ARDHI UNIVERSITY

ASSESSMENT OF 2D DUAL FREQUENCY SMARTPHONE POSITIONING AGAINST GNSS GEODETIC RECEIVER

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BSc Geomatics

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ASSESSMENT OF 2D DUAL FREQUENCY SMARTPHONE POSITIONING AGAINST GNSS GEODETIC RECEIVER

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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 **"Assessment of 2D Dual Frequency Smartphone Positioning Against GNSS Geodetic Receiver"** in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics at Ardhi University.

………………………………..

Ms. Valerie Ayubu

(Supervisor)

Date ………………………

DECLARATION AND COPYRIGHT

I, MAFUMBI ANDREW W 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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Date …………………………...

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1 Sam. 7:12 “Ebenezer, up to now the Lord has been our help”

DEDICATION

Dedicated to Rev. Can Wilson Mafumbi family, for their love, full support, encouragement and prayers throughout my studies.

ABSTRACT

In May 2016, Google announced the availability of GNSS raw measurements from Android 7. For the first time, developers could access raw observations and decoded navigation messages from mass-market devices. Using GNSS raw data leads to improved accuracy of the positional data obtained through dual frequency smartphone device.

This study assessed 2D positioning of a dual frequency chipped smartphone, Samsung Galaxy S20 5G against that of Geodetic GNSS receivers. Since Geodetic receivers used in GNSS positioning are expensive, use more power i.e., external batteries and are heavy and bulk, assessment of this new chipset GNSS feature of DUAL FREQUENCY on its improvement in smartphone positional accuracy has been vital.

Control Points were established at Ardhi University Campus. The six established control points were then observed alongside two existing controls by use of both Geodetic GNSS Receivers for two hours' occupation time and Samsung Galaxy S20 5G for one, two, three- and four-hours' occupation time. It was so done in order to know how much the observed coordinates under these time ranges converge to the assumed original coordinates values as the occupation time goes up.

The obtained data from each station were then processed using online CSRS-PPP for GNSS Receivers data as well as Samsung Galaxy S20 5G data.

The results showed that precise positioning with use of smartphone can be achieved better in places with low multipath, that is, clear view to the sky. The ability of smartphone device to keep track on the satellite signals is lower on places with obstacles and lack of clear view to the sky.

Geodetic points established on low multipath environment and clear sky visibility such as WTANK, MKG9, GM05 and GM02 brought about better results of less than 10cm accuracy. For geodetic points established on high multipath with obstacles like trees hence lack of clear visibility to the sky, such as GM01, GM03, GM04 and GM06 the results have relatively lower accuracy bringing about results with the accuracy ranging from 12cm to 20cm.

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ACRONYMS AND ABBREVIATIONS

API	Application Programming Interface
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
PPP	Precise Point Positioning
TBC	Trimble Business Centre
DOP	Dilution of Precision
TEQC	Translation Editing and Quality Check
RINEX	Receiver Independent Exchange
CSRS-PPP	Canadian Spatial Reference System Precise Point Positioning

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

A while back, smartphones were only tools for calling, today, smartphones are becoming essential for Geomatics application. Regarding the new technology embedded in today's smartphones, DUAL FREQUENCY GNSS SMARTPHONES are gaining attention for their higher accuracy (Dabove, 2020).

In 2016, an application programming interface (API) was added to the Android Operating Systems, which enables the access of GNSS raw observations from Smartphones for performing precise positioning (using dual frequency chipset). GEO++ RINEX Logger, rinex ON, and to RINEX are amongst many applications used to help get raw measurements and store them into a RINEX file (Dabove, 2020).

The ability to store and provide raw observations directly from the API makes smartphones very useful tool for positioning. This is a great towards the new positioning revolution in smartphones (Wanninger, 2020).

The release of dual-frequency smartphones has taken a lead and they are advantageous since are embedded with GNSS Chipset. This GNSS chipset enable tracking of more than one signal from each satellite, each on a different frequency, and on more than one constellation. This reduces the intensity of satellite loss since the other signal is used to lock the satellite (Wanninger, 2020).

Until 2018, all smartphones contained just single frequency GNSS chipset. Dual frequency smartphones were first limited to flagship devices, however, smartphones with GNSS dual frequency capability are now offered (Dabove, 2020).

Dual frequency smartphones in 2023 are now available as widely as possible. Following QUALCOMM announcement to provide their new chipsets which support for the L5 signals along with the standard L1 signal, prospects for advancements in positioning accuracy have gone higher. Middle class smartphones are to soon start being released with this powerful chipset feature of Dual Frequency capabilities.

GNSS Constellations

There are various constellations and collectively, these constellations and their augmentations are called Global Navigation Satellite Systems (GNSS). These include GPS developed and operated by the United States, GLONASS developed and operated by the Russian Federation, GALILEO developed and operated by the European Union, and BeiDou, developed and operated by China. All these providers have offered free use of their respective systems to the international community.

GNSS technology is used in new and innovative ways to improve the accuracy of location tracking. This is making it possible to track objects and people with a much greater degree of precision. This is having a major impact on a wide range of industries, including logistics, shipping, and manufacturing.

Today, most constellations have multiple signals, each operating at its own frequency. This design maximizes accuracy because receivers can use two frequencies to minimize errors created by the ionosphere. Two frequencies also increase the likelihood that signals will be available when the receiver needs them. Some systems use the second or a third frequency to provide correction data to further enhance accuracy. Figure 1.1 shows the difference between single frequency and dual-frequency;

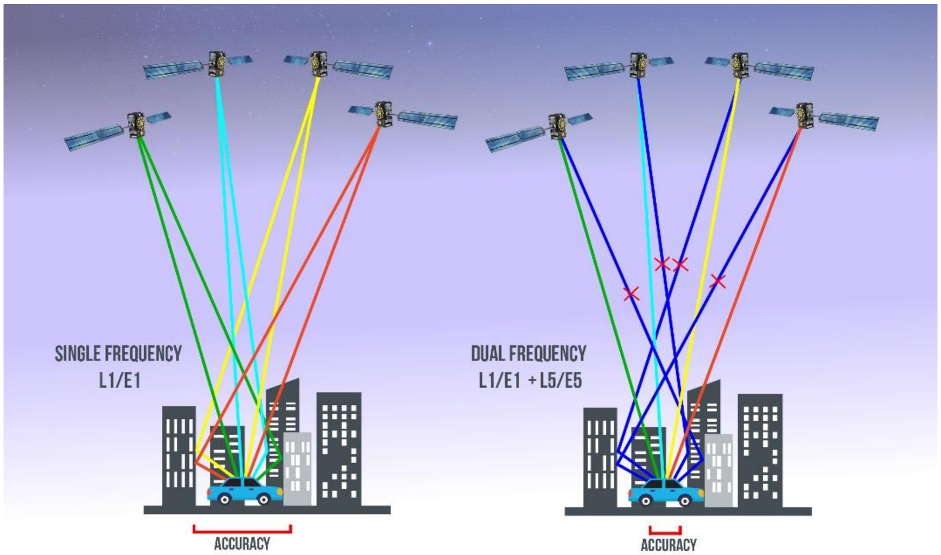

Figure 1.1: Difference between single frequency and dual frequency (E-GNSS Agency, 2020).

FREQUENCY BAND SIGNALS

In the past, a dual-band receiver might simply be one that could receive GPS L1, GLONASS L1 and BeiDou B1, which is really three different frequencies on different constellations. In response to demand for greater accuracy and more robust locating performance, true dual frequency receivers are becoming more common and performing far capabilities as previously defined.

These integrate at least one other "significantly different" frequency from the L1/B1/E1 band set. Modern multi-band receivers have higher expectations placed on them like use of GPS L5 and GALILEO E5a which are more modern and powerful.

GPS

Global Positioning System (GPS) is a satellite-based navigation system developed and operated by the United States made up of over 24 satellites. GPS works in any weather conditions, anywhere in the world, 24 hours a day, with no subscription fees or setup charges. The U.S. Department of Defense (USDOD) originally put the satellites into orbit for military use, but they were made available for civilian use in the 1980s. GPS Technology operates in three frequency bands, L1, L2 and L5 where each frequency has unique properties that make it better suited for certain types of applications (GIS Resource, 2022).

GPS L1 Frequency operates at 1575.42 MHz's It transmits coarse acquisition (C/A) code with a chip rate of 1023 chips per millisecond (open to public), and an encrypted precision (P) code, the P(Y) code, with a chip rate of 10230 chips per millisecond (restricted access, only military).

GPS L2 frequency operates at 1227.60 MHz, which is faster than the L1. This permits the signal to pass through obstacles such as cloud cover, trees, and buildings more effectively. It transmits the P(Y) code and, on newer GPS satellites, the C/A code referred to as L2C (GIS Resource, 2022).

GPS L5 frequency operates at 1176.45 MHz, with higher transmission power and enhanced signal architecture compared to other GPS signals (L1 or L2). It is the most advanced civilian GNSS signal and it is expected that L5 will improve the GPS system's current performance. These codes are faster like the precision codes at L1 and L2, and regarding L5 frequency higher power and lower frequency, L5 frequency is determined to be employed in life-saving transportation as well as other demanding applications such as aviation. L5 is currently widely available (from 12 satellites) and is expected to be fully available in 24 satellites reaching 2024 (GIS Resource, 2022).

GALILEO

GALILEO satellites transmit the E1 signal on the same 1575.42 MHz frequency as GPS's L1. E1 is designed to coexist with this and other nearby signals. It's also very similar to GPS's L1C.

GALILEO's E5 signal is split into E5a and E5b, each 20.46 MHz wide. E5a is centered at 1176 MHz, which is co-located with GPS's L5, while E5b is centered at 1207 MHz's They can be used independently or together. Like GPS's L5, E5 is designed to provide higher precision and higher availability. GALILEO's E6 signal is centered at 1278.75 MHz's Co-located with and similar in use to QZSS's L6 signal, E6 transmits correction data for high-accuracy services, typically to provide precise point positioning (PPP). E6 also provides a higher data rate, making it ideal for applications that require global, high-accuracy positioning (GIS Resource, 2022).

The importance of assessing dual frequency smartphone positioning

A smartphone determines its position by listening to radio signals from satellites in outer space, or Global Satellite Navigation Systems (GNSS). The norm in single frequency smartphones is tracking a single radio signal from each satellite. This can result in inaccuracies of around 5 meters. In real-world, this means mapping app in big cities may not be able to tell exactly which street you're on (Price, 2019).

Dual-frequency GNSS rectifies this issue. Since two is better than one, then instead of relying on just one signal to determine your location, dual frequency devices track more than one signal from each satellite, each on a different radio frequency. For Americans with the GPS systems, the frequencies are called L1 and L5. For Europeans with the Galileo satellites, the frequencies are called E1 and E5a. While single frequency devices only use the L1/E1 frequency, dual-frequency-enabled devices make use of both. The L5/E5a signals are more advanced hence they can be used to refine position accuracy to as low as 30cm versus the 5m mentioned earlier (Price, 2019).

Figure 1.2 shows an image screenshot from **Samsung Galaxy S20 5G** showing its capability of Dual Frequency (Satellite ID 3 GPS signals, L1 and L5) and (Satellite ID 5 GALILEO Signals, E1 and E5a) measurements taken at Ardhi Football Grounds by GPSTest Android App

Figure 1.2: Samsung Galaxy S20 5G showing its Capability of Dual Frequency

It is now possible to make observations for much longer time with dual frequency smartphones of up to six hours' observation time since **duty-cycling model** can be turned off, therefore leading to improved accuracy.

1.2 STATEMENT OF THE PROBLEM

From past years, smartphones have been able to receive only single frequency, that is L1 frequency. Recently, we have smartphones that have the capability to receive dual frequency, that is L1 and L5 for GPS and E1 and E5a for GALILEO.

These advancements of technology have brought numerous benefits to geodetic studies. These advancements have been reflected and extended to smartphone positioning which now have the capability to act as GPS receiver.

Assessment of dual frequency capability on its improvement on smartphone positional accuracy has not been yet done. We do not know exactly by value the advancements on accuracy, and that's what this study is determined to find out.

1.3 RESEARCH OBJECTIVES

1.3.1 Main Objective

The main objective of this research is to assess comparably collected 2D positioning data obtained from dual frequency smartphone to those obtained from Geodetic GNSS Receiver to obtain accuracy of dual frequency smartphone in positioning.

1.3.2 Specific Objectives

The specific objectives include the following;

- To use dual frequency smartphone for geodetic observation
- To use GNSS Receiver for geodetic observation

1.4 SIGNIFICANCE OF THE RESEARCH

The future of GPS technology looks bright. New applications are being developed that will take advantage of the superior capabilities of GPS frequency technology. These new applications include smart cities, autonomous vehicles, and intelligent transportation systems.

It is hence vital to assess dual frequency smartphone positioning since GNSS geodetic receivers are expensive, consume more power and are heavy and bulk. It will be of great significance since dual frequency smartphones are relatively cheaper, consume less power and they are bulk less.

1.5 BENEFICIARIES

Beneficiaries include; Surveyors who incorporate accurate positioning in their works such as Geomatics measurements, Engineering surveys and Cadastral Surveys.

Civilians make use of accurate location services, such as navigating through busy narrow streets, for instance, Kariakoo, Dar es salaam as well as being able to identify their land parcel boundaries, all by themselves. In most cases, it will reduce the cost of Geodetic GNSS Receiver by employing use of dual frequency smartphone, as a low-cost receiver.

1.6 SCOPE AND LIMITATIONS

The study is mainly concentrated with analyzing accuracy of smartphone positioning against that of GNSS Receiver and how it varies through multipath by assessing their performance on open environment as well as multipath factors such as vegetation and buildings over the period of one, two, three- and four-hours' observation time.

The inability of the smartphone to withstand whether conditions like rainfall and strong sun-rays during the day acts as hindering factors on performing the study.

CHAPTER TWO

LITERATURE REVIEW

This chapter gives a comprehensive summary on the literatures related to this study, alongside a summary of previous related studies. It includes discussion regarding results attained as well as methods employed in solving the problem.

2.1 GLOBAL NAVIGATION SATELLITE SYSYEM

Global Navigation Satellite System (GNSS) refers to a term used to describe all forms of satellite-based navigation systems and encompasses all satellite radio-navigation systems that can be accessed globally and provide signals for navigation, positioning, surveillance and timing information for ground, marine, aviation and space applications (Hofmann, 2008).

The GNSS space segment consists of various constellations of satellites orbiting Earth at an altitude of approximately 20,000 km. There are currently four GNSS constellations in operation or in deployment phase: GPS (USA), GLONASS (Russia), BeiDou (China) and Galileo (Europe).

A user position is estimated using the distance measurements (pseudoranges) between the user receiver antenna and the position of at least four satellites. Both are determined by the receiver, which evaluates the satellites signal and navigation message, **respectively**. This information is required by the PVT solution, which provides the user position and time anywhere on the globe. Figure 2.1 shows measurements of code-phase arrival times from at least four satellites;

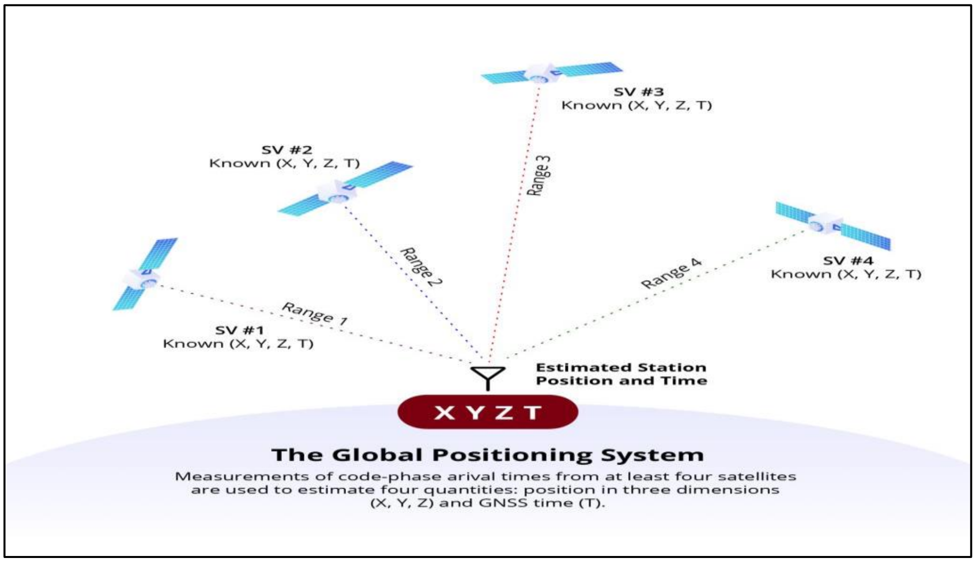

Figure 2.1: GNSS-GPS Trilateration, Code Positioning (Tallysman, 2020).

2.2 POSITIONING WITH GNSS RECEIVER

Static observation mode provides higher precision over long baselines and is used in geodetic control surveys. GNSS receiver is set over a known station whereas the other receiver occupies the station whose coordinates are required. Observation time varies from minutes to several hours, keeping in mind, the longer the observation time, the higher the accuracy. The approximate coordinates of one station can be found by averaging the pseudo range solution (Schofield, 2007).

2.2.1 Cost of GNSS Receiver

Table 2.1 shows the costs for Geodetic GNSS Receivers being relatively high depending in the quality of the components as well as the manufactures technology.

Table 2.1: Cost of GNSS Receivers (Global GPS Systems, 2023)

GNSS SET TYPE	COST (US $)	COST (Tshs)
Carlson BRX7	27,486.36	63,218,628
Pentax G7X	15,361.11	35,330,553
Kolida K1 PRO	10,973.16	25,238,268
South Galaxy G1 PLUS	10,083.56	23,192,188
Satlab SL600	8,577.91	19,729,193
a-GEO L300	7,527.07	17,312,261

2.2.2 Bulkiness of GNSS Receiver

GNSS Receiver set is composed of various components which are huge and heavy to carry, such include external batteries which are sometimes replaced by car batteries, GNSS Receivers, Tripod Stand and Tribrach which are heavy and bulk. Figure 2.2 shows bulkiness of GNSS receiver;

Figure 2.2: Set of GNSS Receiver

2.2.3 Energy Consumption of GNSS Receiver

GNSS Receivers utilize much power especially in the longer observation time tasks such as Static Observation which in turn leads to use of external batteries since the internal ones cannot withstand. This leads to usage of car batteries in order to suffice. Figure 2.3 shows a car battery that sometimes replaces GPS external batteries;

Figure 2.3: Car battery

2.3 POSITIONING WITH DUAL FREQUENCY SMARTPHONE

A GNSS receiver into multi technology products such as smartphones have various components such as GNSS antenna. PIFA (plan inverted F antenna) is one of the typical GNSS antenna embedded into smartphone devices, capable to receive signals from various constellations such as GPS, GLONASS, GALILEO and BeiDou (Abraham, 2011).

An important factor that plays part in an antenna is its location within the smartphone. Designers often have a little choice but to position the antenna in less-than-ideal locations. However, most designers opt to place the antenna in positions where the hands of the user will cover part or not cover at all, in order to result into better signals for the smartphone devices (Abraham, 2011).

2.3.1 Single Frequency GNSS Smartphone

Single Frequency GNSS Smartphone allows tracking of one signal from each satellite from the satellite constellations. This poses a higher chance of satellite loss since only one signal is employed to provide satellite measurements. No presence of the other signal which would otherwise be used to lock the satellite.

Also, Phase observation of single frequency smartphones is not continuous due to the **duty-cycling model**. This model is initially designed to save the low power consumption and prevent battery drainage (Paziewski et al., 2019).

This leads to dis ability of single frequency smartphones to perform much longer observation time with a maximum of 1-hour observation time. The software tends to crash when running static observations for longer observation time (Kanuya, 2021).

2.3.2 Dual Frequency GNSS Smartphone

Dual Frequency GNSS Smartphone is advantageous since it is embeddled with a GNSS chipset that allows tracking of more than one signal from each satellite, each on a different frequency, hence reducing the intensity of satellite loss since the other signal is used to lock the satellite (European GNSS Agency, 2020).

Thanks to the advancements in smartphones technology, now the new GNSS Chipsets support for the L5 signals along with the standard L1 signal, something which is promising for gain of higher accuracy in positioning using Smartphone (European GNSS Agency, 2020).

Dual Frequency GNSS Smartphones have the ability to turn off **duty-cycling mode** hence making it possible to make observations for much longer time for up to 6 hours (Jeonghyeon, 2022).

Dual Frequency GNSS Smartphone Positioning is less costly, less bulky and the power consumption is relatively much lower as compared to the GNSS Receivers. This is advantageous since it brings about usage of less power, less cost as well as less bulkiness.

2.4 RELATED LITERATURES

Various Researches has been conducted regarding the quality of raw data produced through Dual Frequency Smartphones;

A research conducted by Wanninger & Heßelbarth (2020). **GNSS code and carrier phase observations of a Huawei P30 smartphone: quality assessment and centimetre-accurate positioning**. In this work, researchers analysed the quality of the GNSS observations, especially the carrier phase observations, of the dual frequency GNSS chip Kirin 980 built into Huawei P30. More than 80h of static observations were collected at several locations. The code and carrier phase observations were processed in baseline mode with reference to observations of geodetic-grade equipment. They were able to fix carrier phase ambiguities for GPS L1 observations. After successful ambiguity fixing, the 3D position errors (standard deviations) are smaller 4 cm after 5 min of static observation session and 2 cm for long observation sessions (Wanninger, 2020).

A research conducted by Elmezayen & El-Rabbany (2019). **Precise Point Positioning Using World's First Dual-Frequency GPS/GALILEO Smartphone**. In this work, researchers analyse the GNSS precise point positioning (PPP) accuracy of the Xiaomi mi 8 smartphone in post-processing and real-time modes. Raw dual-frequency observations are collected over two different time windows from both of the Xiaomi mi 8 smartphone and a Trimble R9 geodetic-quality GNSS receiver. The data sets were first processed in differential modes using Trimble Business Centre (TBC) software in order to provide the reference positioning solution for both of the geodetic receiver and the smartphone. An in-house PPP software is then used to process the collected data in both of post-processing and real-time modes. Precise ephemeris obtained from the multi-GNSS experiment (MGEX) is used for post-processing PPP, while the new NAVCAST real-time GNSS service, Germany, is used for real-time PPP. Real-time PPP solution is assessed in both of static and kinematic modes. It is shown that the dual-frequency GNSS smartphone is capable of achieving decimeter-level positioning accuracy, in both of post-processing and real-time PPP modes, respectively. Meter-level positioning accuracy is achieved in the kinematic mode (Elmezayen, 2019).

A research conducted by Massarweh & Darugna (2019). **Statistical Investigation of Android GNSS Data: Case Study Using Xiaomi Mi 8 Dual-Frequency Raw Measurements**. In this work, researchers analyse raw GNSS measurements retrieved by using a Xiaomi Mi 8, equipped with the Broadcom BCM47755. The main objective was to explore possibilities given by the open access to raw GNSS measurements in order to achieve an optimal selection of raw data in support to smartphone-based precise positioning. The device has been then tested in static conditions over a geodetic pillar, and two different Android mobile applications ("GNSS Logger" and "GADIP3") have been used for logging the raw GNSS data. By considering carrier-phase observable needed for precise positioning techniques, decimeter-level positioning accuracy has been found (Massarweht, 2019).

Another research conducted by Hakansson (2018). Characterization of GNSS observation from Nexus 9 Android tablet. In this work, researchers assess the raw GNSS observations and the obtained precise position of a Nexus 9 tablet. Various biases of the observations are determined, some of which are not present on geodetic GNSS receivers. The assessment shows that multipath affects greatly on the accuracy of the position obtained by the Nexus 9 tablet. This is due to both, induced error on the measurements and loss of lock of the GNSS signal which in turn greatly affects precise positioning from carrier-phase measurements. Position accuracy ranges from just below 1 meter for moderate setups and to a few decimetres for low levels of multipath, for positioning based on carier-phase observations (Hakansson, 2018).

CHAPTER THREE

METHODOLOGY

This chapter explains the procedures and activities executed so as to attain the objectives. It elaborates from reconnaissance, network design, mission planning, data collection, data processing and outputs.

3.1 DESCRIPTION OF STUDY AREA

The study area for this project is around ARDHI UNIVERSITY compound. The area is well suited for its presence with adequate control points. These are survey points whose relative positions in two or three dimensions are known to specified degrees of accuracy, hence acting as base points for this study.

3.2 RECONNAISSANCE

3.2.1 Office Reconnaissance

Began with the search of existing control stations whereas the coordinate list of the control stations over the area was obtained. Existing control stations were then plotted on a map of a suitable scale to depict the project area and surroundings. Table 3.1 shows control points coordinates;

Table 3.1: List of Control Points

POINT	NORTHINGS	EASTINGS	ELEVATION
WATER TANK	9252082.850	523169.738	101.569
MKG09	9252343.604	523946.676	40.503

3.2.2 Field Reconnaissance

So as to confirm the findings from the office, the control stations were then visited to identify their existence, and study nature of terrain in order to identify requirements, logistics, methods and instrumentation to be used.

Control Points MKG09 and WATER TANK were found to be in good shape to be used, strength of the figure considered.

3.3 NETWORK DESIGN

The proposed control survey network was designed in a tentative position. The map was then exported in kml format for ease navigation to the newly designed station site by use of the GPS ESSENTIAL APP. Final location of the new station site was then placed considering good visibility to the sky and low multipath, good geometry in the network alongside use of independent baselines. Figure 3.1 shows the design of the control network at Ardhi University Campus;

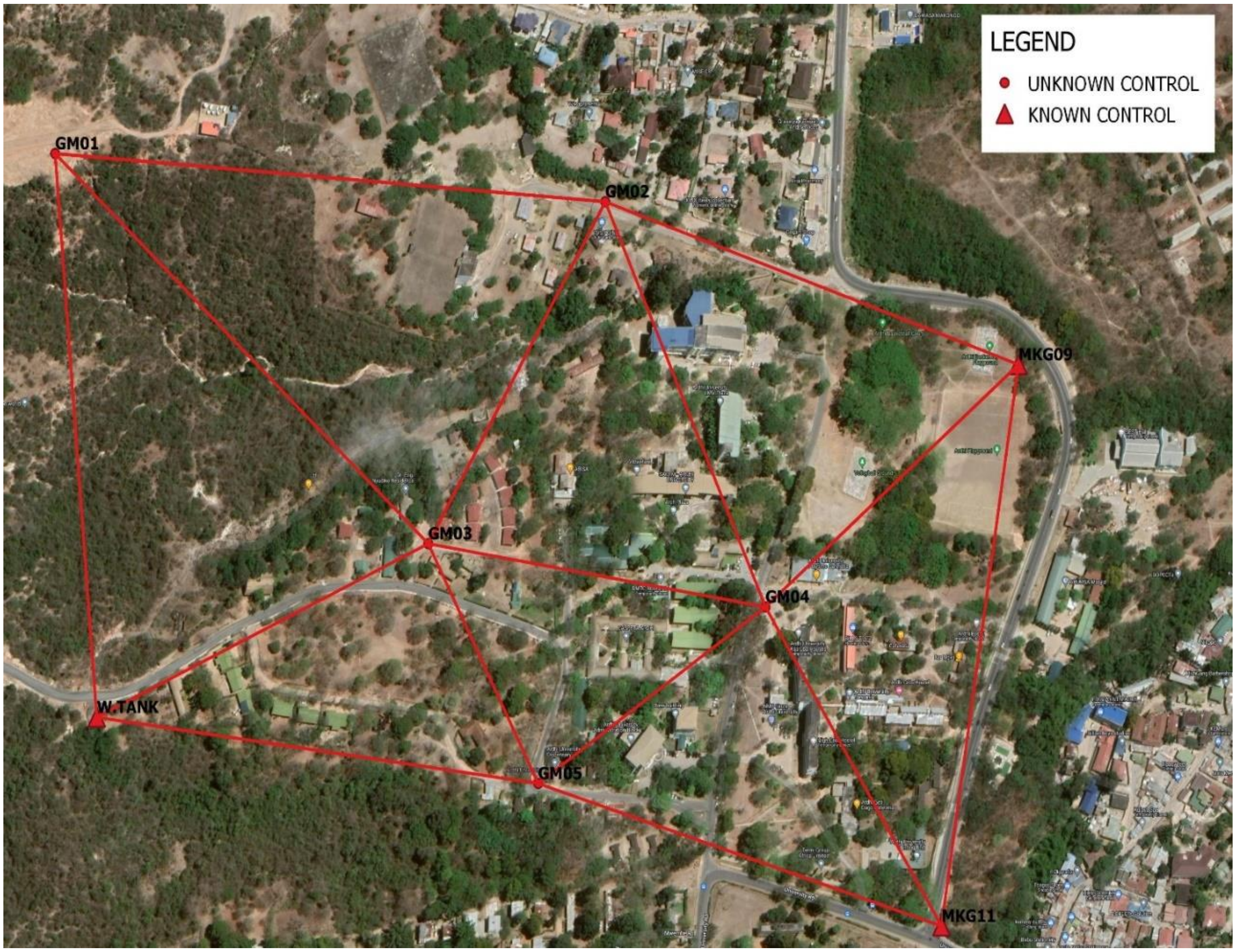

Figure 3.1: Designed Control Network at Ardhi University (Google Earth)

3.4 MONUMENTATION

Iron Pin Concrete (IPC) markers for the newly control stations were placed on the survey area whereas they were monumented on hard ground in order to ensure stability as shown in figure 3.2. Figure 3.3 shows a monumented control point, GM04.

Figure 3.2: Monumentation Process

Figure 3.3: Monumented control point, GM04

3.5 MISSION PLANNING

GPS mission planning is an accurate way for GPS users to determine the number of satellites that will be available over a given period of time and their arrangement (geometry) over any period. This leads to better accuracy of observation since observations would be conducted at a period where most satellites are to be available.

Calculation of the dilution of precision (DOP) was done using Trimble GNSS Planning Online showing the day when the observation is to be carried out in order to realize the time for better observations. Dilution of Precision (DOP) DOP is expressed as a numeric value; below 4 yield excellent precision, 5 to 7 are acceptable, above 7 yield poor precisions. Observations are therefore intended to be performed during times of low value of DOP

Figure 3.4 shows the determination of number of satellites that will be available on 1st May 2023 which was done using Trimble GNSS Planning Online for the day when the observation was to be carried out. Figure 3.5 depicts the Dilution of Precisions for the day when the observation was to be carried out.

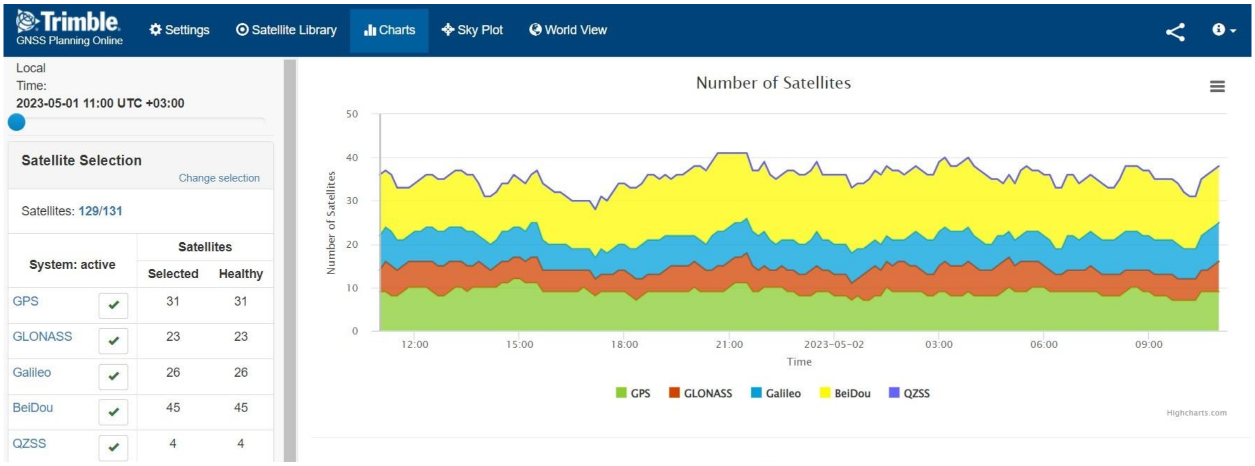

Figure 3.4: Determining Number of Satellites using Trimble GNSS Planning Online

Figure 3.5: Determining DOP’s using Trimble GNSS Planning Online

Mission planning using Trimble GNSS Planning Online was helpful in making the choice of the time to perform observations depending on the number of available satellites and low value of dilution of precision.

3.6 GNSS RECEIVER STATIC OBSERVATION

GNSS Observation was done using Static Method or the occupation time of two (02) hours' time. Figure 3.6 shows a setup of GNSS Receiver Static Observation at MKG9 Control Point;

Figure 3.6: GNSS Receiver Static Observation

3.7 DUAL FREQUENCY SMARTPHONE STATIC OBSERVATION

The observations were done using a dual frequency smartphone device, Samsung Galaxy S20 5G priced around USD$ 400-500. Figure 3.7 shows Samsung Galaxy S20 5G alongside the related specifications;

COMMS	WLAN	Wi-Fi 802.11 a/b/g/n/ac/6, dual-band, Wi-Fi Direct
	Bluetooth	5.0, A2DP, LE
	Positioning	GPS, GLONASS, BDS, GALILEO
	NFC	Yes
	Radio	FM radio (Snapdragon model only; market/operator dependent)
	USB	USB Type-C 3.2, OTG

Figure 3.7: Samsung Galaxy S20 5G Specifications

In order to reach to confident results, it was most important to place the device in a good way. Smartphone holder was then built and designed to allow performance of observations using the dual frequency smartphone. Figure 3.8 shows Samsung Galaxy S20 5G in an upright position mounted on tribrach and tripod;

Figure 3.8: Performance of observations on Smartphone holder at GM05

A static observation using smartphone were done employing Single Point Positioning technique with an occupation time of 6 hours, 4 hours and 2 hours to every point of the network design. The reason of having various observation files with varying occupation times was in order to know how much the observed coordinates under these time ranges converge to the assumed original coordinates values as the occupation time goes up.

Figure 3.9 and 3.10 shows static observation through use of Samsung Galaxy S20 5G at GM04 and GM05 respectively;

Figure 3.9: Static Observation at GM04 Figure 3.10: Static Observation at GM05

To every point, Geo++ RINEX Logger Software was employed which provided raw data in RINEX format version 3.02, later to be post processed in order to attain position information. Figure 3.11 shows use of Geo++ RINEX Logger Software to collect raw GNSS data;

Figure 3.11: Using Geo++ RINEX Logger Software

3.8 QUALITY CHECK

Quality check for observation data is basically important as it compares the actual observed data versus standard observed data, if there were no problem during observation. This ensures the quality and standard of the observed data before post processing. These comparisons are in terms of percentage and if below 60% the observations are regarded as poor, above 60% are regarded as good and above 80% the observations are regarded as excellent.

Quality check were done using EFIX GEOMATICS OFFICE (eOffice) Program as shown in figure 3.12;

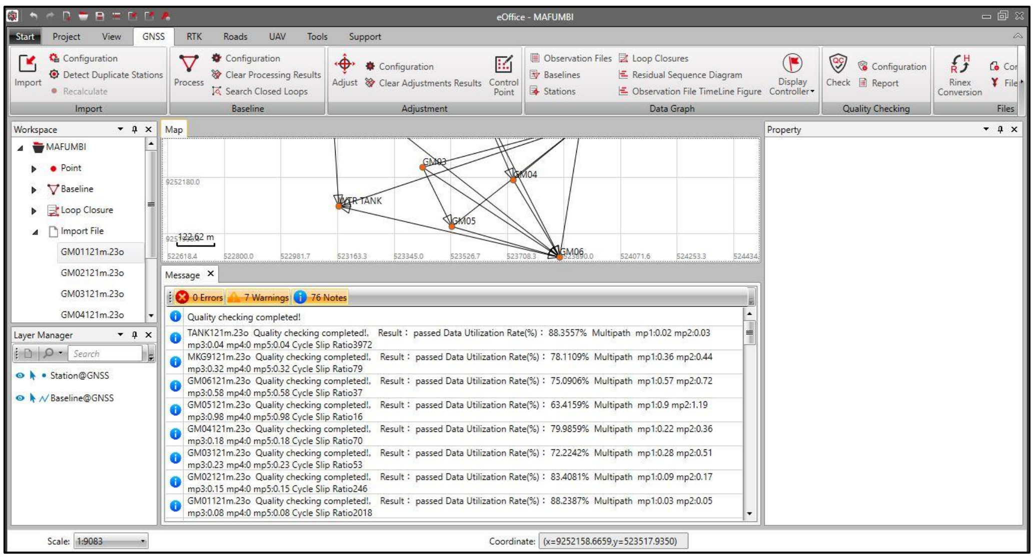

Figure 3.12: Quality check were done using EFIX GEOMATICS OFFICE

In this work, all observations were found to have quality above 60% hence meaning that they were of good quality, as shown in figure 3.13;

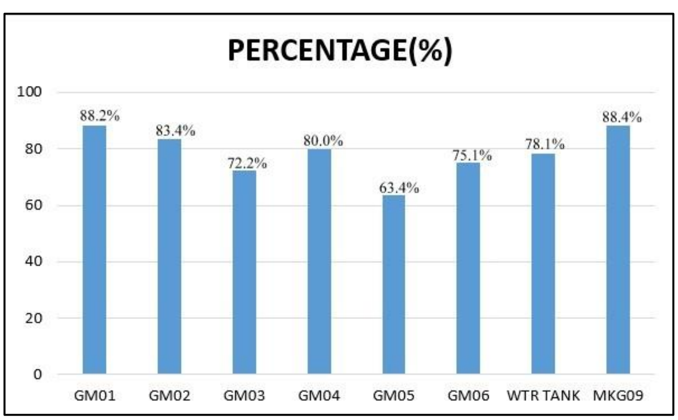

Figure 3.13: Stations and their quality checks in percentage

3.9 DATA PROCESSING

This involved the extraction of raw data from the GNSS Receivers as well as Smartphone Device for post processing in order to obtain positional information.

Files were first renamed into the proper format, that is first four letters describing point name, GM01, second three describing day of year as per the GNSS Calendar, in this case, 121 and last one letter describing session, M, together hence becomes GM01121M. Likewise the other points.

3.9.1 Dual Frequency Smartphone Static Data Processing

Smartphone data processing was done using online Canadian system, CSRS-PPP. The files were imported to the system whereas Static Processing Mode was employed. This makes possible to process data through use of ITRF which is the realization of the ITRS whereas its origin is at the center of mass of the whole earth including the oceans and atmosphere.

This method was hence considered best since it works well with processing of smartphone raw data. It makes use of the same epoch, just as the GPS data epoch.

The Canadian Spatial Reference System also makes possible for processing raw smartphone data in a more accurate way through calculating UTM zone from the longitude of the raw data as shown on figure 3.14. This leads to improved processed positional results.

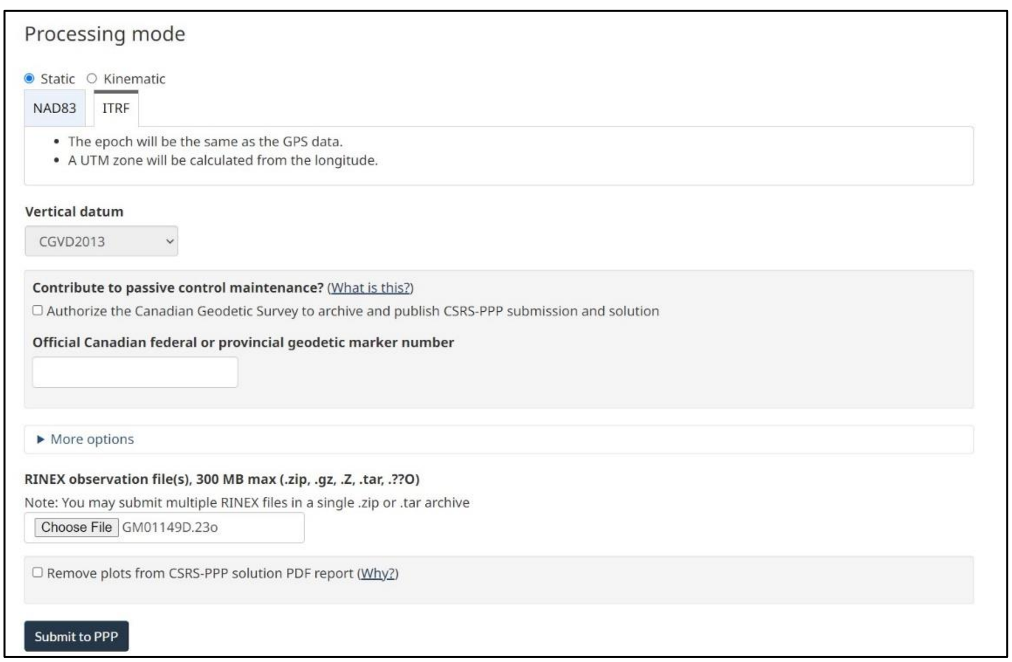

Figure 3.14: Canadian Spatial Reference System, Precise Point Positioning

The raw smartphone data were then submitted to PPP for processing, which takes about 2 to 3 minutes. Figure 3.15 shows the results that were emailed through the email address provided at the start.

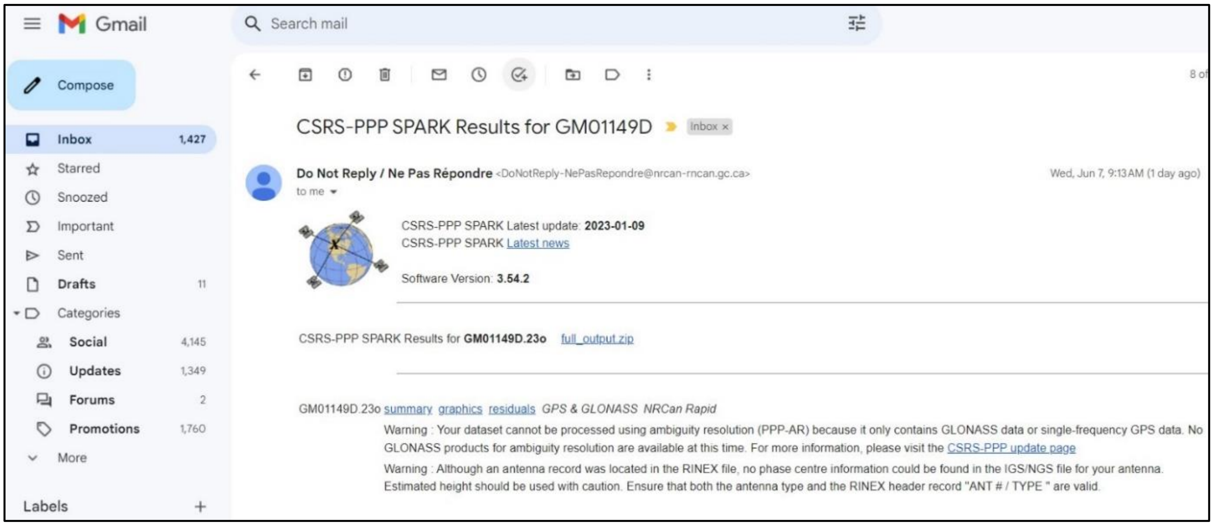

Figure 3.15: CSRS-PPP Smartphone Data Results through email address

The estimated coordinates based on the ITRF20 on UTM Zone 37 South for the raw smartphone raw data were then obtained as shown on figure 3.16;

The estimated coordinates **ITRF20 2023-05-29** for the **GM01149G.23o** RINEX file are as follows:

Latitude	S6° 45' 44.9160" ± 3.337 m (95%)
Longitude	E39° 12' 33.8707" ± 3.463 m (95%)
Ellipsoidal Height	64.872 m ± 10.004 m (95%)

[-6.76247667,39.20940853,64.872]

UTM Zone 37 (South)

Northing	9252503.405 m
Easting	523140.936 m
Scale factor (point)	0.99960663
Scale factor (combined)	0.99959643

[9252503.405,523140.936,64.872]

Cartesian coordinates

X	4907935.226 ± 8.251 m (95%)
Y	4004156.490 ± 6.534 m (95%)
Z	-746063.334 ± 3.526 m (95%)

[4907935.226,4004156.490,-746063.334]

Orbits and Clocks Used: **NRCan/IGS Final**
GNSS Data: **GPS & GLONASS**
GRS80 ellipsoid used for (x,y,z) to (lat,lon,h) transformation

Figure 3.16: Estimated Coordinates ITRF20 for raw smartphone data

3.9.2 GNSS Receiver Static Data Processing

GNSS data processing was done using online Canadian system, CSRS-PPP. The files were imported into the system whereas Static Processing Mode was employed. The raw GNSS receiver data were then submitted to PPP for processing, which takes about 2 to 3 minutes. Figure 3.17 shows the results that were emailed through the email address provided at the start.

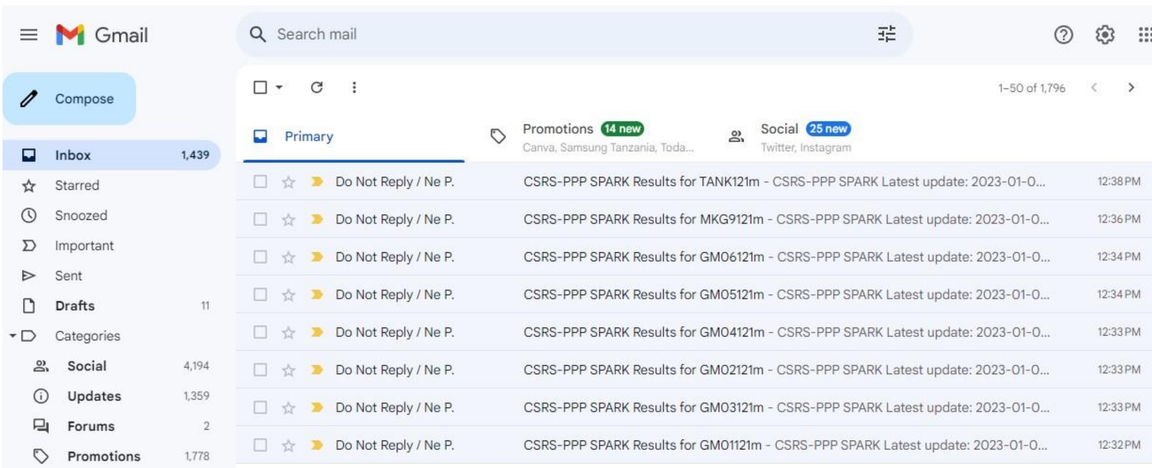

Figure 3.17: CSRS-PPP GNSS Receiver Data Results through email address

The estimated coordinates based on the ITRF20 on UTM Zone 37 South for the Raw GNSS Receiver Data were then obtained as shown on figure 3.18;

The estimated coordinates **ITRF20 2023-05-01** for the **TANK121m.23o** RINEX file are as follows:

Latitude	S6° 45' 58.6109" ± 0.009 m (95%)
Longitude	E39° 12' 34.8145" ± 0.009 m (95%)
Ellipsoidal Height	73.614 m ± 0.040 m (95%)

[-6.76628079,39.20967069,73.614]

UTM Zone 37 (South)

Northing	9252082.861 m
Easting	523169.725 m
Scale factor (point)	0.99960664
Scale factor (combined)	0.99959507

[9252082.861,523169.725,73.614]

Cartesian coordinates

X	4907885.236 ± 0.030 m (95%)
Y	4004153.109 ± 0.027 m (95%)
Z	-746482.137 ± 0.010 m (95%)

[4907885.236,4004153.109,-746482.137]

Orbits and Clocks Used: **NRCan/IGS Final**
GNSS Data: **GPS & GLONASS**
GRS80 ellipsoid used for (x,y,z) to (lat,lon,h) transformation

Figure 3.18: Estimated Coordinates ITRF20 for Raw GNSS Receiver Data

CHAPTER FOUR

RESULT, ANALYSIS AND DISCUSSION

This chapter generally covers the analysis of the results from processed data and the computations from methodology. This includes the comparison of the obtained coordinates of each station from the static observation (control survey) to those of dual frequency smartphone positioning and single GNSS receiver positioning.

4.1 GNSS RECEIVER RESULTS

Table 4.1 shows the positional results of network points observed through GNSS Receiver downloaded from the email address;

Table 4.1: ITRF20 Estimated Coordinates for the network

Point ID	Easting(m)	Northing(m)
GM01	523141.102	9252503.623
GM02	523606.099	9252462.494
GM03	523444.536	9252214.094
GM04	523733.097	9252173.927
GM05	523537.697	9252025.272
GM06	523881.623	9251926.541
MKG09	523946.667	9252343.633
WTR TANK	523169.725	9252082.861

4.2 DUAL FREQUENCY SMARTPHONE RESULTS

Table 4.2 shows the positional results of network points observed through Samsung Galaxy S20 5G smartphone in one-hour occupation downloaded from the email address;

Table 4.2: ITRF20 Estimated Coordinates in 1-hour occupation time

Point ID	Easting(m)	Northing(m)
GM01	523140.292	9252502.587
GM02	523605.570	9252461.810
GM03	523445.374	9252213.076
GM04	523734.022	9252172.998
GM05	523538.491	9252026.445
GM06	523882.769	9251927.447
MKG09	523947.506	9252343.122
WTR TANK	523170.330	9252082.254

Table 4.3 shows the positional results of network points observed through Samsung Galaxy S20 5G smartphone in two hours' occupation downloaded from the email address;

Table 4.3: ITRF20 Estimated Coordinates in 2 hours' occupation time

Point ID	**Easting(m)**	**Northing(m)**
GM01	523140.360	9252502.831
GM02	523605.774	9252461.978
GM03	523445.242	9252213.378
GM04	523733.866	9252174.378
GM05	523538.260	9252026.095
GM06	523882.450	9251927.238
MKG09	523946.908	9252343.467
WTR TANK	523169.958	9252082.426

Table 4.4 shows the positional results of network points observed through Samsung Galaxy S20 5G smartphone in three hours' occupation downloaded from the email address;

Table 4.4: ITRF20 Estimated Coordinates in 3 hours' occupation time

Point ID	**Easting(m)**	**Northing(m)**
GM01	523140.606	9252503.115
GM02	523605.907	9252462.121
GM03	523445.080	9252213.657
GM04	523733.566	9252174.128
GM05	523537.924	9252025.693
GM06	523881.320	9251926.153
MKG09	523946.626	9252343.485
WTR TANK	523169.781	9252082.883

Table 4.5 shows the positional results of network points observed through Samsung Galaxy S20 5G smartphone in four hours' occupation downloaded from the email address;

Table 4.5: ITRF20 Estimated Coordinates in 4 hours' occupation time

Point ID	**Easting(m)**	**Northing(m)**
GM01	523140.936	9252503.405
GM02	523606.025	9252462.333
GM03	523444.655	9252213.896
GM04	523733.284	9252174.030
GM05	523537.775	9252025.362
GM06	523881.426	9251926.350
MKG09	523946.657	9252343.666
WTR TANK	523169.756	9252082.821

4.3 COMPARISON OF GNSS RECEIVER POSITION TO SMARTPHONE POSITIONS

Comparison of position obtained from Geodetic GNSS Receiver to those obtained from Samsung Galaxy S20 5G was carried out so as to determine the deviations. The comparisons were done in such a way that Geodetic Receiver positional information act as reference position.

Table 4.6 shows deviations of Smartphone Positioning from Geodetic GNSS Receiver Positioning in 1 hour;

Table 4.6: Comparison in 1-hour occupation time

	Leica GS15		**S20 5g Smartphone**		**Difference**	
Point ID	**E(m)**	**N(m)**	**E(m)**	**N(m)**	**△E(m)**	**△N(m)**
GM01	523141.102	9252503.623	523140.290	9252502.582	0.812	1.041
GM02	523606.099	9252462.494	523605.568	9252461.805	0.531	0.689
GM03	523444.536	9252214.094	523445.372	9252213.071	0.836	1.023
GM04	523733.097	9252173.927	523734.020	9252172.993	0.923	0.934
GM05	523537.697	9252025.272	523538.489	9252026.440	0.792	1.168
GM06	523881.623	9251926.541	523882.767	9251927.442	1.144	0.901
MKG09	523946.667	9252343.633	523947.504	9252343.117	0.837	0.516
WTANK	523169.725	9252082.861	523170.328	9252082.249	0.603	0.612

Table 4.7 shows deviations of Smartphone Positioning from Geodetic GNSS Receiver Positioning in two hours;

Table 4.7: Comparison in 2 hours' occupation time

	Leica GS15		**S20 5g Smartphone**		**Difference**	
Point ID	**E(m)**	**N(m)**	**E(m)**	**N(m)**	**△E(m)**	**△N(m)**
GM01	523141.102	9252503.623	523140.358	9252502.826	0.744	0.797
GM02	523606.099	9252462.494	523605.772	9252461.973	0.327	0.521
GM03	523444.536	9252214.094	523445.240	9252213.373	0.704	0.721
GM04	523733.097	9252173.927	523733.864	9252174.373	0.767	0.446
GM05	523537.697	9252025.272	523538.258	9252026.090	0.561	0.818
GM06	523881.623	9251926.541	523882.448	9251927.233	0.825	0.692
MKG09	523946.667	9252343.633	523946.906	9252343.462	0.239	0.171
WTANK	523169.725	9252082.861	523169.956	9252082.421	0.231	0.440

Table 4.8 shows deviations of Smartphone Positioning from Geodetic GNSS Receiver Positioning in three hours;

Table 4.8: Comparison in 3 hours' occupation time

	Leica GS15		**S20 5g Smartphone**		**Difference**	
Point ID	**E(m)**	**N(m)**	**E(m)**	**N(m)**	**△E(m)**	**△N(m)**
GM01	523141.102	9252503.623	523140.604	9252503.110	0.498	0.513
GM02	523606.099	9252462.494	523605.905	9252462.116	0.194	0.378
GM03	523444.536	9252214.094	523445.078	9252213.652	0.542	0.442
GM04	523733.097	9252173.927	523733.564	9252174.123	0.467	0.196
GM05	523537.697	9252025.272	523537.922	9252025.688	0.225	0.416
GM06	523881.623	9251926.541	523881.318	9251926.148	0.305	0.393
MKG09	523946.667	9252343.633	523946.624	9252343.480	0.043	0.153
WTANK	523169.725	9252082.861	523169.779	9252082.878	0.054	0.017

Table 4.9 shows deviations of Smartphone Positioning from Geodetic GNSS Receiver Positioning in four hours;

Table 4.9: Comparison in 4 hours' occupation time

	Leica GS15		**S20 5g Smartphone**		**Difference**	
Point ID	**E(m)**	**N(m)**	**E(m)**	**N(m)**	**△E(m)**	**△N(m)**
GM01	523141.102	9252503.623	523140.934	9252503.400	0.168	0.223
GM02	523606.099	9252462.494	523606.023	9252462.328	0.076	0.166
GM03	523444.536	9252214.094	523444.653	9252213.891	0.117	0.203
GM04	523733.097	9252173.927	523733.282	9252174.025	0.185	0.098
GM05	523537.697	9252025.272	523537.773	9252025.357	0.076	0.085
GM06	523881.623	9251926.541	523881.424	9251926.345	0.199	0.196
MKG09	523946.667	9252343.633	523946.655	9252343.661	0.012	0.028
WTANK	523169.725	9252082.861	523169.754	9252082.816	0.029	0.045

4.4 GRAPHICAL COMPARISON OF GNSS RECEIVER TO SMARTPHONE POSITION

Figure 4.1 shows graphical comparison to represent the difference of the positions in northings obtained from Smartphone to those of GNSS Receiver in one-hour occupation time;

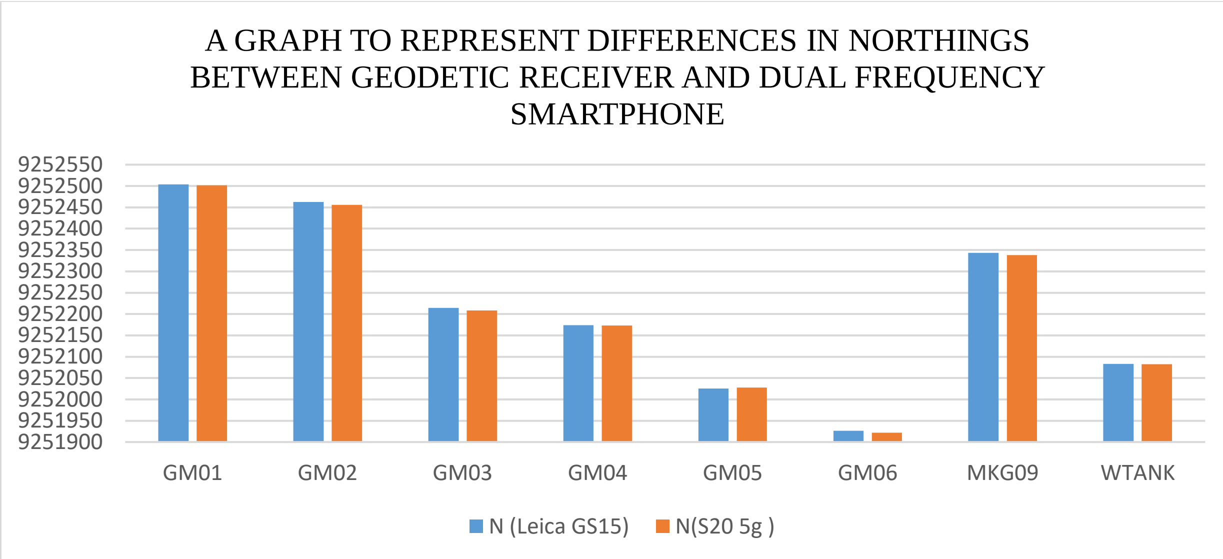

Figure 4.1: Graphical comparison of the northings in 1-hour occupation time

Figure 4.2 shows graphical comparison to represent the difference of the positions in northings obtained from Smartphone to those of GNSS Receiver in two hours' occupation time;

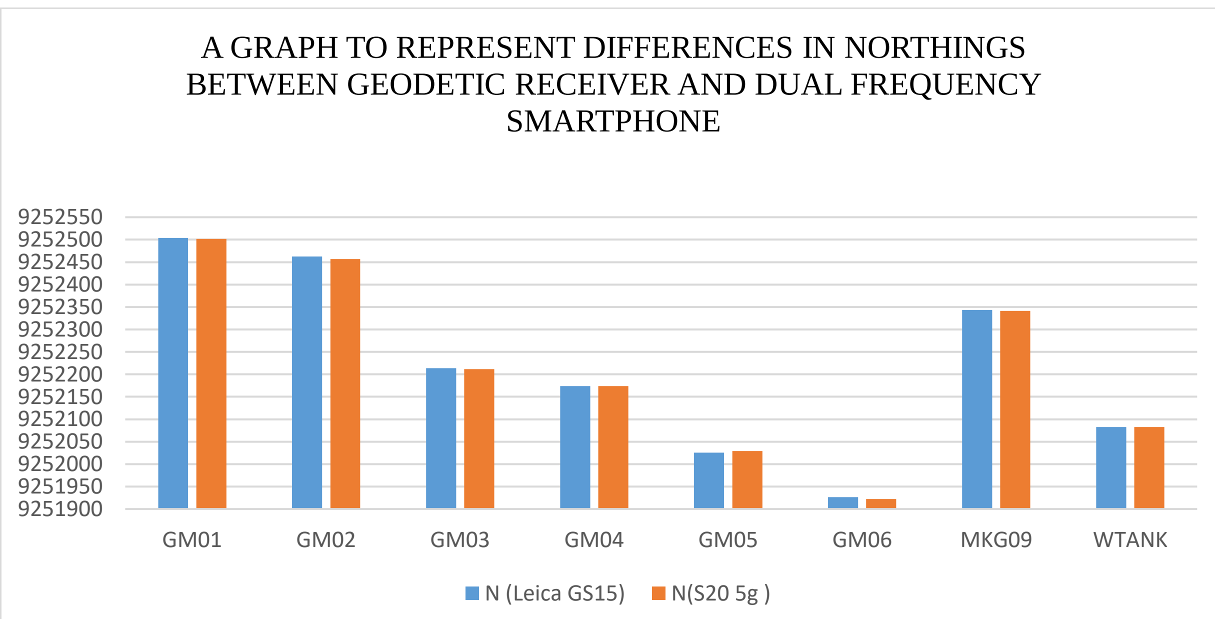

Figure 4.2: Graphical comparison of the northings in 2 hours' occupation time

Figure 4.3 shows graphical comparison to represent the difference of the positions in northings obtained from Smartphone to those of GNSS Receiver in three hours' occupation time;

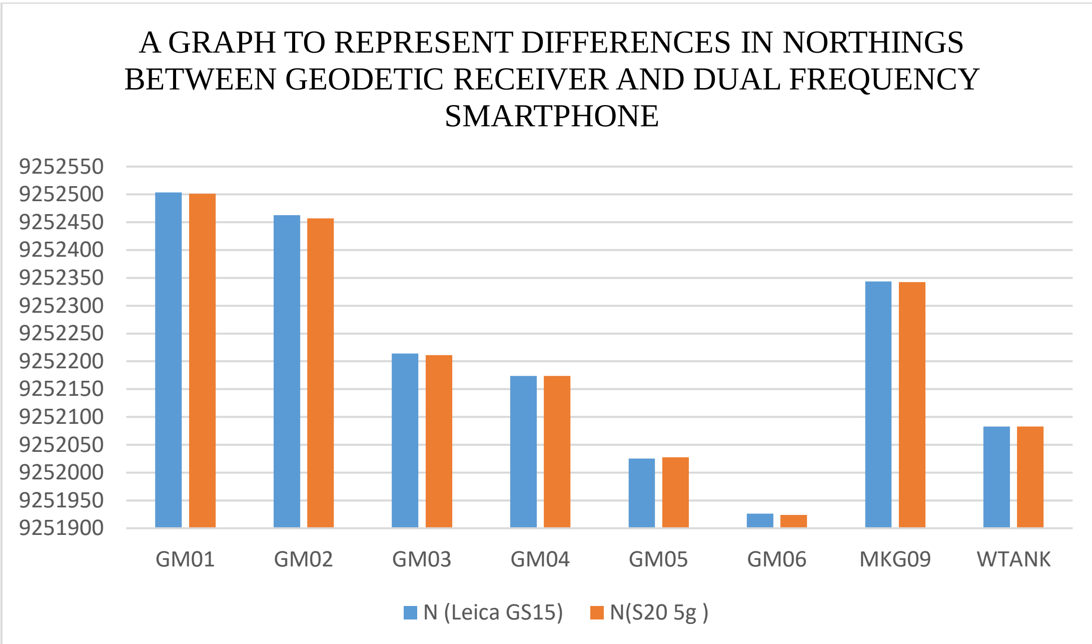

Figure 4.3: Graphical comparison of the northings in 3 hours' occupation time

Figure 4.4 shows graphical comparison to represent the difference of the positions in northings obtained from Smartphone to those of GNSS Receiver in four hours' occupation time;

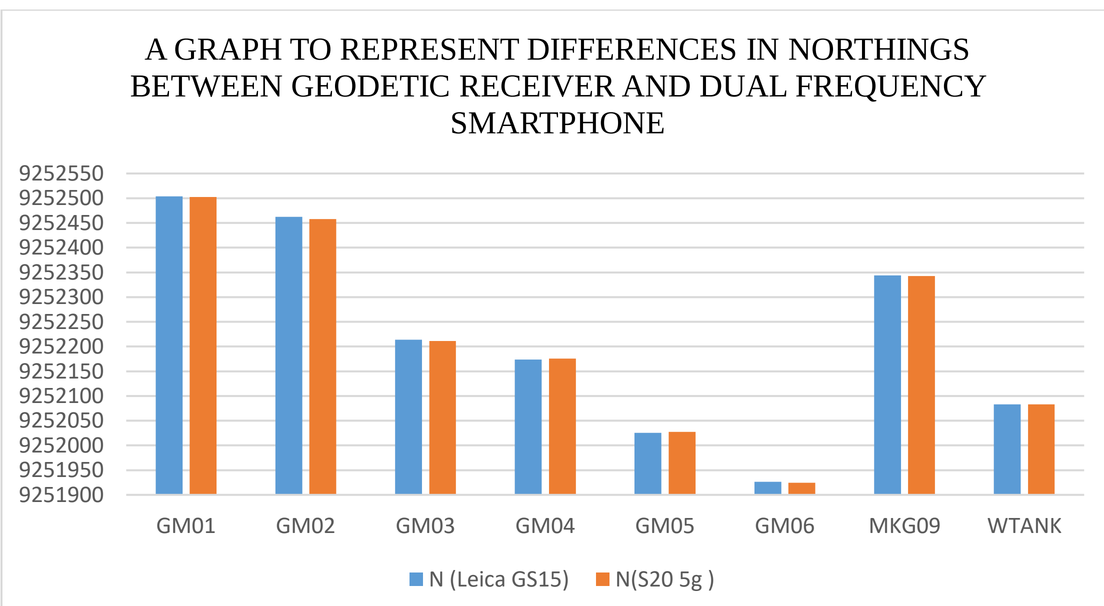

Figure 4.4: Graphical comparison of the northings in 4 hours' occupation time

Figure 4.5 shows graphical comparison to represent the difference of the positions in eastings obtained from Smartphone to those of GNSS Receiver in one-hour occupation time;

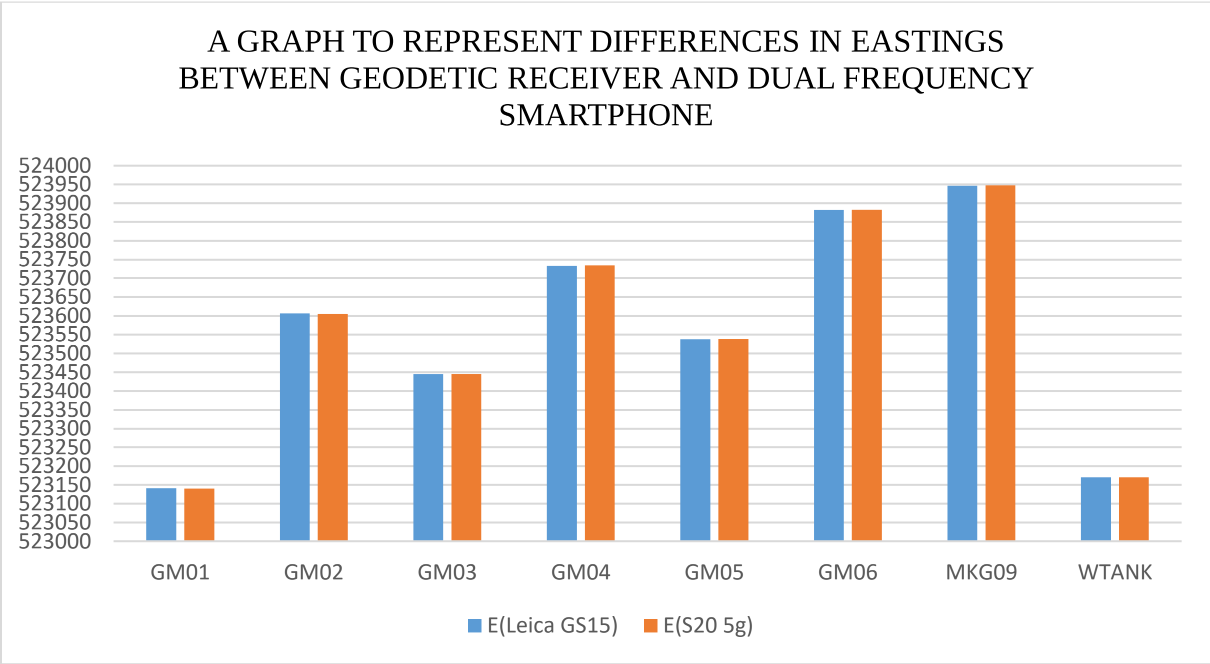

Figure 4.5: Graphical comparison of the eastings in 1-hour occupation time

Figure 4.6 shows graphical comparison to represent the difference of the positions in northings obtained from Smartphone to those of GNSS Receiver in two hours' occupation time;

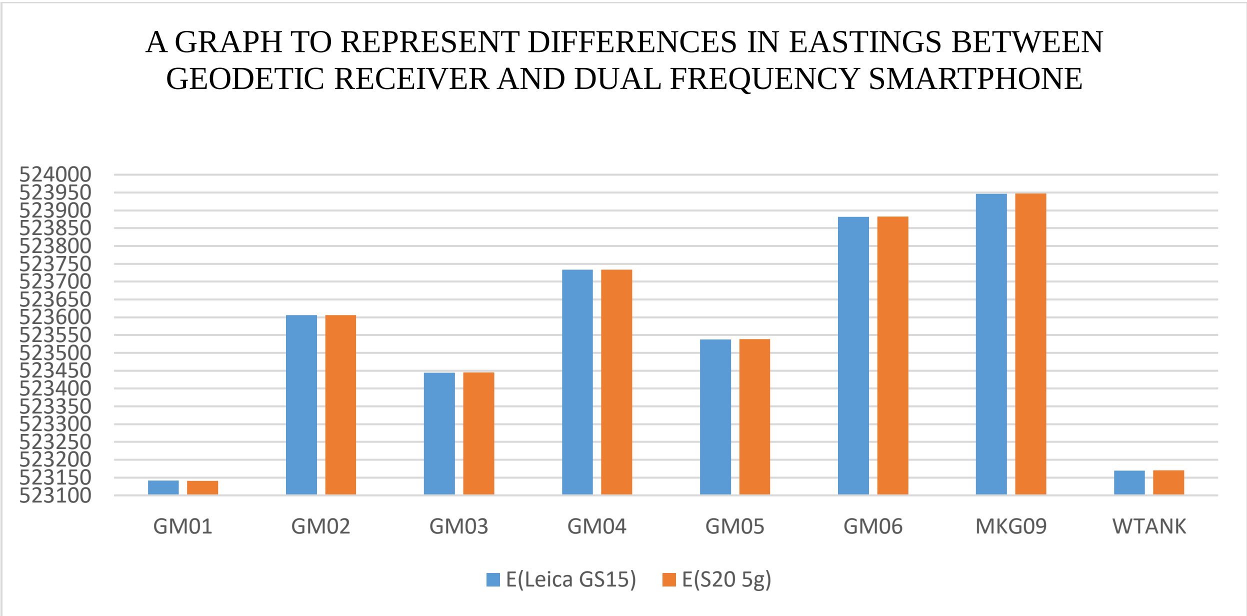

Figure 4.6: Graphical comparison of the eastings in 2 hours' occupation time

Figure 4.7 shows graphical comparison to represent the difference of the positions in eastings obtained from Smartphone to those of GNSS Receiver in three hours' occupation time;

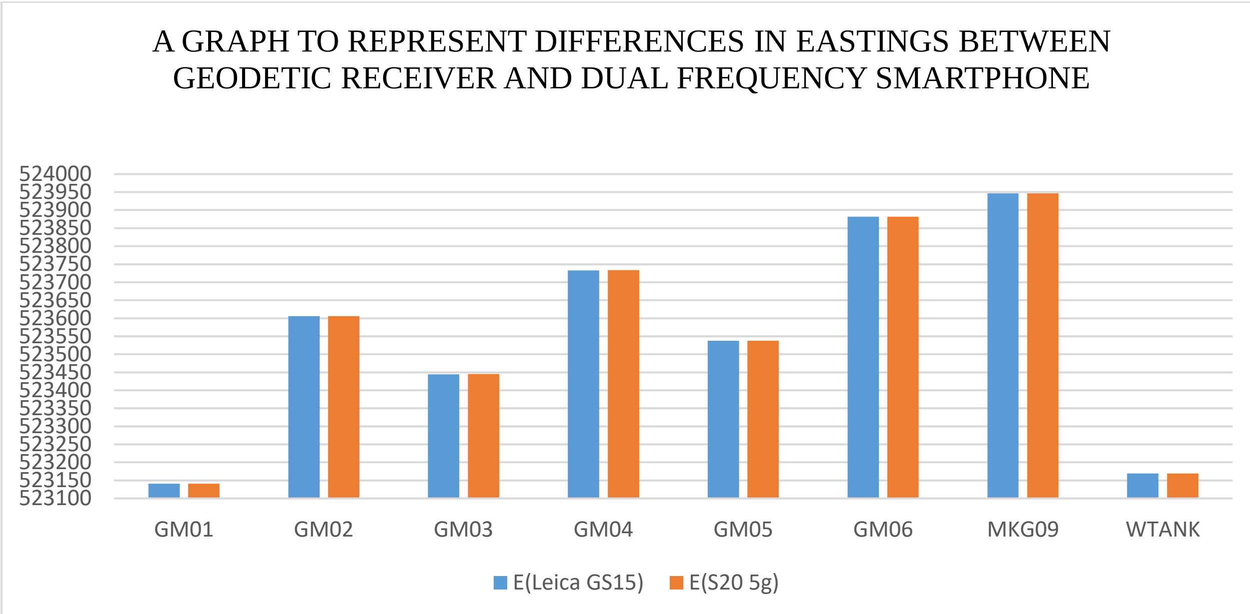

Figure 4.7: Graphical comparison of the eastings in 3 hours' occupation time

Figure 4.8 shows graphical comparison to represent the difference of the positions in eastings obtained from Smartphone to those of GNSS Receiver in four hours occupation time;

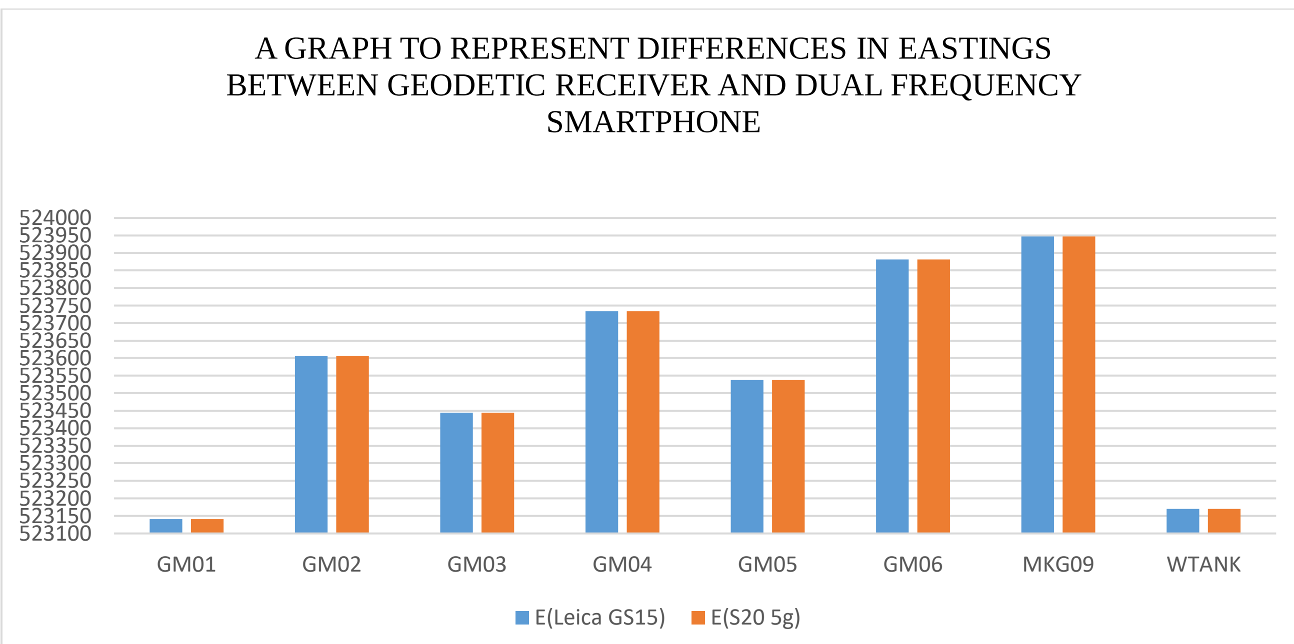

Figure 4.8: Graphical comparison of the eastings in 4 hours' occupation time

4.5 DISCUSSION OF THE RESULTS

The deviation of the smartphone positional data from the geodetic receiver positional data varies depending on the nature of the surrounding environment.

In this research, geodetic points established on low multipath environment and clear sky visibility such as WTANK, MKG9, GM05 and GM02 tend to bring about better results of less than 10cm accuracy. For geodetic points established on high multipath with obstacles like trees hence lack of clear visibility to the sky, such as GM01, GM03, GM04 and GM06 the results have relatively lower accuracy bringing about results with the accuracy ranging from 12cm to 20cm.

The positioning uncertainties of static for more occupation time of observation demonstrated that precise positioning is possible with a better precision for the environment with clear visibility and low multipath. Results obtained for 4 hours' occupation time of observation were better compared to those of 3 hours, 2 hours and 1 hour.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Despite the advancements in dual frequency smartphones, it showed that precise positioning with use of smartphone can be achieved better only in clear view to the sky. The ability of smartphone device to keep track on the satellite signals is evidenced to be relatively lower on places with obstacles and lack of clear view to the sky.

Stations GM01, GM03, GM04 and GM06 established close to buildings, in between buildings and trees tend to bring about results with greater uncertainty ranging from 12cm to 20cm accuracy.

Stations WTANK, MKG9, GM02 and GM05 established on clear view to the sky tend to bring about better results of less than 10cm accuracy.

The inability of the smartphone to withstand environmental conditions like rainfall and strong sun-rays during the day is the hindering factor of positioning on any weather.

Therefore, dual frequency smartphone positioning can be used to yield accurate positional results on places of low multipath, with an exception of environmental conditions like rainfall and strong sun-rays during the day. It tends to yield relatively low accurate results in cases where there is very high multipath, that is, obstacles and lack of clear view to the sky.

5.2 RECOMMENDATION

In this research, only one smartphone device which is Samsung Galaxy S20 5g was used to collect raw data. Other dual frequency smartphone devices should also be employed in conducting this research in the future as the smartphone technology advances rapidly.

Each application for raw GNSS data logging provides its own version of raw data, making it either possible to process in available software's and online forums or not. Therefore, various other applications for collecting raw GNSS data from Smartphone devices should also be employed, such as rinexON, toRINEX and GNSSlogger.

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APPENDICES

APPENDIX 1: GPS Survey Observation Sheets