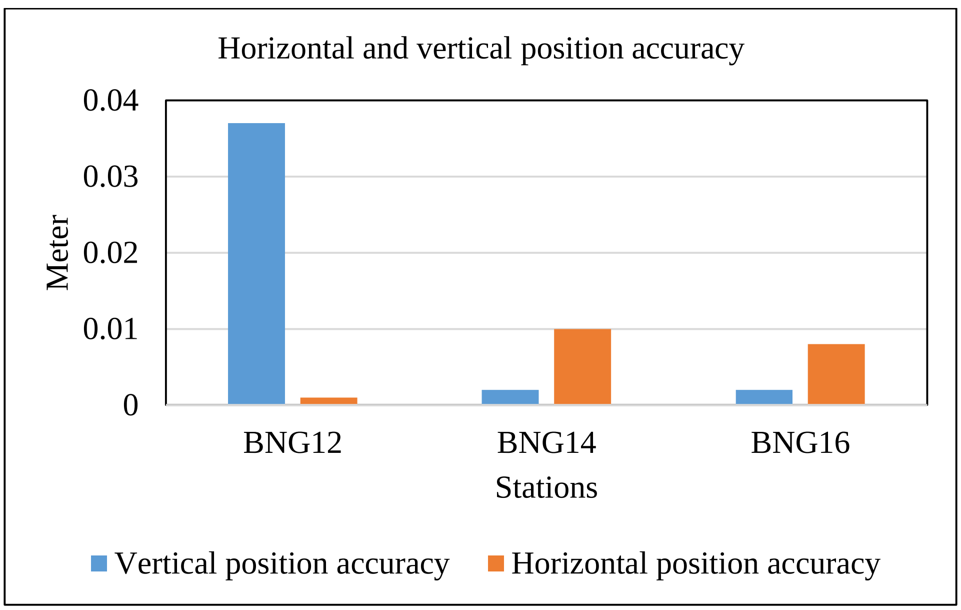


*Figure 4.3: Horizontal and vertical position accuracy*

Figure 4.4 shows position accuracy and the result is in millimeter level. For the station BNG12 tracks many number of satellite of beidou compared to gps which results in 3.5cm position accuracy. This indicates that in Tanzania we can track BEIDOU satellites.

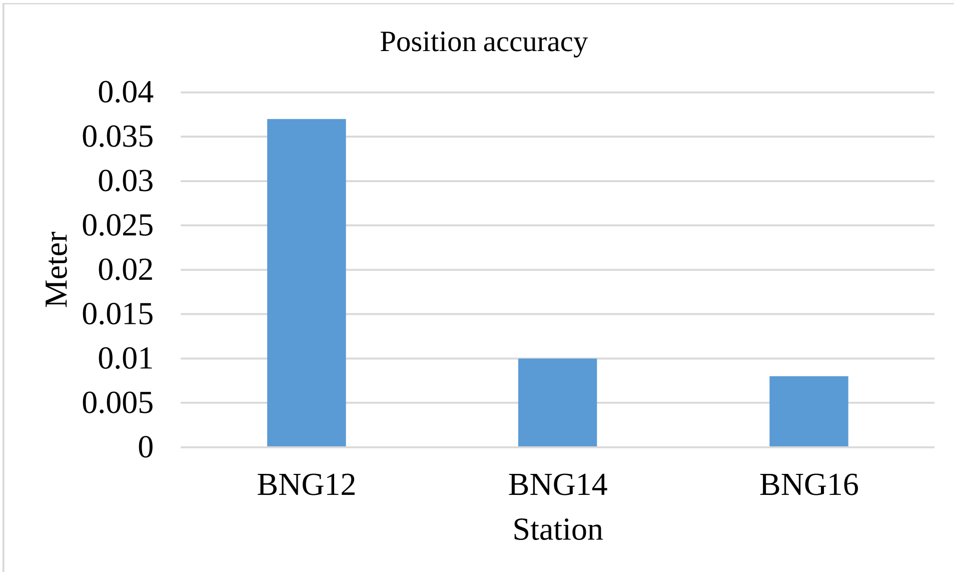


*Figure 4.4: Positional accuracy between GPS only and BEIDOU only for all stations*

GPS only and BEIDOU+GPS

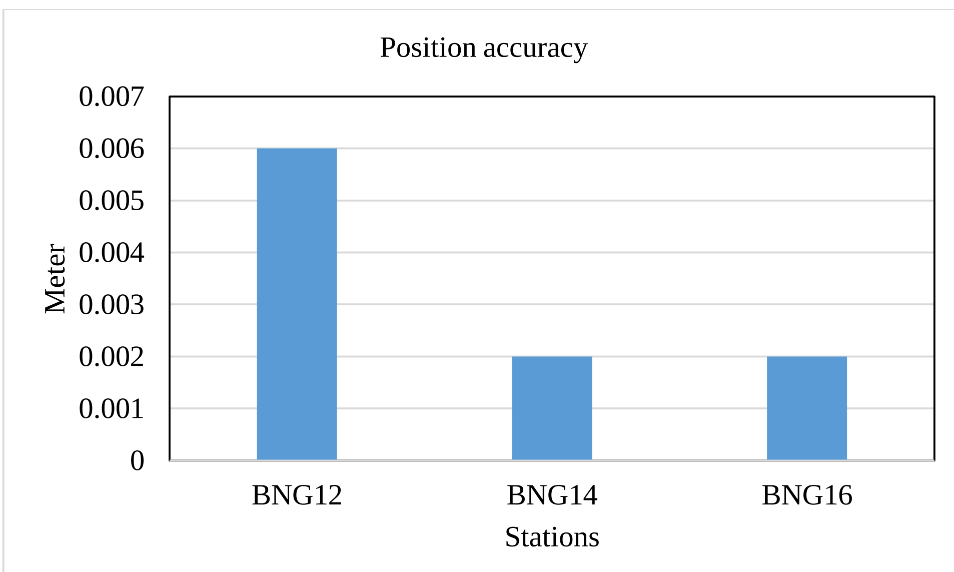


*Figure 4.5: Positional accuracy between GPS only and BEIDOU+GPS for all stations*

In general, the BDS+GPS solution provides reliable results based on the GPS solution since it has minimal coordinate difference with a positional accuracy less than 7mm in all stations.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

The main objective of this research was to validate results between BEIDOU solutions to the GPS solution obtained from Trimble business center software after baseline processing. According to the results, BDS+GPS provides reliable results since it has minimum coordinate difference in both directions which are less than 6mm. The BDS during observation had a greater number of satellites that were tracked by receivers at a time especially in station BNG12 tracks many number of beidou satellites. So, in Tanzania it is easy to track satellites from GPS and BDS systems.

## 5.2 Recommendation

The following are recommendations and potential future research on the reliability and availability of position solutions using multiple GNSS constellations:

I. Due to the availability of Galileo satellites. The future studies can involve all the four GNSS constellations and assess the impact of Galileo on position solution.

II. Assess the performance of the Precise Point Positioning and Differential GPS methods are compared using combined GPS/BEIDOU measurement and investigate the possible benefits of multi- GNSS combination on the PPP and DGPS methods.

III. To analyze and evaluate the accuracy of positioning using dual and multi frequency for both absolute and relative observation.

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