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VALIDATION OF 2^{nd} ORDER TAREF 11 GNSS NETWORK

A Case Study of Dar es Salaam Coast

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BSc Geomatics

Dissertation

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VALIDATION OF 2nd ORDER TAREF 11 GNSS NETWORK

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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 2nd order TAREF 11 GNSS network, a case study of Dar es Salaam Cost"** in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics at Ardhi University.

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Dr. Elifuraha Saria (Supervisor)

Date ………………………

DECLARATION AND COPYRIGHT

I, MOHAMED MOHAMED B 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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MOHAMED MOHAMED B

22805/T.2019

(Candidate)

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I am therefore solely responsible for any errors, if any, found in this report.

DEDICATION

This dissertation is dedicated to my beloved parents Bakar Akida and Sikitu Bakari whom valued education and hence inspired me to pursue this program. And to all of my family member your support were unmeasurable in my academic journey

ABSTRACT

This study presents the comprehensive validation of the Second Order TAREF11 GNSS Network. It focuses on assessing the accuracy and reliability of the new reference frame for Tanzania (TAREF 11) using control points located at Dar es salaam to ensure its suitability for geodetic and surveying applications. Also, the research examines the network's performance, precision, and consistency through comprehensive field tests and comparisons with the data of the established reference stations of 2011. The static GNSS technique was employed to collect data in which factors such as baseline length, measurement precision, and repeatability was considered. A total of four points were used which are T07D, T08D, T14D and TANZ observed for the minimum of 6 hours to obtain the required performance. Data was collected in RINEX format and processed by GAMIT-GLOBK referring to ITRF14 to obtain positions of the aforementioned points. The obtained positions were validated using the data of the same points obtained in 2011 to check the difference among them. From the results the highest difference in uncertainty for eastings was 0.0063m of T07D and the lowest difference was 0.0018m of T14D. For northing the highest difference in uncertainties was 0.0048m of T07D and the lowest was 0.002m of T14D. So, the obtained results shows that the Second Order TAREF11 GNSS network in Dar es Salaam meets the required accuracy and reliability standards for various applications in surveying, geospatial data collection, and navigation. The research indicates that the TAREF11 GNSS network is well-suited for geodetic applications in the region such as establishing control points, mapping, and supporting infrastructure development projects. Also, the study provides valuable insights into the precision of the TAREF11 network, demonstrating its ability to deliver consistent and precise positioning data across the city of Dar es Salaam. The study install confidence among local users including surveyors, engineers, and government agencies in relying on the TAREF11 GNSS network for various positioning needs. The validated GNSS network holds significant implications for precise surveying and geospatial data applications in the region, enabling better decision-making and infrastructure development.

. **Keywords:** Global Navigation Satellite System (GNSS), validation

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

AFREF	African Reference Frame
CORS	Continuous Operating Reference Stations
2D	Two Dimensional
3D	Three Dimensional
MIT	Massachusetts Institute of Technology
GLOBK	Global Kalman Filter
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IERS	International Earth Rotation Service
IGS	International GPS Service
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial References System
RINEX	Receive Independent Exchange
MLHHSD	Ministry of Lands, Housing and Human Settlement Development
SMD	Surveying and Mapping Division in Tanzania
SLR	Satellite Laser Ranging
TAREF11	Tanzania Reference Frame 11
TEQC	Translate, Edit and Quality Check
UTM	Universal Transverse Mercator
VLBI	Very Long Base Line Interferometry
WGS84	World Geodetic System 198

CHAPTER ONE

INTRODUCTION

1.1 Background

Control point refers to the precisely measured and marked location on the earth's surface with known coordinates. These points serve as reference markers to establish the framework for conducting accurate surveys (Charles D. Ghilani, Paul R.Wolf, 2014). In Tanzania there are several control points established to serve various surveying activities which are tied to TAREF11. The Tanzania New Geodetic Reference Frame (TAREF 11) is a modern geodetic reference frame established in 2011 by the Tanzanian National Bureau of Statistics (NBS) in collaboration with the International GNSS Service (IGS) and other international organizations. TAREF 11 is designed to provide a consistent and accurate reference frame for surveying, mapping, and navigation in Tanzania. TAREF 11 is primarily based on Global Navigation Satellite Systems (GNSS) data collected from a network of 28 continuously operating reference stations (CORS) distributed across Tanzania. The CORS network provides high-precision data that is used to estimate the coordinates of points on the Earth's surface (Twumasi, Y. A., Geng, J., & Li, Y., 2019). The coordinates in TAREF 11 are expressed in the International Terrestrial Reference Frame (ITRF), which is a global reference frame established by the International Earth Rotation and Reference Systems Service (IERS). TAREF 11 is a significant improvement over previous reference frames in Tanzania, such as TANREF95 and TANREF2000, which were based on outdated technologies and models. TAREF 11 is based on modern GNSS technology and uses the latest models for estimating coordinates, including the International GNSS Service (IGS) products. Also, TAREF 11 is designed to be consistent with the latest international standards for geodetic reference frames, such as the International Terrestrial Reference System (ITRS) and the Global Terrestrial Reference System (GTRS). This ensures that TAREF 11 is compatible with other reference frames and can be used for international applications (Mayunga, S., Mtamakaya, D.,, 2013).

The TAREF11 control points are used in activities such as construction projects to establish accurate and reliable control points to ensure that the construction activities are carried out according to design specifications and tolerances, to monitor the stability of structures over time which is important for ensuring the safety of buildings and infrastructure. In land surveying and mapping applications Surveyors use geodetic networks to establish precise reference points that can be used to accurately locate boundaries, features, and structures on the ground. Also, the TAREF11 control points can be used to monitor ground deformation caused by tectonic activities, subsidence, and other natural or anthropogenic processes. These points can detect even minor changes in the position of objects points over time to assess risks associated with natural disasters such as earthquakes and landslides (Mayunga, S., Mtamakaya, D.,, 2013).

Although the TAREF11 control points are used as reference in various surveying activities but also it can affect the precision or accuracy of surveying observation. Factors such as damage of control monuments caused by various activities especially construction can cause in deformation and hence leading to wrong surveying observation. From this factor there is a need to validate the TAREF11 control points to check its status in terms of accuracy and precision so as to know its validity in continuing conduction of surveying activities.

Validation of geodetic reference frames involves assessing the quality, accuracy, and consistency of the reference frame by comparing it with independent measurements or models. This process involves identifying the sources of errors and uncertainties in the reference frame, evaluating their impacts on geospatial measurements, and developing strategies to minimize these errors and uncertainties. Validation can also involve assessing the long-term stability of the reference frame by monitoring its changes over time and comparing it with historical data or models. The validation serves as a quality control step to ensure that the control points meet the required standards and can be relied upon for geodetic surveys. The realization of geodetic control points involves the initial establishment or determination of their coordinates through precise surveying techniques. This may include GNSS observations, terrestrial surveys, leveling, or other geodetic methods. Once the control points have been realized, they are typically subjected to validation to verify their accuracy and suitability for use in subsequent surveys or geospatial applications. The validation process is crucial to confirm the reliability of the control points and to identify any potential errors or discrepancies. If the validation reveals significant differences between the measured and reference coordinates, further investigation and adjustment may be required to rectify any inconsistencies. The validated control points can then be used with confidence in subsequent geodetic surveys, mapping projects, or other applications that rely on accurate spatial reference information (Teunissen, 2009).

Several factors can create a demand for revalidation of geodetic control points after many years have passed. Time-Dependent Geodetic Changes, phenomena such as tectonic plate movements, crustal deformation, subsidence, or uplift. Over the course of many years, these geodetic changes can introduce shifts or displacements in the control point coordinates. Revalidation helps to account for such changes and ensures that the control points remain accurate and reliable. Reference Frame Updates, Geodetic surveys and positioning systems are typically based on reference frames which define the coordinate system and datum used for spatial measurements. Reference frames are periodically updated to account for improved models, changes in Earth's shape, or advancements in geodetic techniques. When a reference frame update occurs, it is often necessary to revalidate the control points using the new reference frame to ensure compatibility and accuracy. Infrastructure Development, the construction of large-scale infrastructure projects, such as dams, bridges, or highways, may require precise geodetic control. Over time, these projects can introduce localized changes to the terrain or alter the landscape, potentially affecting the accuracy of the existing control points. Surveying Methodology Improvements, advances in surveying techniques and technology can lead to more precise measurements and improved accuracy. If significant advancements have been made since the last validation, revalidation may be necessary to take advantage of these improved methodologies and ensure the highest level of accuracy in the control point coordinates. Legal or Regulatory Requirements, some jurisdictions may have specific regulations or requirements for the validation of geodetic control points at regular intervals. Compliance with these legal or regulatory obligations may necessitate revalidation of the control points after a certain period has elapsed (Anna, P., Wioletta, S., & Klaudia , W., 2021) .

A study on Verification of the polish geodetic reference frame by means of a new solution based on permanent GNSS data from the years of 2011 and 2014 was conducted with a total number of 35 station (Tomasz, L., Marcin, R., 2016). The new solution for the Polish geodetic primary GNSS network was created to verify the currently used reference frame (PL-ETRF2000). A GNSS data obtained by daily observation sessions was included and processed in a newer reference frame (IGb08) according to up-to-date methodology and using the latest version of observed discontinuities in position time series, mostly due to GNSS equipment changes, which occurred after the introduction of PL-ETRF2000.

A study on Establishment and Validation of Continuously Operating Reference Stations Geosystems Network on Static and Real-Time Kinematic was conducted in Benin City Nigeria (Oladosu, S., Ehigiator-Irughe, R., & Muhammad, M., 2022). A total of fifteen existing control points located far and near were observed using two Tersus GNSS receivers (A&B) concurrently. Statistical adjustment using Trimble Business Center software was performed with Chi square test at (95%) precision confidence level and degree of freedom being nine (9) showed that the result of the adjustment was reliable. Means of 0.007m, 0.003m 0.000m for Easting, Northings and Heights were obtained while the standard errors (σ) in E, N and H are 0.003m, 0.007m and 0.000m respectively.

In contrast with the previous study, this research uses LEICA GNSS receiver observe the second order TAREF11 control station of T07D, T08D, T14D and TANZ located at Dar es salaam for 6 hours. The validation is performed by processing the collected data using GAMIT-GLOBK to determine uncertainties in Northings and Eastings and comparing positional difference between obtained Coordinates and the available coordinates data of the aforementioned control points from Surveying and Mapping Division (SMD).

1.2 Problem Statement

" Inconsistent regional coverage of previous Geodetic reference frame and international standards and guidelines to ensure compatibility and interoperability with Global positioning system and other factors has caused the Ministry of Lands, Housing and Human Settlement Development through the Survey and Mapping Division (SMD) to the develop of a new geodetic system for Tanzania -TAREF11. The development and transition to a new Geodetic reference frame, such as TAREF11 aim to address those limitations from the previous operated geodetic reference frame and provide an improve framework for accurate positioning and surveying in Tanzania. Given the importance of the new system (TAREF11) in both mapping, tectonic and deformation study in Tanzania. Despite the establishment of the TAREF11 geodetic reference frame and the implementation of the second-order TAREF11 GNSS network, there is a need to investigate the accuracy and reliability of the network through validation on TAREF11 control points in Dar es Salaam, Tanzania as no efforts have been made to speed its validation. This research aims to address the need for validation of the second-order TAREF11 GNSS network on TAREF11 control points in Dar es Salaam, Tanzania, considering the changing physical environment (such as tectonic activities, urbanization, and infrastructure development, may have introduced changes to the survey control points over time), technological advancements, and surveying practices (variations in surveying practices, such as different data collection techniques or equipment usage, can affect the accuracy of the TAREF11 GNSS network). The study will investigate the accuracy and reliability of the network, contributing to the enhancement of precise positioning and geospatial applications in the region"

1.3 Research Objectives

1.3.1 Main Objective

TAREF 11 is GNSS network that provides real-time data to support various applications such as surveying, mapping, navigation, and disaster response. The purpose of the validation study is to evaluate the performance of the TAREF 11 network in the context of Dar es Salaam and to determine if it meets the specifications and requirements for the intended applications.

1.3.2 Specific Objective

the specific objectives of the research are as follows**:**

i. To determine the accuracy of the TAREF 11 GNSS network: The research will evaluate the precision and accuracy of the TAREF 11 GNSS network in Dar es Salaam by comparing its measurements with those obtained from other GNSS systems or from ground truth measurements.

ii. To assess the reliability of the TAREF 11 GNSS network: The research will evaluate the reliability of the TAREF 11 GNSS network by analyzing its performance under different environmental conditions, such as atmospheric disturbances, multipath effects, and shadowing.

iii. To evaluate the effectiveness of the TAREF 11 GNSS network for real-world applications: The research will evaluate the suitability of the TAREF 11 GNSS network for real-world applications, such as navigation, surveying, and mapping. The research will also compare the performance of the TAREF 11 GNSS network with other GNSS networks and traditional surveying techniques.

iv. To develop recommendations for the future use of the TAREF 11 GNSS network: The research will provide recommendations for the future use of the TAREF 11 GNSS network in Dar es Salaam, including suggestions for improving its accuracy and reliability.

1.4 Study area

The case study of this research was Dar es salaam which is the largest city and hub of Tanzania. It is also a capital city with the population of over six million people. The location of Dar es salaam is 06˚48’58” S 39˚16’49” E, and it have 5 districts which are Ilala, Kinondoni, Ubungo, Temeke and Kigamboni, but for this research we based on 3 districts which were Kigamboni, Ubungo and Kinondoni. Dar es salaam has a total area of 1,493km^2. The figure 1.1 showing the location of Dar es salaam region on a map of Tanzania and Dar es salaam districts

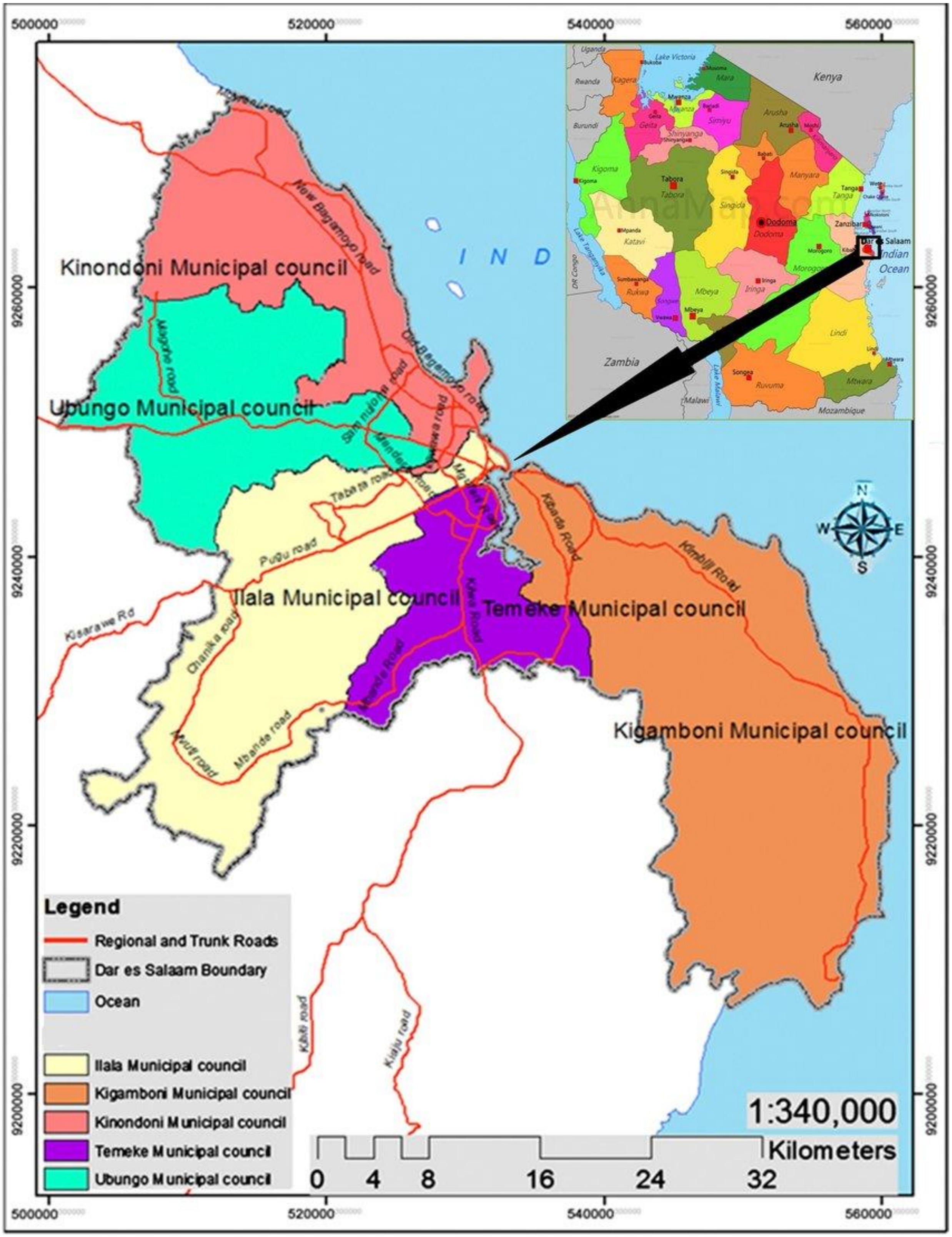

Figure 1-1: Map showing Kigamboni, Kinondoni and Ubungo districts used as the study area (Salome, E. B., Neema, E. M., & Edith, A.M, 2019)

1.5 Scope and Limitations of the Study

Scope: The scope of this research is to validate the accuracy of TAREF 11 GNSS points in specific areas of Dar es Salaam, Tanzania. This were included collecting and analyzing data from TAREF 11 GNSS receivers to determine the accuracy and reliability of the points in the specified areas.

Limitations:

i. The research is limited to specific areas of Dar es Salaam, and the results may not be applicable to other regions.

ii. The research was only considered GNSS receivers and TAREF11 second order points, and may not be applicable to other GNSS systems.

iii. The accuracy of the points may be affected by various factors such as atmospheric conditions and satellite geometry, which may not be fully controlled or accounted for in the research.

iv. The research may be limited by the availability of data from TAREF 11 second order points in the specific areas of Dar es Salaam.

v. The research was limited by the resources and time available for data collection and analysis.

1.6 Significance of the Research

The significance of this research lies on its potential to improve our understanding and accuracy of Global Navigation Satellite System (GNSS) technology in the area. GNSS is widely used in various applications such as positioning, navigation, and surveying, and its accuracy and reliability play a crucial role in these applications. By validating the second-order TAREF 11 GNSS network in Dar es Salaam, the researchers aim to assess its performance and identify any issues or limitations that may impact its accuracy. This information can be used to improve the network, enhance its performance, and ensure that it provides reliable and accurate GNSS data to its users. In addition, the research can also provide valuable insights into the GNSS environment in Dar es Salaam, which can be used to inform future GNSS network design and implementation in the area. The results of the research may also be useful for other cities in Tanzania and other regions, where GNSS technology is widely used.

1.7 Dissertation Outline

This Thesis consists of five chapters, Chapter one covers the background of the new Tanzania Reference Frame (TAREF11) and importance of checking validity of these points. Chapter two, Literature review of existing information on the modern geodetic reference frame, it explains on the TAREF11 and the reference frame context in Africa and other places out of Africa. Chapter three contains the methodology, which describes the data type, sources of data and procedures used to process data using GAMIT/GLOBK software as well as results obtained. Chapter four describes results from GAMIT/GLOBK processing and the validation of these results. Chapter five contains a conclusion summary and puts future recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Reference Coordinate System and Frame

In modern terminology there is differences between reference systems, reference frames and conventional reference systems and frames. A reference system is the complete conceptual definition of how a coordinate system is formed. It defines the origin and the orientation of fundamental planes or axes of the system (Dejene, 2013). A conventional reference system is a reference system where all models, numerical constants and algorithms are explicitly specified. A reference frame means the practical realization of a reference system through observations. It consists of a set of identifiable fiducial points on the sky (e.g., stars, quasars) or on Earth's surface (e.g., Fundamental stations). It is described by a catalog of precise positions and motions (if measurable) at a specific epoch. In satellite geodesy two fundamental systems are required. A space-fixed, conventional inertial reference system (CIS) for the description of satellite motion, and An Earth-fixed, conventional terrestrial reference system (CTS) for the positions of the observation stations and for the description of results from satellite geodesy (Dejene, 2013).

A reference coordinate system is a mathematical framework used to locate an object or event in space and time. It consists of a set of axes or coordinates, which are used to specify the position of an object relative to a fixed point or origin. The choice of reference coordinate system depends on the context of the problem and the nature of the objects or events being studied. For example, in physics, the choice of reference coordinate system is crucial for describing the motion of objects. The most commonly used reference coordinate system in physics is the Cartesian coordinate system, which consists of three mutually perpendicular axes (x, y, and z) that intersect at the origin. The position of an object can be specified by its coordinates (x, y, z) relative to the origin. In contrast, a frame of reference is a physical or conceptual structure that is used to describe the motion of objects. It consists of a set of reference points or objects, which are used to define the position and orientation of the coordinate system relative to the objects being studied. For example, in special relativity, the choice of frame of reference is crucial for describing the behavior of light and other objects moving at high speeds. The most commonly used frames of reference in special relativity are inertial frames, which are frames that are not accelerating. In an inertial frame, the laws of physics take their simplest form and are consistent with the principle of relativity.

2.1.1 International Terrestrial Reference Frame

The International Terrestrial Reference Frame (ITRF) is a globally recognized and widely used reference frame for geodetic measurements such as GPS, VLBI, SLR, and DORIS. It provides a standard framework for determining precise positions on the Earth's surface, as well as for studying Earth's rotation, tides, and other geophysical phenomena. Terrestrial geodetic reference frames are being developed everywhere throughout the world for surveying, geodynamic and mapping purposes. In the last 3 decades after the commencement of the International Astronomical Union (IAU) and later the International Association of Geodesy (IAG), the International Earth Rotation and Reference Systems Service (IERS) developed the International Terrestrial Reference 12 System (ITRS). The ITRS was then realized through the International Terrestrial Reference Frame (ITRF; Boucher & Altamimi, 1989;Ray *et al.*,1999; Altamimi *et al.*, 2011). The ITRS and its realization were contributed by various space geodetic techniques including Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), Global Positioning System (GPS), and Doppler Orbitography and Radio positioning Integrated on Satellite (DORIS). The ITRS contains mathematical expressions of the precisely determined Coordinates, velocities, and their corresponding variance-covariance matrix. The realizations of ITRS are the monuments on the grounds expressed by the aforementioned coordinates (Saria *et al.*, 2013).

Depending on the purpose and how the frame is determined and its area coverage, it may be global, for example the ITRF with worldwide coverage of more than 3000 space geodetic sites. The ITRF is widely used in a variety of scientific and engineering applications, including navigation, geodesy, satellite positioning, and global climate studies. It is also a key component of the Global Geodetic Reference Frame (GGRF), which is used by the International Association of Geodesy (IAG) and other organizations to provide a consistent reference frame for all geodetic measurements worldwide. The ITRF velocities are constructed from the theory of No Net rotation frame and thus it cannot be used to understand internal deformation in the interior of the continent. To precisely study the continental wide geodetic problem example, tectonic or geodesy, the regional reference frames were established however they were tied to the ITRF.

Some of these continental wide reference frames have been quantified and published, for example EUREF, NAREF and SIRGAS however AFREF is still in its final stages to be quantified. Continental wide reference frame is required for intercountry mapping issues, international boundary conflicts and regional tectonic studies. For country wide mapping and other geodetic issues, the countrywide geodetic reference frame is established. Depending on the available technology development and the purpose of national reference frame establishments, the country wide reference frame may be tied to the ITRF example the upcoming Tanzania Reference Frame (TAREF11)

2.1.2 African Reference Frame (AFREF)

The African Reference Frame (AFREF) is a geodetic reference frame established to improve the accuracy and consistency of geospatial data and measurements across Africa. This reference frame provides a standard coordinate system for use in mapping, surveying, navigation, and other geospatial applications, allowing for seamless integration of data from different sources. AFREF was developed by the International Association of Geodesy (IAG) and the International GNSS Service (IGS) in collaboration with African geodetic organizations. It is based on a network of continuously operating GNSS (Global Navigation Satellite System) stations distributed across Africa and connected to the International Terrestrial Reference Frame (ITRF) through a process called datum transformation. AFREF was officially adopted in 2013 by the African Association of Surveyors and Geomaticians (AASG) and is recognized by the International Association of Geodesy as the geodetic reference frame for Africa. One of the main benefits of AFREF is that it improves the accuracy of geospatial data and measurements by reducing the errors introduced by using different coordinate systems and datum transformations. It also facilitates the integration of African geospatial data into global datasets, allowing for more comprehensive analysis and decision-making. The objectives of proposed AFREF are to define a reference system for Africa, to define and establish a geocentric reference datum, create a unified geodetic reference frame and vertical reference frame and support efforts to establish a precise African geoid (Combrinck, 2008).

AFREF GNSS network continuous operating reference stations (CORS) tracking stations operating 24 hours a day and complies with international standards, which can provide positional solutions including movement in their relative positions due to African major tectonic plate

(Nubian and Somalian plates) (Combrinck, 2008). In 2012, The Africa Reference Frame (AFREF) started processing 80 geodetic GPS points (Wonnacott, 2006). The first independent processing of static coordinates has been done with Africa and European teams from various centers. The four processing centers include Hartebeesthoek Radio Astronomy Observatory (Hart RAO), South Africa; Ardhi University, Tanzania; Centre for Geodesy and Geodynamics, Nigeria and University of Beira Interior, Portugal. The Africa network was established by the precision Global Positioning System (GPS)network. The network was continuously observed and precise GPS data for 13 days from (DoY) 337 to 350 of 2012 were acquired. In order to establish to establish consistency data processing was independently done by the Africa and European team whereby the first unconstrained solutions were based on Terrestrial Reference Frame ITRF2008 at reference epoch 2012 (Wonnacott, 2006).

2.1.3 Countrywide Reference Frame

The French Geodetic Network, also known as RGF93, is a reference system for geodetic coordinates in France. It was created in 1993 by the French National Geographic Institute (IGN) to replace the previous reference system, known as NTF (New Triangulation of France), which had been in use since the 18th century. The purpose of RGF93 was to improve the accuracy and consistency of geodetic measurements in France, and to make it easier to integrate French data with international geodetic systems. RGF93 is based on the Geodetic Reference System 1980 (GRS80), which is a global reference system defined by the International Earth Rotation and Reference Systems Service (IERS). RGF93 uses a Lambert Conformal Conic projection with two standard parallels to represent the curved surface of the Earth on a flat map. The projection is centered on Paris and covers all of metropolitan France, Corsica, and some surrounding territories. To establish RGF93, the IGN carried out a national survey campaign, using the latest geodetic technologies and equipment, to accurately measure the coordinates of a network of about 3000 reference points across France. These reference points are distributed across the country and are used as control points for all geodetic measurements in France, such as GPS surveys, aerial photography, and satellite imagery. The accuracy of RGF93 is estimated to be within 1-2 cm for horizontal positions and 2-3 cm for vertical positions. This level of accuracy is sufficient for most applications in France, including mapping, navigation, and engineering projects. RGF93 has become the standard geodetic reference system in France and is used by many government agencies, research institutions, and private companies. It is also widely used in international scientific collaborations, such as the European Space Agency's Earth Observation program (Touboul, 1998)

The French Geodetic Network 1993, In metropolitan France, the official geodetic system is the RGF93, which allows the materialization a precise reference point on the metropolitan territory while adapting to modern technologies. Compatible with worldwide references, the RGF93 is a component of the European ETRS89 system. As part of the maintenance of national geodetic references, the IGN (National Institute of Geographic and Forestry Information), a TERIA partner, has recalculated all the data of the Permanent GNSS Network for the period 1998-2019. With an impact of less than a centimeter, these updates have been migrated without any interruption in service to ensure accurate and consistent results for your measurements. The RGF93 succeeds the old French geodetic system, the *New Triangulation of France or NTF* (French article). This old process allowed the materialization of landmarks by angular measurements from the end of the 19th century onwards. (More information on the IGN website) Faced with the deployment of the GNSS system in 1989, the observation is simple: the NTF no longer met the needs of surveyors or topographical surveys. From then on, the RGF93 was born.

The principle of RGF93:

The RGF93 provides concrete access to a geodetic system.

It can be:

- “Materialized” thanks to a set of physically defined points (terminals, markers) whose coordinates are known in the RGF.
- “Active”, represented by all the permanent GNSS stations in the RGP (Permanent GPS Network)

RGF (French Geodetic Network)

Consists of 3 parts:

- RRF: French Reference Network with 23 points determined by spatial geodesy
- RBF**:** French Base Network made up of 1009 sites determined by spatial geodesy

- RDF: French Retail Network composed of NTF sites whose coordinates have been recalculated in RGF93

RGP (Permanent GPS Network)

The Network is in constant evolution: 517 stations currently

Find the list of stations on the official IGN website: http://rgp.ign.fr/STATIONS/liste.php0

RGF93 specifications:

i. Three-dimensional geocentric
ii. Linked to the global reference system ITRS (International Terrestrial Reference System)
iii. Associated with the ellipsoid IAG GRS 1980
iv. Using the international meridian (Greenwich meridian) as the original meridian
v. Associated projections are the Lambert-93 projection and the CC 9 Zones projection. Horizontal accuracy between 1 and 2 cm (compared to global systems)
vi. Vertical accuracy between 2 and 5 cm (compared to global systems)
vii. Suitable for modern positioning technologies

The maintenance of the reference system in France

Since the beginning, several maintenances have been carried out.

In 2019 – 2020, the IGN carried out maintenance work on the RGF93 by recalculating all the data from the RGP. These recalculations led to coordinate readjustments for some of the stations on the network:

i. IGS antenna calibration updates (86 stations)

ii. Own movement of stations and resetting of periodic signals (60 stations)

iii. Some error recovery (10 stations)

To ensure interoperability between European countries, the RGF93 is strongly based on the European coordinate system (ETRS89), and in particular on its realization ETRF2000 through a theoretical transformation. At a time of massive use of PPP calculation methods, many users of centimetric geo-positioning rely on this transformation. However, it has been found that this transformation leads to a bias in the FGR93 results of these users. Thus, in order to ensure an optimal access service to the national reference, the IGN has decided to carry out a general maintenance of the RGF93 with effect from 5 January 2021

2.2 Global Navigation Satellite System (GNSS) technology

GNSS stands for Global Navigation Satellite System, which is a satellite-based navigation system that provides accurate positioning, timing, and navigation services to users worldwide. GNSS systems use a network of orbiting satellites, ground control stations, and user equipment to provide positioning and timing information with global coverage. The most well-known GNSS systems are the Global Positioning System (GPS) operated by the United States, the Global Navigation Satellite System (GLONASS) operated by Russia, and the BeiDou Navigation Satellite System (BDS) operated by China. GNSS technology has many applications, including navigation for aviation, maritime, land-based vehicles, and personal devices such as smartphones. In addition to navigation, GNSS systems are used for surveying, mapping, and scientific research. According to the European GNSS Agency (GSA), the primary objective of GNSS is "to provide reliable, continuous, and global positioning, navigation, and timing services that can be used by a variety of applications, including transportation, agriculture, surveying, and more." GNSS has become an essential component of modern society, enabling many technological innovations and improvements in efficiency and safety. Global Navigation Satellite Systems (GNSS) are satellite-based navigation systems that provide location and time information to users worldwide. The primary function of GNSS technology is to determine the position, velocity, and time (PVT) of a user's receiver by measuring the time delay of signals transmitted from multiple satellites. GNSS systems like GPS, GLONASS, and Galileo offer a high level of accuracy in determining a user's location. The accuracy of GNSS measurements depends on several factors, including the number of satellites visible, the quality of the receiver, and the signal propagation environment. Generally, GNSS receivers can achieve a horizontal accuracy of a few meters and a vertical accuracy of several meters. Despite their high level of accuracy, GNSS technology has some limitations and potential sources of error. Some of the limitations of GNSS technology include the signal blockage due to obstructions like buildings, trees, and other structures that may result in the loss of signals, and multipath error caused by the reflection of signals off surfaces like buildings and water bodies. Other sources of errors in GNSS technology include ionospheric and tropospheric delays, satellite clock errors, and receiver noise. These errors can be reduced through the use of advanced correction techniques like differential GPS (DGPS), real-time kinematic (RTK) positioning, and precise point positioning (PPP). GNSS stands for Global Navigation Satellite System, and it refers to a collection of satellites in orbit around the Earth that provide positioning, navigation, and timing services to users on the ground. A GNSS network refers to a system of ground-based stations that are used to collect and process GNSS signals, with the goal of improving the accuracy, reliability, and availability of positioning information (Hofmann-Wellenhof, B., Linctenegger, H., & Wasle, E., 2008)

These ground-based stations, also known as reference stations, receive signals from GNSS satellites and use them to determine their precise location. By comparing the signals received from multiple satellites, reference stations can compute highly accurate position and timing information that can be used by a wide range of applications and users. The data collected by GNSS networks is used in a variety of applications, including surveying, mapping, construction, agriculture, transportation, and more. The data is typically made available to users in real-time or near-real-time, either through dedicated communication networks or over the internet. One example of a GNSS network is the Continuously Operating Reference Station (CORS) network operated by the National Geodetic Survey (NGS) in the United States. The NGS CORS network consists of over 2,000 stations across the country and provides high-precision positioning data to users in a wide range of industries.

GNSS (Global Navigation Satellite System) networks play a critical role in modern surveying and geodetic applications. These networks consist of a group of satellites that transmit signals to receivers on the ground, which are used to determine precise positions and time. One of the key advantages of GNSS networks is their ability to provide highly accurate and consistent data, which is essential for a range of applications such as mapping, engineering, and geodesy. Additionally, the use of GNSS technology has enabled more efficient and cost-effective surveying methods, reducing the time and labor required to collect data. GNSS networks are also used in geodetic applications, which involve the measurement and monitoring of the Earth's shape, orientation, and gravity field. By using GNSS receivers to measure the position and motion of points on the Earth's surface, geodetic scientists can better understand the behavior and changes of the Earth's crust and tectonic plates (Geodesy, 2017)

Some examples of geodetic applications of GNSS networks include:

i. Monitoring of crustal deformation and earthquakes (e.g., GPS Earth Observation Network of Japan)

ii. Determination of sea level changes (e.g., Global Sea Level Observing System)

iii. Maintenance of global geodetic reference frames (e.g., International GNSS Service)

2.3 Second- order GNSS network

Second Order Global Navigation Satellite System (GNSS) networks are high-precision geodetic networks that utilize real-time kinematic (RTK) positioning techniques to determine the positions of a network of reference stations with sub-centimeter accuracy. Second order GNSS networks are used to provide high accuracy positioning solutions for surveying, engineering, and other geospatial applications. In second order GNSS networks, reference stations are established at known positions with precise coordinates using surveying techniques. These stations receive signals from multiple GNSS satellites and transmit the signals to a processing center where the data is processed to determine the precise coordinates of the reference stations in real-time. These precise coordinates can then be used to provide high-accuracy positioning solutions for other GNSS users in the network. One of the primary applications of second order GNSS networks is in surveying and geodesy. The high accuracy positioning solutions provided by these networks can be used to establish precise control networks for construction projects, land surveys, and other engineering applications. Second order GNSS networks can also be used to monitor tectonic plate movements, track land subsidence, and measure the deformation of structures such as dams and bridges. Second order GNSS networks are also used in precision agriculture to provide accurate positioning information for automated agricultural equipment such as tractors, sprayers, and harvesters. This information can be used to optimize crop yields by minimizing overlap and reducing waste (Ning, X., Li, J., & Zhang , X.,, 2019)

2.4 Validation of GNSS network

GNSS (Global Navigation Satellite System) validation is the process of verifying the accuracy and reliability of the measurements made by a GNSS network. The main goal of GNSS validation is to ensure that the GNSS data is of sufficient quality for its intended use. This can be done through various methods and techniques, including statistical analysis, data comparison, and error modeling. One method of GNSS validation is to compare the data from multiple receivers within the same network. This is known as inter-receiver validation and involves comparing the measurements from different receivers to identify any errors or inconsistencies. Another method is to compare the GNSS data with ground truth measurements, such as survey markers or other reference stations, to verify its accuracy. Data analysis techniques used in GNSS validation include statistical analysis, such as calculating standard deviations and confidence intervals, and error modeling, which involves identifying and quantifying sources of error in the data. Sources of error in GNSS data can include atmospheric disturbances, multipath interference, and receiver noise (Teunissen, 2009)

There are several sources of error in GNSS data, and these can be categorized into two main types: systematic errors and random errors. Systematic errors are caused by factors that affect all measurements in a similar way, such as atmospheric refraction. Random errors, on the other hand, are caused by factors that vary from one measurement to another, such as receiver noise. Some common sources of error in GNSS data include; Atmospheric refraction, Multipath interference, Receiver noise, Satellite clock errors, Ephemeris errors and Signal blockage or attenuation. There are various software tools and platforms available for GNSS validation, such as the open-source software RTKLIB and commercial software packages like Trimble Business Center. These tools can be used to perform various analysis and validation tasks, such as data filtering, smoothing, and error correction.

2.5 The new Tanzania Reference Frame (TAREF 11)

The TAREF11 is a Tanzanian geodetic reference frame which is yet to be realized covering all Tanzania Mainland excluding the Islands of Mafia, Unguja and Pemba. Through the Survey and Mapping Division (SMD) of Tanzania the observations were conducted in 2009 for three epochs which ended in 2011. The computation has been continuing and until now there is draft report at the Ministry of Land, Housing and Human Settlement Developments (MLHHSD) in which the computed coordinates are aligned to ITRF2008 and are waiting for validation and other procedures to be used by the surveying community. The new Tanzania Reference Frame (TAREF11) comprises of 686 geodetic points categorized in three classes (Figure 2.1). The first class is Zero order with 16 points, the second is First order with 72 points and third class is the second order which comprises of 600 geodetic points spaced at 40-kilometer grid country wide (Mayunga, S., Mtamakaya, D.,, 2013). Although it is expected to have more regional densification. The Second order geodetic control points are the one expected as immediate points for surveying use. Its realization has a lot of advantages including the provision of the National 3D geodetic frame to replace 2D quasi geodetic Arc Datum 1960. Other advantages include easy integration with Regional, International and Continental geodetic frame and solutions thus; simplifying the surveying and mapping processes. In addition, its realization by using the modern space geodetic positioning techniques e.g., GNSS makes it possible for applications using different scales locally and globally without distortions. The new frame is semi-dynamic and therefore it can be used for tectonic and deformation study.

The TAREF 11 is a three-dimensional geodetic frame (3D) where the third dimension is computed using the ellipsoidal height corrected by the Tanzania gravimetric geoid (TZG13) computed in 2013 (Ulotu, 2013). The Tanzania gravimetric geoid was computed using the aerial gravity survey data collected in 2012 and some ground data collected in previous years on the different areas of Tanzania. For the details on its computation, the reader is referred to (Ulotu, 2013). Before the establishment of TAREF11, Tanzania has been and is still using the old system the ARC Datum1960 based on the modified ellipsoid Clark 1880. This system had a lot of limitations. These limitations made Tanzania, through the Survey and Mapping Division (SMD) to overhaul the old system once TAREF11 is realized and validated, however it is now six years no efforts have been conducted to validate the system. This study focuses on the validation the new geodetic reference frame for Tanzania (TAREF 11) using data from the capital city of Dar es salaam. This validation will recommit the Ministry of Land, Housing, and Human Settlement Development (MLHHSD) if the submitted solution by geodetic standard and if can be used by Land surveying community, since its official realization has delayed for years

2.6 Related Studies

One previous study on the validation of the Tanzania New Geodetic Reference Frame (TAREF 11) GNSS network in Tanzania was conducted by Yaw A. Twumasi, Jianghui Geng, and Yujie Li in 2019. The study was published in the Journal of Applied Geodesy and titled "Validation of TAREF11 GNSS network using IGS reference stations in Tanzania". The study aimed to validate the accuracy and reliability of TAREF 11 by comparing the coordinates of TAREF 11 GNSS network stations with those of the International GNSS Service (IGS) reference stations in Tanzania. The IGS reference stations are highly accurate and provide a reliable reference frame for comparison. The study collected GNSS data from 15 TAREF 11 GNSS network stations and six IGS reference stations between December 2017 and May 2018. The data was processed using the precise point positioning (PPP) method to estimate the coordinates of the stations. The results of the study showed that the TAREF 11 GNSS network is accurate and reliable, with root mean square (RMS) errors of less than 2.5 cm in the horizontal and less than 4.5 cm in the vertical direction. The study also found that the accuracy of TAREF 11 varies depending on the location of the stations, with better accuracy observed in areas with a higher density of reference stations (Twumasi, Y. A., Geng, J., & Li, Y. (2019)

In conclusion, the study validated the accuracy and reliability of TAREF 11 by comparing the coordinates of TAREF 11 GNSS network stations with those of the IGS reference stations in Tanzania. The study found that TAREF 11 is accurate and reliable, with good performance across Tanzania. The study provides valuable information for users of TAREF 11, such as surveyors, mappers, and navigators, who can rely on the reference frame for their work.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter describes necessary procedures and techniques that were employed in conducting the research starting with fieldwork planning, network design, data acquisition and processing to the final results. Accurate positioning and surveying are crucial in the development and management of cities such as Dar es Salaam, Tanzania. These processes provide essential data that supports decision-making, planning, and implementation of various development projects in the city. In this context, accurate positioning and surveying help to achieve the following: Land Use Planning, Infrastructure Development, Property Valuation, Disaster Management and Environmental Management. In summary, accurate positioning and surveying are crucial in the development and management of cities such as Dar es Salaam. They provide essential data that supports decision-making, planning, and implementation of various development projects. Without accurate surveying, it would be difficult to plan and manage the city effectively, leading to potential problems such as inefficient land use, infrastructure failures, property disputes, and environmental degradation.

A reference station network is a collection of GNSS receivers that are geographically distributed over a region and are used to provide a set of reference points with known coordinates. These reference points can be used to improve the accuracy of GNSS positioning by using differential correction techniques. This is particularly important in surveying and geomatics applications, where high accuracy positioning is often required. The TAREF 11 GNSS network was chosen as the basis for the study because it is the most comprehensive and reliable GNSS reference station network in Tanzania. The study may have been focused on validating the accuracy of the TAREF 11 network in a specific area (Dar es Salaam), which would require comparing the coordinates determined from the TAREF 11 network with ground truth measurements in that area. This validation would be important to ensure the accuracy of surveying and geomatics applications that rely on the TAREF 11 network in that region. Overall, the validation of the TAREF 11 GNSS network in Tanzania involved a rigorous process of data collection, processing, analysis, and quality control. The results of the validation provided confidence in the accuracy and reliability of the network, which can be used for a range of applications such as surveying, mapping, and navigation.

The research topic is focused on the validation of a second-order TAREF 11 GNSS network in the case of Dar es Salaam. The research questions and hypothesis that the methodology and procedures are intended to address are:

1. Research question: How accurate is the second-order TAREF 11 GNSS network in Dar es Salaam? Hypothesis: The second-order TAREF 11 GNSS network is accurate within the acceptable limits set by the International Association of Geodesy (IAG) and the International GNSS Service (IGS).

2. Research question: How reliable is the second-order TAREF 11 GNSS network in Dar es Salaam? Hypothesis: The second-order TAREF 11 GNSS network is reliable and can provide consistent and repeatable results.

3. Research question: What are the sources of errors and uncertainties in the second-order TAREF 11 GNSS network in Dar es Salaam? Hypothesis: The sources of errors and uncertainties in the second-order TAREF 11 GNSS network in Dar es Salaam include atmospheric conditions, satellite geometry, multipath effects, and equipment errors.

The methodology and procedures are intended to address these research questions and hypotheses by collecting GNSS measurements from different stations within the TAREF 11 network, processing the data using various software tools, analyzing the results, and comparing them to reference data obtained from other sources. The procedures also include analyzing the sources of errors and uncertainties and testing the impact of the local geoid model on the accuracy of the network. The goal is to provide a comprehensive evaluation of the second-order TAREF 11 GNSS network in Dar es Salaam, which can be used to validate its accuracy and reliability for various applications.

3.2 Field campaign and network design

The fieldwork was conducted in three districts of Dar es salaam region which are Ubungo, Kinondoni and Kigamboni. Network design is an essential aspect of any Global Navigation Satellite System (GNSS) survey project as it determines the success of the project. The aim of this research project is to validate the second order TAREF 11 GNSS network in Dar es Salaam. This chapter will provide an overview of the network design methodology that will be used in the research. The design of a geodetic control network must take into account a variety of criteria to ensure that the network is accurate, reliable, and consistent. Some of the key criteria for the design of a geodetic control network include:

1. Network density: The density of the network should be sufficient to meet the requirements of the intended application. Higher-density networks provide greater accuracy and reliability but may be more expensive to establish.

2. Network geometry: The network should be designed to provide good geometric distribution of the control points. This means that the control points should be spaced evenly and distributed in a way that allows for accurate measurements over the entire area of interest.

3. Control point stability: The control points should be stable over time and not subject to significant movement due to geological or other factors.

4. Observational redundancy: The network should include enough control points to provide redundancy in observations, which helps to detect and correct errors in measurements.

5. Measurement accuracy: The measurements used to establish the control points should be accurate and precise, with well-defined error models.

6. Datum compatibility: The control network should be compatible with the datum used for the intended application, such as the World Geodetic System (WGS) or a local coordinate system.

7. Cost: The cost of establishing the control network should be balanced against the requirements of the intended application and the available resources.

By considering these and other criteria, a well-designed geodetic control network can provide a reliable and accurate framework of reference points for a wide range of geospatial applications, but for this research we deal with the existing established network.

Geodetic control networks are used to establish a precise framework of reference points on the Earth's surface, which are used for various applications such as mapping, surveying, and navigation. Design triangles are an important component of geodetic control networks and are used to ensure that the network is well-conditioned and provides accurate results. The criteria for design triangles on a geodetic control network include the following:

1. Minimum Included Angle: The minimum included angle of a triangle should be greater than 30 degrees to ensure good geometric configuration and minimize the effects of observational errors.

2. Maximum Triangle Side Length: The maximum side length of a triangle should be less than 1/3 of the distance between the nearest adjacent control points to ensure that the network is well-conditioned and the accuracy of the results is maintained.

3. Aspect Ratio: The aspect ratio of a triangle, defined as the ratio of the longest side to the shortest side, should be less than 5 to ensure that the network is well-conditioned and the accuracy of the results is maintained.

4. Redundancy: The network should have sufficient redundancy to detect and correct errors. This can be achieved by including additional triangles that overlap with existing triangles.

These criteria are based on established geodetic principles and are widely accepted in the industry. They are described in detail in various textbooks and technical papers on geodetic surveying, such as "Geodesy" by Wolfgang Torge and "Surveying" by Jack C. McCormac.

Geodetic control networks are crucial for surveying and mapping activities as they provide a framework of accurately positioned control points that can be used as a reference for other survey measurements. However, there are certain things that should be avoided in the design of geodetic control networks to ensure their accuracy and reliability. These include:

1. Using low-quality or outdated equipment: The use of outdated or low-quality equipment for surveying and measurement can lead to errors in the positioning of control points, resulting in inaccuracies in subsequent surveys. It is therefore important to use high-quality equipment that is well-calibrated and regularly maintained.

2. Poor site selection: The selection of sites for control points should be done carefully, taking into consideration factors such as accessibility, visibility, stability of terrain, and

distance from other control points. Poor site selection can lead to inaccuracies in subsequent surveys.

3. Insufficient redundancy: Redundancy in geodetic control networks refers to the use of multiple control points to measure a single location, which helps to minimize errors and improve accuracy. Insufficient redundancy can lead to inaccuracies in subsequent surveys.
4. Inadequate network design: The design of geodetic control networks should be carefully planned to ensure that the network is well-connected and that there are sufficient control points to provide accurate positioning for all surveying activities. Inadequate network design can lead to inaccuracies in subsequent surveys.

In geodetic control network design, triangles are used to measure distances and angles between control points. There are two main techniques for designing triangles in geodetic control networks: triangles in space and triangles in conventional techniques. Triangulation in space is a technique where the control points are located in three-dimensional space and the triangles are formed by connecting the points with straight lines. This technique is commonly used in modern surveying and mapping applications, such as GPS and satellite imagery. It allows for high accuracy measurements over large areas, and it can account for variations in elevation and terrain. On the other hand, conventional triangulation is a technique where the control points are located on the ground, and the triangles are formed by measuring angles and distances between the points using surveying equipment, such as theodolites and EDMs. This technique has been used for many decades and is still widely used today. It is generally less accurate than triangulation in space, but it is often more practical for smaller areas or areas with limited access. For this research we based on the designed triangles in space

A geodetic control network is a system of interconnected points on the Earth's surface that are precisely surveyed and used as reference points for mapping and surveying applications. The design of a geodetic control network must take into account various factors to ensure accuracy and reliability. Some of the ill conditions that can affect the design of a geodetic control network include:

1. Non-uniform distribution of control points: If the control points are not evenly distributed throughout the area of interest, the resulting mapping and surveying may be inaccurate. Therefore, it is important to carefully plan the location and spacing of control points to ensure proper coverage.
2. Poor quality of control point coordinates: The accuracy of a geodetic control network depends on the quality of the coordinates of the control points. Errors in the measurement or calculation of control point coordinates can lead to inaccurate mapping and surveying. Thus, it is important to use high-quality surveying equipment and techniques to ensure accurate measurements.
3. Insufficient redundancy: Redundancy refers to the number of control points used to determine the position of a point on the Earth's surface. Insufficient redundancy can lead to inaccuracies in the geodetic control network. Therefore, it is important to have enough control points to provide a high level of redundancy.
4. Changes in the Earth's surface: The Earth's surface is constantly changing due to natural and human activities. These changes can affect the accuracy and reliability of a geodetic control network. Therefore, it is important to periodically update and adjust the network to account for these changes.

The following tables 3.1 and 3.2 show the coordinates in UTM(WGS84) and distances of TAREF11 control points used in this research and which are supported to be validated

Table 3- 1: TAREF11 stations coordinates published by SMD

SITE NAMES	**LOCATION**	**UTM COORDINATES**		**ELLIPSOIDAL (m)**
		EASTINGS(m)	**NORTHINGS(m)**	
TANZ	ARU	522976.9181	9252159.8412	70.4607
T07D	UBUNGO	522072.9607	9248431.6383	79.7877
T08D	COCO BEACH	531542.8285	9250739.9563	-15.8684
T14D	MJI MWEMA	539035.2408	9243316.1496	-12.2723

Table 3-2: Showing distance between stations from TAREF11 GNSS network

STATION	**DISTANCES (m)**
TANZ-T07D	3837.754
TANZ-T08D	8691.250
TANZ-T14D	18330.461
T07D-T08D	9736.662
T07D-T14D	17716.405
T08D-T14D	10544.802

And the proposed geodetic network for my research which were used for validation of some points of second order TAREF11 GNSS network, the network involves the points which are T07D, T08D, T14D and TANZ as shown on figure 3.1 below.

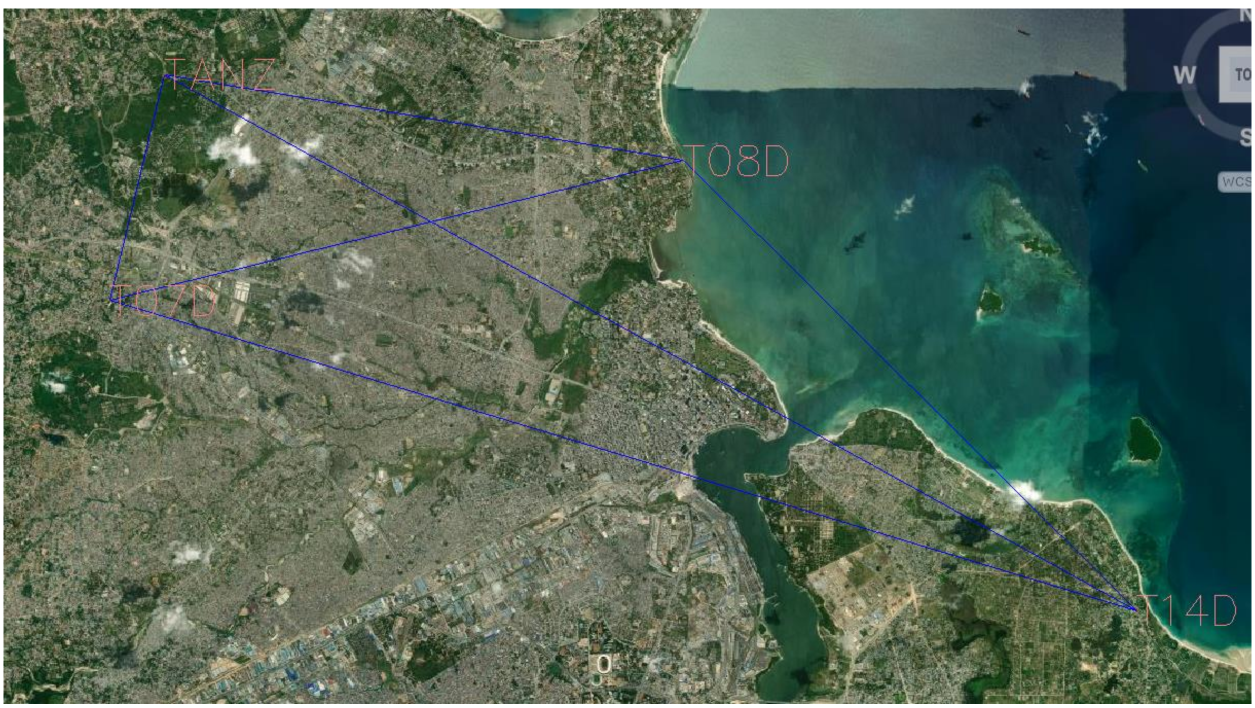

Figure 3-1: Showing locations of the TAREF11 stations used for the study found at Coco beach, Ubungo, and Kigamboni

3.3 Data acquisition and Quality check

Data collection for this research commenced on 22th may 2023 i.e. (day of the year 142). The districts in Dar es Salaam region involved in this campaign are Ubungo, Kinondoni and Ilala. Instruments used in this research are dual frequency Leica Viva GNSS GS15 receivers owned by the Ardhi University. According to the requirements, the set observational time was six hours, and simultaneously observing all stations in one network. At each station the receiver was set to observe above 15 degrees cut off angle with observation recording rate set at 5 seconds to comply with International GNSS services observation files. The Leica Viva GNSS receivers were set to collect data in static mode, thereafter; the raw data are collected for post processing. Static mode is one of the GNSS surveying mode used for high Precision Point Position (Hofmann-Willendorf *et al*., 2007), other GNSS surveying modes include Fast Static, Stop and Go, as well as the Kinematic mode and RTK Mode. Instrument setup on station and observation at Kigamboni Mji Mwema are shown on Figure 3.2 below

Figure 3-2: Image showing data collection on T14D by using Leica GPS receiver

The collected data were downloaded from the instruments for each field campaign in the receiver dependent format (m file - Binary format) compatible with only LEICA GPS processing software. The data were translated into Receiver Independent Exchange format (RINEX) using open-source program known as (Translation Editing and Quality Check - TEQC) free available at www.unavco.org. The advantage of using TEQC is that it permits editing of the metadata on the RINEX file header using a single line command.

3.4 Data sets and data format

The geometric distribution of the GNSS stations used in the study to derive the position for TAREF 11 monuments are depicted in the figure below. Receiver Independent Exchange (RINEX) data were automatically downloaded from Leica Viva GNSS GS15 receivers, so the figure 3.3 below show the sample of RINEX file.

```
     2.11           OBSERVATION DATA    G (GPS)             RINEX VERSION / TYPE
NetR9 4.60          Receiver Operator   22-MAY-23 00:00:00  PGM / RUN BY / DATE
TANZ                                                        MARKER NAME
UNAVCO              UNAVCO                                  OBSERVER / AGENCY
5145K79596          Trimble NetR9       4.60                REC # / TYPE / VERS
31050706            TRM55971.00     NONE                    ANT # / TYPE
  4908015.1336  4004010.1970  -746408.6283                  APPROX POSITION XYZ
        0.0001        0.0000        0.0000                  ANTENNA: DELTA H/E/N
     1     1                                                WAVELENGTH FACT L1/2
     6    C1    L1    S1    L2    S2    P2                  # / TYPES OF OBSERV
    15.000                                                  INTERVAL
  2023     5    22     0     0    0.0000000     GPS         TIME OF FIRST OBS
L2C CARRIER PHASE MEASUREMENTS: PHASE SHIFTS REMOVED        COMMENT
L2C PHASE MATCHES L2 P PHASE                                COMMENT
                                                            END OF HEADER
 23  5 22  0  0  0.0000000  0 11G11G30G 5G19G 4G 7G20G14G17G 9G 6
  24480901.273 6 128648145.995 6        40.300   100245206.48845        17.800
  24480903.121 5
  24287415.422 6 127631178.628 6        40.200    99452845.05248        31.900
  24287423.480 8
  24912931.867 6 130918331.792 6        39.600   102014323.96547        27.500
  24912938.168 7
  22213904.156 8 116734997.799 8        46.400    90962215.64249        34.100
  22213902.840 9
  23338056.578 7 122642526.361 7        41.400    95565598.15346        21.800
  23338058.777 6
  24939490.930 6 131057861.399 6        39.000   102123003.42547        27.800
  24939497.113 7
  22912103.586 7 120403931.109 7        42.700    93821372.12147        25.000
  22912108.656 7
  21229069.289 8 111559431.018 8        46.000    86929474.06849        36.700
  21229073.539 9
```

Figure 3-3: Showing RINEX data format used for the processing

The Receiver Independent Exchange Format (RINEX) is a simple ASCII format used by all researchers and other private companies to share GPS data in a single format, independent from the type of equipment that was used to collect data. Usually, the three RINEX file types format includes the observation file, containing the code- and phase measurements to each satellite, the navigation file based on the broadcast navigation message and meteorological file (Gurtner, W., Estey, L.,, 2008). RINEX files contain precise measurements recorded by GNSS receivers, such as GPS (Global Positioning System), GLONASS (Global Navigation Satellite System), Galileo, and other regional systems. These measurements include pseudo range, carrier phase, Doppler, and other relevant data. RINEX files also contain information about the receiver and the observational setup, such as antenna type, receiver location, and time of observation. The primary purpose of RINEX is to facilitate the post-processing of GNSS data. Post-processing involves combining data from multiple GNSS receivers to improve positioning accuracy, conduct scientific analysis, or perform other geodetic calculations. By providing a common format, RINEX enables interoperability between different receiver models and software applications, allowing researchers and professionals to share and analyze data more efficiently. RINEX files are typically generated by GNSS receivers or data loggers. Once the data is collected, it can be converted into RINEX format using specialized software provided by the receiver manufacturer or third-party applications. Conversely, RINEX files can also be converted into receiver-specific formats for use with proprietary software. In addition to raw measurements, RINEX files can also include navigation data, which contains information about satellite orbits, clock corrections, and other parameters necessary for precise positioning calculations. This navigation data is essential for post-processing applications that require precise satellite ephemeris and clock information. According to International GNSS services standards, all RINEX file names must contain only four characters: site name, the day of the year, the session and the year of observation. For example, the RINEX file name convention for Ubungo Riverside was given a code name T07D which contains the required 4 characters, since it was observed on day of the year 142 and is two files per day it was given 1420 and 1421 meaning 142 is the day of the year and 0 and 1 is the session. The data was collected in 2023 as such for the year is written 23. During translation it may be required to produce both the observation and navigation files. These files are denoted by “o” for the observation file and “n” for the navigation file. This means that for the observation file at Ubungo Riverside the RINEX file is denoted by the name T07D1420.23o, T07D1421.23o and navigation file name by T07D1420.23n and T07D1421.23n. To observe the quality of the collected data each RINEX file was compared with the navigation file as well as the notional data which could have been collected if there were no sky obstruction. In practice, for a good quality data, the percentage ratio of actual collected data to the notionally collected data should not be less than 80 percent. The figure 3.4 below shows the sample of data quality check by REQC

```
Processing parameters are:
Receiver tracking capability       : 32 SVs
Maximum ionospheric rate (L1)      : 400.00 cm/min
Report data gap greater than       : 10.00 min
               but less than       : 90.00 min
Expected rms of MP12 multipath     : 65.00 cm
Expected rms of MP21 multipath     : 65.00 cm
Expected rms of MP15 multipath     : 65.00 cm
Expected rms of MP51 multipath     : 65.00 cm
Multipath slip sigma threshold     : 4.00 sigma
% increase in MP rms for C/A | A/S : 100.00 %
Points in MP moving averages       : 50
Minimum signal to noise for L1     : 4
Minimum signal to noise for L2     : 4
Minimum signal to noise for L5     : 4
Width of ASCII summary plot        : 72
Data indicators on summary plot    : yes
Do ionospheric observable          : yes
Do ionospheric derivative          : yes
Do multipath observables           : yes
Do 1-ms receiver clock slips       : yes
Tolerance for 1-ms clock slips     : 1.00e-002 ms
Do receiver LLI slips              : yes
Do plot file(s)                    : no
```

Figure 3-4: Showing Quality check for the data after being checked from TEQC

The above image shows the result of the quality check on T07D observed site and quality check for other stations are presented on appendix. From these results we can deduce that the data were collected at high quality sites with minimal sky view obstruction indicating good quality on the obtained estimates.

3.5 GPS Data processing

The GNSS observation for this project was processed using GAMIT-GLOBK software and comparisons were made between the positions from GAMIT-GLOBK and TAREF11 positions from the official report of TAREF11 of March 15,2018. The Tanzania wide solution for TAREF11 were provided by the Ministry of Land Human Settlement Development at the

Survey and Mapping Division (SMD) and were processed by a consultant, The processing of the collected data sets for this project is explained in the following section

3.5.1 GAMIT-GLOBK processing

Prior to GNSS data processing, the data of the same epoch were downloaded from different Continuous Operating GNSS Services (CORS) sites around Africa. This was done so as to constrain the solution during the processing. These CORS are operated by different scientific groups including African Array Project, SEGMEnT project around Lake Nyasa; CORS maintained by SMD, International GNSS Services (IGS) as well as other individual countries' initiatives. Secondly, the solution to be tied to the ITRF for a regional solution to make it consistent before it is tied to the global solution. The Africa CORS sites downloaded to process with the GNSS data includes ZAMB from Zambia, SUTH and HRAO from South Africa, MBAR from Uganda, RABT from Morocco, ABPO from Madagascar, VACS from Mauritius and Africa Array sites operated in Tanzania TANZ at Ardhi University. All these sites are freely available and can be directly downloaded from UNAVCO website through file transfer protocol (FTP) using the address "ftp dataout.unavco.org". The GPS observations, both the downloaded and observed, were analyzed on a day-by-day basis using least squares solution from 0.00 to 24.00 Universal time (UT). The precision of the downloaded observations operated by IGS are known to some extent and therefore they are used to constrain the GAMIT solution using the site table file (sittbl).The parameters estimated in the GAMIT solutions are the station coordinates, the 9 initial condition of each satellite which are the 3D position (X,Y,Z), 3D velocities (Xdot, Ydot, Zdot), one solar radiation pressure parameter one tropospheric delay every four hours at each site, and phase ambiguities using double-differenced GPS phase measurements, with International GPS Service (IGS) final orbits and International Earth Rotation Service (IERS) earth orientation parameters relaxed. Typically, the parameter estimates can be performed in four ways by applying loose constraints to parameters or tight constraints to parameters and either estimate the initial phase ambiguity as direct values or resolve the integers estimates.

The output from GAMIT processing is the loosely constrained least squares solution for each day which contains the estimates for station coordinates, satellite position and their variance covariance matrix. These solutions comprise the regional estimates containing all IGS sites in Africa, CORS operating in Africa and the solution for the 12 observed networks.

The second stage of GAMIT-GLOBK processing is the combination of the quasi observables (loose constraint solutions) from GAMIT processing into Kalman filter (GLOBK; Herring et al., 2010). The solutions obtained from GAMIT run regional network which can be biased when tied to the International Terrestrial Reference Frame (ITRF). In order to create a good tie, it is required to combine the regional daily solution with global solution files downloaded from MIT website (ftp everest.mit. edu) These IGS solutions are daily processed at MIT with globally distributed IGS core stations. The global loose solution was combined with the regional solution using Kalman filter (GLOBK). The filter takes the common solution of the pseudo-observable from both solutions (regional and global) which includes the station coordinates, satellite state vectors and a prior weight set into them and updates the estimate of parameters. During this time the filter uses the initial state vector to assess the consistency of the combination (Internal constraints) using Chi-squares. The smaller the Chi-square values, the better the quality of the combination. However, the combination would not be possible if there are no common sites. After the combination and assessment of the goodness of the combination, the reference frame was imposed by minimizing the position deviation of ~40 globally distributed IGS core sites with respect to the International Terrestrial Reference Frame 2008 (Altamimi, Z., Collilieux, X., Metivier, L., 2011), at the same time estimating orientation and translation transformations.

In GLOBK solution, several parameters can be estimated as final solutions; however, two ways of estimation exist namely, stochastically or deterministically. In the first case the GLOBK allows the daily variation of parameters while in the latter case, it does not allow daily variation. In stochastic estimation, a noise function is assigned to the parameters function to allow for the daily variation. GPS estimates can be subjected to vast amounts of noise, however the only noise which affect the GPS estimate are white noise, Flicker and brown or Random walk noise. The white noise is mainly contributed by the manufacturer on the instrumental zero error and therefore it is always present in any estimate. The Flicker noise on the other hand is affected by the systematic error that cannot be modeled correctly for example, atmospheric delays on GPS signals. The Brown or random walk noise is a result of monument instability and is always random because the monument behaves differently with different scenarios. Previous studies on GPS daily position time series have proved that the deviation from the progressive mean can be described as a combination of white and flicker noise however, with some random walk noise on some sites (Mao, A.L., Harrison, C.G.A., & Dixon , T.H,, 1999).

It is known that GLOBK solution uses First Order Gauss Markov (FOGM) model to predict uncertainties on site velocity, depending on the time span of the time series (Herring et al., 2010). Its motivation stems from the need for computational efficiency and the ability to handle time series with varying lengths and data gaps (Saria et al., 2013). However, since the solution obtained had only one epoch, it was impossible to compute the estimates using realistic sigma.

CHAPTER FOUR

RESULT, ANALYSIS AND DISCUSSION

4.1 Introduction

This chapter presents analysis of results obtained from processing software (GAMIT-BLOBK), as well as the provisional results submitted at Survey and Mapping Division (SMD) of the Ministry of Land, Housing, and Human Settlement Development (MLHHSD). Analyses include coordinates and their uncertainties comparisons between the results obtained from this processing (GAMIT-GLOBK) to the provisional results published by the Survey and Mapping Division (SMD) of TAREF11 GNSS network. The analysis also assesses the accuracy and reliability of the second-order TAREF11 GNSS network through Hypothesis testing and confidence interval of computed results which lead to the validation of those points after Hypothesis testing pass. The agreement between the positions of the control points from TAREF11 report and GAMIT-GLOBK will approve the precision of the coordinates for normal surveying use.

4.2 Results

The output from GAMIT processing is the loosely constrained least squares solution for each day which contains the estimates for station coordinates, satellite position and their variance covariance matrix. These solutions comprise the regional estimates containing all IGS sites in Africa, CORS operating in Africa and the solution for the 3 observed control stations. The software calculates the coordinates of the geodetic stations in the network based on the adjusted GPS data. It provides the latitude, longitude, and elevation (or height) for each station. The coordinates are typically given in a standardized geodetic reference frame, such as the International Terrestrial Reference Frame (ITRF), also GAMIT-GLOBK provides estimates of the uncertainties associated with the estimated coordinates. These uncertainties reflect the errors and noise present in the GPS data and the precision of the adjustment process.

For comparison of 2D position the coordinates from figure 4.1 below changed from longitude and latitude to UTM coordinate system through UTM convertor

```
#SUMMARY VELOCITY ESTIMATES FROM GLOBK
# Long.      Lat.        E & N Rate      E & N Adj.      E & N +-    RHO        H Rate   H adj.    +-   SITE
# (deg)     (deg)          (mm/yr)       (mm/yr)       (mm/yr)                 (mm/yr)
  358.78069   46.15894   16.91   17.52    0.00    0.00 1000.00 1000.00 -0.000     8.97    0.00 1000.00 LROC_GPS
  357.35951   53.34481    0.00    0.00    0.00    0.00 1000.00 1000.00  0.000     0.00    0.00 1000.00 DARE_5PS
  357.04835   35.28119    0.00    0.00    0.00    0.00 1000.00 1000.00  0.000     0.00    0.00 1000.00 MELI_2PS
  356.91138   40.52490   18.90   15.29    0.00    0.00 1000.00 1000.00  0.000     0.29    0.00 1000.00 YEBE_GPS
  355.75035   40.42916   18.82   16.42    0.00    0.00 1000.00 1000.00 -0.000    -0.23    0.00 1000.00 MADR_7PS
  355.50341   48.38050   16.70   16.93    0.00    0.00 1000.00 1000.00  0.000    -0.59    0.00 1000.00 BRST_5PS
  354.75991    6.87056   22.65   18.74    0.30    0.54  685.98  685.97 -0.000     0.68   -0.87  699.21 YKRO_GPS*
  354.75991    6.87056   22.65   18.74    0.30    0.54  685.98  685.97 -0.000     0.68   -0.87  699.21 YKRO_2PS*
  354.33266  -15.94253   23.21   18.95    0.52    0.48  984.72  984.73 -0.000     0.09    0.22  994.44 STHL_GPS*
  353.79436   36.46435    0.00    0.00    0.00    0.00 1000.00 1000.00 -0.000     0.00    0.00 1000.00 SFER_LPS
  353.14571   33.99811    8.32    8.78   -8.32   -8.78  707.11  707.11  0.000     0.40   -0.40  707.11 RABT_GPS
  353.14571   33.99811    8.32    8.78   -8.32   -8.78  707.11  707.11  0.000     0.40   -0.40  707.11 RABT_2PS
  351.18694   42.18398   17.64   16.97    0.00    0.00 1000.00 1000.00 -0.000    -1.19    0.00 1000.00 VIGO_2PS
  350.58148   38.69342    0.00    0.00    0.00    0.00 1000.00 1000.00 -0.000     0.00    0.00 1000.00 CASC_5PS
  345.66734   -7.91628    0.00    0.00    0.00    0.00 1000.00 1000.00  0.000     0.00    0.00 1000.00 ASCG_GPS
  344.80208   64.26729   14.58   14.65    0.00    0.00 1000.00 1000.00  0.000    14.71    0.00 1000.00 HOFN_6PS
  344.36673   27.76374   17.15   17.74    0.57    0.25  984.92  984.91 -0.000    -0.68    0.24  994.43 MAS1_6PS*
  343.09239   32.64795    0.00    0.00    0.00    0.00 1000.00 1000.00  0.000     0.00    0.00 1000.00 FUNC_4PS
  342.10617   28.76387    0.57    0.25    0.57    0.25  984.84  984.83 -0.000     0.24    0.24  994.43 LPAL_3PS*
  338.04966   70.48534    0.00    0.00    0.00    0.00 1000.00 1000.00  0.000     0.00    0.00 1000.00 SCOR_2PS
  338.04451   64.13879    0.00    0.00    0.00    0.00 1000.00 1000.00  0.000     0.00    0.00 1000.00 REYK_JPS
  337.06507   16.73206    0.00    0.00    0.00    0.00 1000.00 1000.00  0.000     0.00    0.00 1000.00 CPVG_4PS
  334.33724   37.74775   12.32   16.16    0.00    0.00 1000.00 1000.00  0.000    -2.01    0.00 1000.00 PDEL_4PS
```

Figure 4-1: Showing loosely constrained least square solutions from the GAMIT

4.2 Comparison and Discussion

4.2.1 Position Uncertainties

It may observe that some differences on positions obtained using the same software may be due to the processing strategies and the methods analysis center treats errors during processing. For example, the provision TAREF11 positions of SMD was obtained using GAMIT-GLOBK software and the same software is employed obtained positions in this research; however, their positions and uncertainties are different. Only three stations (T07D, T08D and T14D) with positions are involved in the comparison. Figures 4.1; 4.2 and 4.3 compare the position uncertainties in the solution processed in this study. The precision in the estimated positions between GAMIT-GLOBK and TAREF11 were compared. The two solutions were processed using the same software but due to the method of handling the errors, the precision differ. In GAMIT-GLOBK, the errors were accounted for when inputting data, such as incorrect file formats, missing or incomplete data files, or inconsistency in data formats or coordinate systems, also unappropriated configuration and parameter setups for accurate data processing. The figures 4.2 and 4.3 below shows the uncertainties between TAREF11 and GAMIT-GLOBK position precision in E component and in N component.

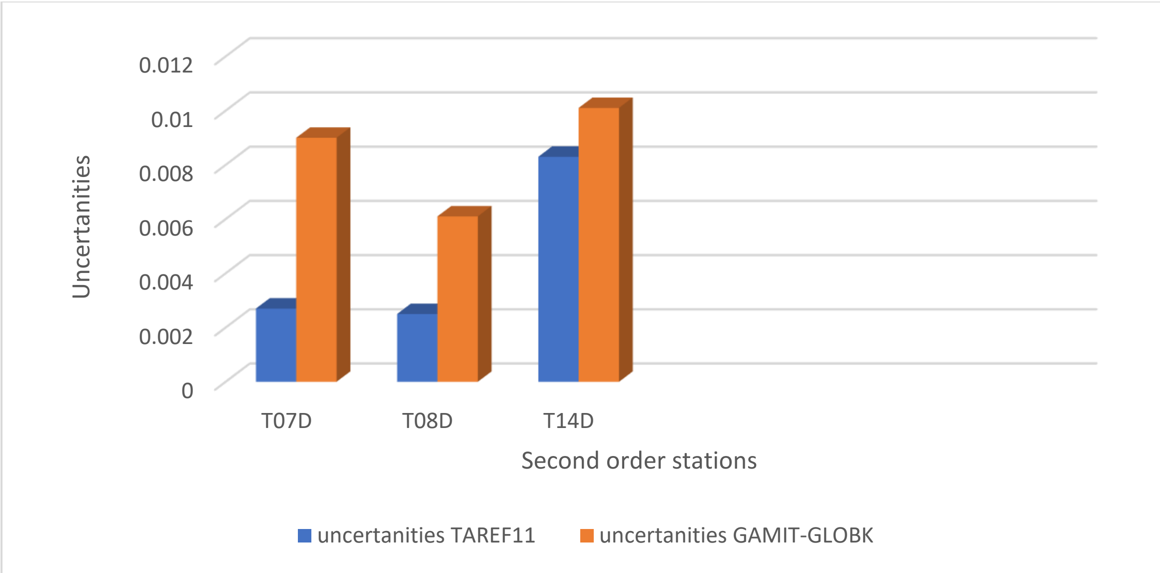

Figure 4-2: Precision comparisons between GAMIT_GLOBK and TAREF11 in E component

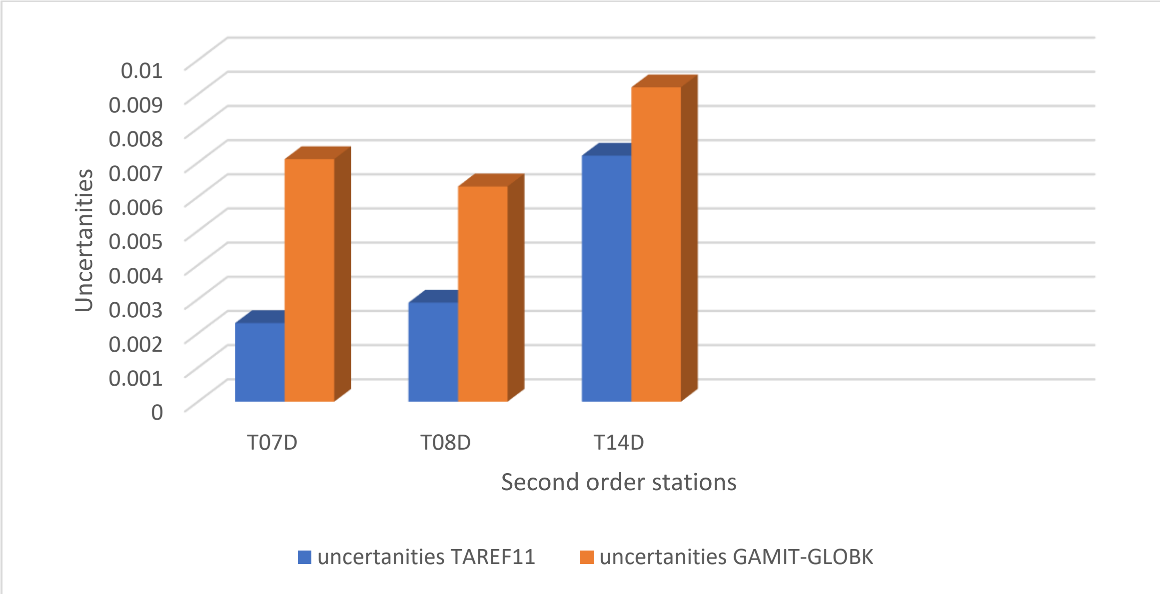

Figure 4-3: Precision comparisons between GAMIT-GLOBK and TAREF11 in N- component

Figures 4.2 and 4.3 compare the uncertainties in E and N for TAREF11 second order stations and GAMIT-GLOBK processed positions. The result showed small uncertainties in some sites for E component, and for almost all sites in N component. Large uncertainties for theTAREF11 solution are observed in the E component on station T07D, the large difference being observed at site T07D with approximately 1 cm. In the case of N component, the differences in uncertainties observed are very small, with maximum of 5 millimeter at T07D site. The overall position uncertainties difference between TAREF 11 and GAMIT GLOBK solution is very small, with maximum of 2 millimeter at T08D site in N components.

The precision of the two positions were compared, the result reveals, the higher precision in TAREF11 followed by the GAMIT-GLOBK. Large differences were observed in E and N components for all the three solutions. The reason for poor precision may be due to failure to choose IGS sites that will be used to tie the solution to ITRF during processing and sometimes very few or poor IGS sites from Africa with poor network geometry.

4.2.2 Coordinate Comparison

The provisional TAREF11 final coordinates were compared to the position estimate computed in this study**.** Two positions were computed, the GAMIT-GLOBK and TAREF11 for 3 sites adopted as the final geodetic position for Tanzania: they are considered as a base position. The positions determined in this study are then compared to the base solution to investigate their agreement. The table 4.1 below shows thee position differences between TAREF11 and GAMIT-GLOBK coordinates in UTM (WGS84)

Table 4-1: Showing position differences between TAREF11 and GAMIT-GLOBK

Processing Position type	EASTINGS(m)	NORTHINGS(m)
TAREF11 (T07D)	**522072.9607**	**9248431.6383**
GAMIT	522072.9696	9248431.6067
Differences	0.0089	0.0316
TAREF11 (T08D)	**531542.8285**	**9250739.9563**
GAMIT	531542.8283	9250739.9381
Differences	0.0002	0.0182
TAREF11 (T14D)	**539035.2408**	**9243316.1496**
GAMIT	539035.2384	9243316.2671
Differences	0.0024	0.1175

Since the TAREF11 position was computed at a different time from the position computed in this study, all solutions were propagated to a common reference epoch and the same reference frame to propagation equation 4.1 According to the documentation for the TAREF11 solution, the estimated position were aligned to ITRF2014 at reference epoch 2018, while the position obtained in this study is aligned with ITRF2014 at reference epoch 2023

4.2.3 Position Comparison between TAREF11 and GAMIT-GLOBK

Figure 4.4 compares the coordinates between TAREF11 and GAMIT-GLOBK for all survey sites which have a common coordinate solution. Given the problem on TAREF11 network observation that no existing monuments were observed, only three GPS sites were T07D, T08D and T14D. The comparison is based on the coordinate difference between the three aforementioned TAREF11 monuments. The study observed a low coordinate difference of 2 millimeters at station T08D and high coordinate difference of 2.4 millimeters at T14D in the E component. Also, low positional difference~1 centimeter at T08D in the N component and the high difference was observed at station T14D about ~ 11 centimeters.

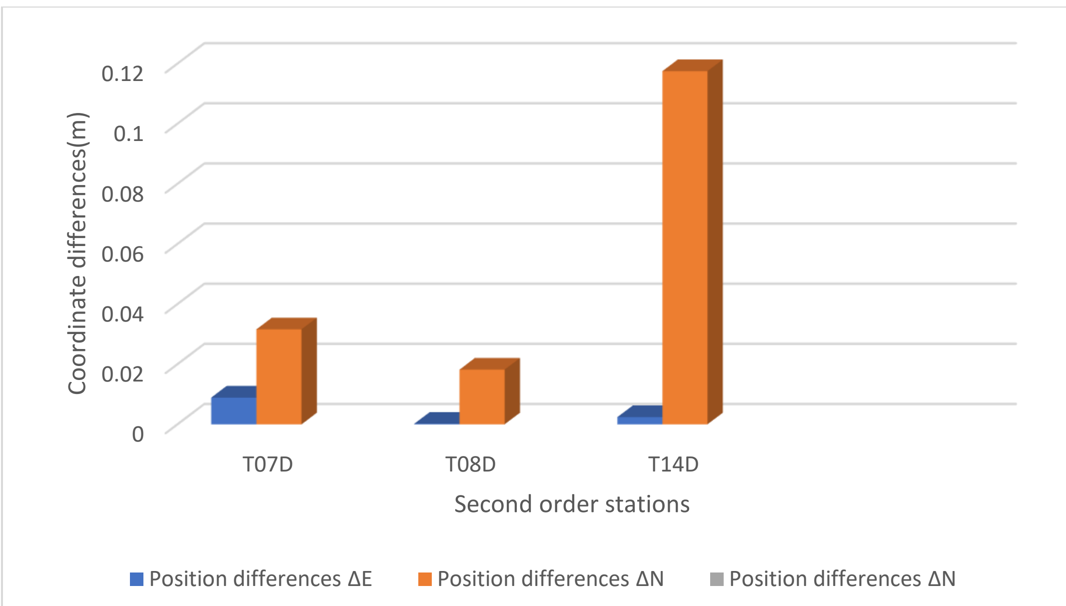

Figure 4-4: Graph showing position differences between TAREF11 and GAMIT-GLOBK

4.3 Validity and Reliability

For validity and reliability of the data, hypothesis testing was conducted and calculate confidence intervals for the processed data from GAMIT-GLOBK. Hypothesis Testing is for determining if the observed discrepancies are statistically significant or if they fall within an acceptable tolerance range, this can help to assess the validity of the control points. Confidence

Intervals to quantify the uncertainty associated with the estimated control point coordinates, this provides a measure of the reliability of the validation results.

4.3.1 Analysis of the accuracy of control points

From the instrument accuracy specification, σp = 5 mm + 0.5 ppm we can get standard error (So). For this study I will use the standard error from previous research on deformation monitoring of Ruvu bridge which is 5.000163151mm

- To test validity of these control points we should perform hypothesis testing to see that the uncertainties or difference between two epoch is acceptable
- We can now define a null hypothesis (Ho) that, no deformation has taken place on TAREF11 second order monuments, such as Ho: Bx =0
- The alternative hypothesis (Ha) that deformation has taken place on TAREF11 second order monuments, such as Ha: Bx< >0

Where x- vector of unknown

- So, test the two Ha and Ho we will use Global Congruence Test (GCT)

Consider the table below which show displacement in Easting and in Northings. The tables 4.2, 4.3 and 4.4 below shows the displacements in Northings and Eastings between TAREF11 and GAMIT-GLOBK UTM(WGS84) coordinates and their variances.

Table 4-2: Showing displacement in Northing and Easting directions between TAREF11 and GAMIT-GLOBK

POINTS	FIRST EPOCH		SECOND EPOCH		DISPLACEMENT	DISPLACEMENT
	NORTHING (m)	EASTING (m)	NORTHING (m)	EASTING (m)	ΔN (m)	ΔE (m)
T07D	9248431.6383	522072.9607	9248431.6067	522072.9696	-0.0316	0.0089
T08D	9250739.9563	531542.8285	9250739.9381	531542.8283	-0.0182	-0.0002
T14D	9242324.1496	539035.2408	9243324.2671	539032.5324	0.1175	0.0024

Table 4-3: Showing UTM (WGS84) coordinates from TAREF11 with their variances (As first epoch)

STN	EASTINGS	NORTHINGS	σE^2	σN^2
T07D	522072.9607	9248431.6383	7.29E-6	5.29E-6
T08D	531542.8285	9250739.9563	6.25E-6	8.41E-6
T14D	539035.2408	9243316.1496	6.89E-5	5.184E-5

Table 4-4: Showing UTM(WGS84) coordinates from GAMIT-GLOBK with their variances (As second epoch)

STN	EASTINGS	NORTHINGS	σE^2	σN^2
T07D	522072.9696	9248431.6067	8.1E-5	5.04E-5
T08D	531542.8283	9250739.9381	3.72E-5	3.97E-5
T14D	539032.5324	9243324.2671	5.76E-6	0.0138

I. For T07D

$d = [\Delta E\ \Delta N]^T = [0.0089\ \ 0.0316]^T$ ………(i)

$Qx_1 = [\ \sigma E^2, 0\ \ 0, \sigma N^2]^T = [7.29E\text{-}6, 0\ \ 0, 5.29E\text{-}6]^T$ ………...(ii)

$Qx_2 = [8.1E\text{-}5, 0\ \ 0, 5.04E\text{-}5]^T$ ………….(iii)

$Qdd = Qx_1 + Qx_2$ …………. (iv)

$Qdd = [8.83E\text{-}5, 0\ \ 0, 5.57E\text{-}5]^T$ ………….(v)

Given So = 5.000163151

$df_1 = 2$, $df_2 = 9$

$FM = [d^T Qdd^{-1} d]/Sof$

Where $f = df_1 + df_2$,

$f = 11$

After computing we get FM= 0.3423

Then theoretical value of F from f-distribution table $F_{2,9,0.005}$ is 4.26

So, since FM<F then point T07D not deform

II. T08D

$d = [\Delta E\ \Delta N]^T = [0.0002\ \ 0.0182]^T$ ……..(vi)

$Qx_1 = [\ \sigma E^2, 0\ \ 0, \sigma N^2]^T = [6.25E\text{-}6, 0\ \ 0, 8.41E\text{-}6]^T$ ……(vii)

$Qx_2 = [3.72E\text{-}5, 0\ \ 0, 3.97E\text{-}5]^T$ ……(viii)

$Qdd = Qx_1 + Qx_2$ ………(ix)

$Qdd = [4.35E\text{-}5, 0\ \ 0, 4.81E\text{-}5]^T$ ………(x)

Given So = 5.000163151

$df_1 = 2$, $df_2 = 9$

$FM = [d^T Qdd^{-1} d]/Sof$

Where $f = df_1 + df_2$,

$f = 11$

After computing we get FM= 0.1244

Then theoretical value of F from f-distribution table $F_{2,9,0.005}$ is 4.26

So since FM<F then point T08D not deform

III. T14D

$d = [\Delta E\ \Delta N]^T = [0.0024\ \ 0.1175]^T$ ………(xi)

$Qx_1 = [\ \sigma E^2, 0\ \ 0, \sigma N^2]^T = [6.89E\text{-}5, 0\ \ 0, 5.184E\text{-}5\ ]^T$ ………(xii)

$Qx_2 = [5.76E\text{-}6, 0\ \ 0, 0.0138]^T$ ………..(xiii)

$Qdd = Qx_1 + Qx_2$ ……...(xiv)

$Qdd = [7.47E\text{-}5, 0\ \ 0, 0.0139]^T$ ………(xv)

Given So = 5.000163151

$df_1 = 2$, $df_2 = 9$

$FM = [d^T Qdd^{-1} d]/Sof$

Where $f = df_1 + df_2$,

$f = 11$

After computing we get FM= 0.0195

Then theoretical value of F from f-distribution table $F_{2,9,0.005}$ is 4.26

So since FM < F then point T14D not deform

4.3.2 Computation of 95% Confidence Ellipses/Intervals

The 95% confidence ellipses/intervals are computed with the standard errors of the adjusted parameters and the 95% confidence level expansion factor, 1.96. In this, the error associated with the observed monitoring point in two different epochs is computed and multiplied by 1.96. Beshr and Kaloop (2013)

To assess rate horizontal deformation of the TAREF11 second order monuments, the magnitude of displacement should be obtained by subtracting the north direction of the first epoch from that of the second epoch and easting direction of first epoch from that of the second epoch

- Confidence level is given by the formular $E_P = C_P*\sigma$

Where E_p- certain percentage error

C_p-corresponding numerical factor

i. For T07D

confidence level 95%

$\Delta E = E_2-E_1 = 0.0089$ ……...(xvi)

$\Delta N = N_2-N_1 = 0.0316$ ……. (xvii)

$dE_{95\%}$, standard error is 7.0714mm from mostly survey

$dh = C_{95}* sqr[\sigma E^2 + \sigma N^2]$ ……..(xviii)

$dh = 1.9599* sqr[0.0089^2 +0.0316^2] = 0.0643$ ……..(xix)

since $dh < dE_{95\%}$ then point T08D not deform at confidence level 95% horizontal

ii. For T08D

confidence level 95%

$\Delta E = E_2-E_1 = 0.0002$ ……(xx)

$\Delta N = N_2-N_1 = 0.0182$ ……. (xxi)

$dE_{95\%}$, standard error is 7.0714mm from mostly survey

$dh = C_{95}* sqr[\sigma E^2 + \sigma N^2]$ …….(xxii)

$dh = 1.9599* sqr[0.0002^2 +0.0182^2] = 0.0356$ …….(xxiii) since dh < $dE_{95\%}$ then point T07D not deform at confidence level 95% horizontal

iii. For T14D

confidence level 95%

$\Delta E = E_2 - E_1 = 0.0024$ ……. (xxiv)

$\Delta N = N_2 - N_1 = 0.1175$ ……. (xxv)

$dE_{95\%}$, standard error is 7.0714mm from mostly survey

$dh = C_{95} * sqr[\sigma E^2 + \sigma N^2]$ ……(xxvi)

$dh = 1.9599 * sqr[2.7084^2 + 8.1175^2] = 0.2303$ ……..(xxvii)

since dh < $dE_{95\%}$ then point T14D not deform at confidence level 95% horizontal

So finally, I can say that all the points are valid from statistical testing and also through confidence interval of 95% and also by compared the solution uncertainties on the two estimated solution and the provisional solution (TAREF11 solution) submitted at the Survey and Mapping Division (SMD) of the Ministry of Land, Housing, and Human Settlement Development (MLHHSD). The differences between the uncertainties were found not exceeding 2cm and hence conclude that the solutions were well estimated. Secondly this study compared the estimated positional coordinate. The difference between the solution estimated in this study and the TAREF11 solution did not exceed ~12 cm making it within tolerance range for third order controls.

4.4 Summary of the Comparative Analysis

Comparisons were made on the uncertainties of the results as well as the resulting position for all geodetic sites in all the selected the three districts in Dar es salaam. In general, In the case of positional differences, the computed differences are within a few centimeters range with a maximum ~11 centimeters between GAMIT-GLOBK and TAREF11 for the point T14D, the large positional difference of this point from the compared data between GAMIT-GLOBK and TAREF11 may be due to

i. Instrumental errors: Geodetic measurements are subject to errors introduced by the instruments used such as GPS receivers. Calibration issues, faulty equipment, or improper handling can result in inaccuracies in the recorded positions.
ii. Satellite geometry: In the case of GPS, the geometry of the satellites in view can impact the accuracy of the position determination. Poor satellite geometry can result in less precise position fixes.
iii. Human errors: Mistakes made by surveyors during fieldwork, data entry, or data manipulation can also contribute to large position differences
iv. Other factors include Incorrectly calibrated or uncalibrated antennas, longer baselines between GNSS stations can be more sensitive to various error sources, leading to larger positional differences compared to shorter baselines.

For more clarifications see the table 4.5 below which shows the uncertainties and position differences between TAREF11 and GAMIT-GLOBK in UTM (WGS84).

Table 4-5: Table showing summary for the uncertainties and position differences between TAREF11 and GAMIT-GLOBK

STATIONS	**UNCERTANTIES**		**POSITION DIFFERENCES**	
	EASTINGS	**NORTHINGS**	**EASTINGS**	**NORTHINGS**
TAREF11(T07D	0.0027	0.0023	0.0089	0.0316
GAMIT	0.009	0.0071		
Differences	0.0063	0.0048		
TAREF11(T08D)	0.0025	0.0029	0.0002	0.0182
GAMIT	0.0061	0.0063		
Differences	0.0036	0.0034		
TAREF11(T14D)	0.0083	0.0072	0.0024	0.1175
GAMIT	0.0101	0.0092		
Differences	0.0018	0.002		

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study has validated the new geodetic reference frame for Tanzania (TAREF 11) particularly at Dar es salaam, Tanzania using only the available second order station at the three locations (Ubungo Riverside, Coco beach and Kigamboni Mji mwema). Due to the specific objectives this study conclude the following:, The study confirms that the Second Order TAREF11 GNSS network in Dar es Salaam meets the required accuracy and reliability standards for various applications in surveying, geospatial data collection, and navigation, the research establishes that the TAREF11 GNSS network is well-suited for geodetic applications in the region, such as establishing control points, mapping, and supporting infrastructure development projects, the study provides valuable insights into the precision of the TAREF11 network, demonstrating its ability to deliver consistent and precise positioning data across the city of Dar es Salaam, the study may instill confidence among local users, including surveyors, engineers, and government agencies, in relying on the TAREF11 GNSS network for their positioning needs. Overall, the validation of the Second Order TAREF11 GNSS network in Dar es Salaam strengthens the case for its continued usage and underscores its significance in supporting geospatial applications and development efforts in the region

5.2 Recommendation

Based on the results, analysis as well as the conclusion presented, this study recommended the following. First, the study observed that some monuments are still very stable and can exist for many years. In addition, the community should give knowledge about importance of these points for more protection

Lastly recommend other students to do validation for the rest of the points found in Dar es salaam as at town there are many human activities which can disturb the monuments of these points

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APPENDICES

A.1.TEQC results for data quality check T07D

```
version: teqc  2019Feb25

 SV+-------|--------------------------|--------------------------|--------
--+ SV
  5|Loooooooo
|  5
 24|LooIIIoooooIIII
| 24
 15|LIIoooooooooooooooooooo
| 15
 18|LoooooIIoIoIIIIIIIIIIIIIooI                          LooIIIII
| 18
 12|LooooooooooooooooooooooIoIo
| 12
 25|LooooooooooooooooooooooooooooooIIIIIIII
| 25
 23|IooIoooooooooooooooooooooooooooooooIooIII
| 23
 28|
IILIIIIIIIIIIIIIIIIIIIIIIIIoIIIIIIIIIIIIIoooooIoooooooooooooooooooooo| 28
 10|    IIIIIIoIoooooooooooooooooooooooooo-oooooooIIIIII
| 10
 29|          Iooooooooooooooooooooooooooo-ooooIooI2M
| 29
 32|               IIIoIIIIIIIIoIooooooooo-oooooooooooooooooooooooooIoo
| 32
 26|                   IIIIIIIIIIIIIIoIIoo-
oooooooooooooooIooIIIIIooooIoIIII| 26
 31|
IIIIIIIoLLoIooIoIIIIIIIooIMIIoIooooooooooooooooooo| 31
 16|
LIoIIIoIIIooMoIIoooIooooIIoooIoIoooIIIoII| 16
 27|
IIIIIIIIooooooooooooooooooooooo| 27
  8|
IIIIILIIIooIIoooIooo|  8
  2|
Looooooooooooooooo|  2
  4|
IIIIILIIIII|  4
 21|
LIIoIo| 21
R17|LLLLN
|R17
R13|LNNNNLLNLLL
|R13
R18|LNLLNLLLLLN                           LNNNNNNNNNNNNNNNNNNNNNNNNNNN
|R18
R 2|NNNNNLNNNNNNNNNNN
|R 2
```

```
R14|LNNNNNNNNNNNNNNNNNNNNNNNNNNLLLN
|R14
R 3|LNNLNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
|R 3
R15|LLLNLLLLNNNNNNNNNNNNNNNNNNNNNNNNNNNNLLNNNLLN
|R15
R 4|         LNNNNNNLNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
|R 4
R16|
LLLLLNNLLLLNNNLNLNLLLLLLLNNNNLLLLLNNNNNNNNLLNNNNNNLLLLNLN|R16
R 5|                            LLLLLNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
|R 5
R 6|                                                 LL LLLLNNLNNN LLLL
LLL |R 6
R19|
LNNNNNNNNNNNNNNNNNN|R19
R 7|
LNLNNLLLLLLLLL|R 7
R 9|
LLNLLNNNN|R 9
R20|
LNNNNNNN|R20
Obs|deefffffeefeeeeeedefffffggfedddeeeeedddddcccccbbccabcdeeeeffeefegfeee
fe|Obs
Clk|-                                   ^
|Clk
   +-------|--------------------------|--------------------------|--------
--+
08:06:38.500
16:13:28.000
2023 May 22                                                            2023
May 22

*********************
QC of RINEX  file(s) : t07d1420.23o
*********************

4-character ID          : T07D (# = 1244)
Receiver type           : LEICA GS15 (# = 1511244) (fw = 4.03/6.110)
Antenna type            : LEIGS15         NONE

Time of start of window : 2023 May 22  08:06:38.500
Time of  end  of window : 2023 May 22  16:13:28.000
Time line window length : 8.11 hour(s), ticked every 3.0 hour(s)
Observation interval    : 0.5000 seconds
Total satellites w/ obs : 34
NAVSTAR GPS SVs w/o OBS :  1   3   6   7   9  11  13  14  17  19  20  22
                          30
    GLONASS SVs w/o OBS :  1   8  10  11  12  21  22  23  24
Rx tracking capability  : 32 SVs
Poss. # of obs epochs   :  58420
Epochs w/ observations  :  58360
Epochs repeated         :      0  (0.00%)
Complete observations   : 717162
```

```
 Deleted observations   :  23991
Obs w/ SV duplication   :      0  (within non-repeated epochs)
Moving average MP12     : 0.217926 m
Moving average MP21     : 0.285990 m
Moving average MP15     : 0.133044 m
Moving average MP51     : 0.117651 m
Points in MP moving avg : 50
Mean S1                 : 6.89 (sd=1.57 n=734876)
Mean S2                 : 6.51 (sd=1.69 n=714481)
Mean S5                 : 7.55 (sd=1.07 n=291785)
No. of Rx clock offsets : 1
Total Rx clock drift    :  0.000000 ms
Rate of Rx clock drift  :  0.000 ms/hr
Avg time between resets : 486.825 minute(s)
Freq no. and timecode   : 3 15842 01ff00
Report gap > than       : 10.00 minute(s)
       but < than       : 90.00 minute(s)
epochs w/ msec clk slip : 0
other msec mp events    : 0 (: 1418)   {expect ~= 1:50}
IOD signifying a slip   : >400.0 cm/minute
IOD slips               :   3221
IOD or MP slips         :   3173
      first epoch    last epoch    sn1   sn2   sn5
SSN 23  5 22 08:06 23  5 22 16:13  6.89  6.51  7.55
      first epoch    last epoch    mp12  mp21  mp15  mp51
SMP 23  5 22 08:06 23  5 22 16:13  0.22  0.29  0.13  0.12
      first epoch    last epoch    hrs   dt  #expt  #have   %   mp1   mp2
o/slps
SUM 23  5 22 08:06 23  5 22 16:13 8.106 .50     -  717162  -   0.22  0.29
226
```

A.2.TEQC results for data quality check T08D

```
version: teqc  2019Feb25

 SV+-----------------------------|-----------------------------|----------
--+ SV
  5|L
|  5
 24|Looooooo
| 24
 15|Looooooooooooooooo
| 15
 12|Looooooooooooooooooooo
| 12
 18|Looooooooooooooooooooo                            LLoooooooo
| 18
 25|LoooooooooooooooooooooooILoooooooooo
| 25
 23|LoooooooooooooooooooooooIIooooooooooo
| 23
 10|LoooooooooooooooooooooooIooooooooooooooooooIooooo
| 10
```

```
28|LoooooooooooooooooooooooIIoooooooooooooooooIooooooIoooooooooooooooooooo
o| 28
 29|  LoooooooooooooooooooooIooooooooooooooooooIoo
| 29
 32|        LoooooooooooooooIooooooooooooooooooIooooooIoooooooooooooooo
| 32
 26|
LooIooooooooIooooooooooooooooooIooooooIooooooooooooooooooooo| 26
 31|
LooooooooIooooooooooooooooooIooooooIooooooooooooooooooooo| 31
 16|
LoooooooooooooooooIooooooIooooooooooooooooooooo| 16
 27|
LooIooIooooooIooooooooooooooooooooo| 27
  8|
LIooooooooooooooooooooo|  8
  2|
Loooooooooooooooooooo|  2
  4|
Loooooooooooo|  4
 21|
Loooooo| 21
R18|LNN                               LNNNNNNNNLNNNNNNLNNNNNNNNNNNNNN
|R18
R13|LNNN
|R13
R 2|LNNNNNNNNN
|R 2
R14|LNNNNNNNNNNNNNNNNNNNNN
|R14
R 3|LNNNNNNNNNNNNNNNNNNNNNNNLLNNNNNN
|R 3
R15|LNNNNNNNNNNNNNNNNNNNNNNNLNNNNNNNNNNNNNN
|R15
R 4|  LNNNNNNNNNNNNNNNNNNNNNLNNNNNNNNNNNNNNNNNNLNNNN
|R 4
R16|
LNNNNNNNNNNNNNLNNNNNNNNNNNNNNNNNNLNNNNNNLNNNNNNNNNNNNNNNNNNNNN|R16
R 5|                 LLNNNNNLNNNNNNNNNNNNNNNNNNLNNNNNNNNNNNNNNNNNNN
|R 5
R 6|
LLNNNNNNLNNNNNNNNNNNNNNNNNLLL|R 6
R19|
LNNNNNNNNNNNNNNNNNN|R19
R 7|
LNNNNNNNNNNNNNNN|R 7
R 9|
LNNNNNNNNNN|R 9
R20|
LNNNNNNN|R20
Obs|feffeeeeeeeefffgggggeddddeeeeeeeddeddddcccddddccbbcddeeefffgfggfgggfff
ff|Obs
```

```
Clk|                                        ^
|Clk
   +-------------------------|--------------------------|----------
--+
09:00:40.000
16:14:25.000
2023 May 22                                                     2023
May 22

********************
QC of RINEX  file(s) : t08d1420.23o
********************

4-character ID          : T08D (# = 1114)
Receiver type           : LEICA GS15 (# = 1511114) (fw = 4.03/6.110)
Antenna type            : LEIGS15         NONE

Time of start of window : 2023 May 22  09:00:40.000
Time of  end  of window : 2023 May 22  16:14:25.000
Time line window length : 7.23 hour(s), ticked every 3.0 hour(s)
Observation interval    : 5.0000 seconds
Total satellites w/ obs : 33
NAVSTAR GPS SVs w/o OBS :  1   3   6   7   9  11  13  14  17  19  20  22
                          30
    GLONASS SVs w/o OBS :  1   8  10  11  12  17  21  22  23  24
Rx tracking capability  : 32 SVs
Poss. # of obs epochs   :   5206
Epochs w/ observations  :   5199
Epochs repeated         :      0  (0.00%)
Complete observations   :  69589
 Deleted observations   :   2165
Obs w/ SV duplication   :      0  (within non-repeated epochs)
Moving average MP12     : 0.229303 m
Moving average MP21     : 0.163993 m
Moving average MP15     : 0.104623 m
Moving average MP51     : 0.094099 m
Points in MP moving avg : 50
Mean S1                 : 7.63 (sd=1.06 n=71702)
Mean S2                 : 7.11 (sd=1.24 n=69577)
Mean S5                 : 7.82 (sd=0.74 n=29941)
No. of Rx clock offsets : 0
Total Rx clock drift    :  0.000000 ms
Rate of Rx clock drift  :  0.000 ms/hr
Avg time between resets : Inf minute(s)
Freq no. and timecode   : 3 15842 01fe00
Report gap > than       : 10.00 minute(s)
       but < than       : 90.00 minute(s)
epochs w/ msec clk slip : 0
other msec mp events    : 0 (: 128)   {expect ~= 1:50}
IOD signifying a slip   : >400.0 cm/minute
IOD slips               :     91
IOD or MP slips         :     62
      first epoch    last epoch    sn1   sn2   sn5
SSN 23  5 22 09:00 23  5 22 16:14  7.63  7.11  7.82
```

```
      first epoch    last epoch    mp12  mp21  mp15  mp51
SMP 23  5 22 09:00 23  5 22 16:14  0.23  0.16  0.10  0.09
      first epoch    last epoch    hrs   dt  #expt  #have   %   mp1   mp2
o/slps
SUM 23  5 22 09:00 23  5 22 16:14 7.221   5     -   69589  -   0.23  0.16
1122
```

A.3.TEQC results for data quality check T14D

```
version: teqc  2019Feb25

 SV+----------------------|----------------------------------|------------
--+ SV
 15|Loooooo
| 15
 18|LoIooIooIIIo                                  LIIIIIIIIoI
| 18
 12|LooIIIIIIIIL
| 12
 25|LooIoooIIIIIIIIMI2IIII
| 25
 23|LoooooooooIooIoooooooooIoIIIII
| 23
 29|LoooooooooIooIooooooooooooooooooooMoooooo
| 29
 10|LoooooooooIooIooooooooooooooooooooooooooIIoo
| 10
 32|IIIIIIoIoIIIIIIIIIooIIIIIIooIooooooooooooooooooooooooooooooooIIIo
| 32

28|LooooooIIIIoIoIIIIIIooooIIIIIIIIIIIIIIIoIoooooooooooooooooooooooo
I| 28
 26| IoIIIooooIooIooooooooooooooooooooooooIIIooIooIIoIIILIIIIII-IIL--
IILIII| 26
 31|
IoooooIooIooooooooooIILLLLIIIIIIooooooIooIoIoooooIcIIIoooooooooooooo| 31
 16|
LoooooooooooooooooooooooooooooooooooooooooIooooooooIII| 16
 27|
IIIoIoooooooooooooooooooooooooooooooooooII| 27
  8|
IooIoIoooooooooooooooIooooo|  8
  2|
Iooooooooooooooooooooooo|  2
  4|
IIIIIIIoooo|  4
 21|
Looooooo| 21
R14|LNNNNLLLL LL
|R14
R 3|LNNNNNNNNNNNNLNNNNNNNNNN
|R 3
R15|LNNNNNNNNNNNNLNNNNNNNNLNLLLLL
|R15
```

```
R 4|LNNNNNLLNNNNNLNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
|R 4
R16|LNNNNNNNNNNNNLNNNNNNNNNNNNNNNLNNNNNLLNLNNNNNLLL      L   L   L
LLNNNNNNNNNN|R16
R 5|        LLLNNLNNNNNNNNNNNNLLNNNNNNNNNNNNNNNNNLNNNNNNNNNNNNNNNN
|R 5
R18|                           LLNNNNNNNNNNNNNNNNLNNNNNNNNNNNNNNNNNLLL
|R18
R19|
LLNNNNNNNNNNNNNNNNNNNNNNLNNNNL|R19
R 6|
LNNNNNNNNNNNNNNNNNNNNNNNNNNN|R 6
R 7|
LNNNNNNNNNNNNNN|R 7
R20|
LNNNNNNNNNNNNN|R20
R 9|
LLLLLLLLNLLL|R 9
Obs|efffgggeffggddddeeeeeddcccddcbcccccccccccbbbbccdddddeddeeefdfggfffffe
ff|Obs
Clk|-        ^
|Clk
   +----------------------|----------------------------------|------------
--+
10:08:10.500
16:12:16.000
2023 May 22                                                            2023
May 22

********************
QC of RINEX  file(s) : t14d1420.23o
********************

4-character ID          : T14D (# = 0857)
Receiver type           : LEICA GS15 (# = 1510857) (fw = 4.03/6.110)
Antenna type            : LEIGS15         NONE

Time of start of window : 2023 May 22  10:08:10.500
Time of  end  of window : 2023 May 22  16:12:16.000
Time line window length : 6.07 hour(s), ticked every 3.0 hour(s)
Observation interval    : 0.5000 seconds
Total satellites w/ obs : 29
NAVSTAR GPS SVs w/o OBS :  1   3   5   6   7   9  11  13  14  17  19  20
                          22  24  30
    GLONASS SVs w/o OBS :  1   2   8  10  11  12  13  17  21  22  23  24
Rx tracking capability  : 32 SVs
Poss. # of obs epochs   :  43692
Epochs w/ observations  :  43675
Epochs repeated         :      0  (0.00%)
Complete observations   : 527923
 Deleted observations   :  24639
Obs w/ SV duplication   :      0  (within non-repeated epochs)
Moving average MP12     : 0.152820 m
Moving average MP21     : 0.197920 m
```

```
Moving average MP15     : 0.092704 m
Moving average MP51     : 0.089812 m
Points in MP moving avg : 50
Mean S1                 : 7.11 (sd=1.43 n=550139)
Mean S2                 : 6.55 (sd=1.59 n=527278)
Mean S5                 : 7.58 (sd=0.96 n=221712)
No. of Rx clock offsets : 1
Total Rx clock drift    :  0.000000 ms
Rate of Rx clock drift  :  0.000 ms/hr
Avg time between resets : 364.092 minute(s)
Freq no. and timecode   : 3 15842 01fc00
Report gap > than       : 10.00 minute(s)
       but < than       : 90.00 minute(s)
epochs w/ msec clk slip : 0
other msec mp events    : 0 (: 725)   {expect ~= 1:50}
IOD signifying a slip   : >400.0 cm/minute
IOD slips               :   1483
IOD or MP slips         :   1477
      first epoch    last epoch    sn1   sn2   sn5
SSN 23  5 22 10:08 23  5 22 16:12  7.11  6.55  7.58
      first epoch    last epoch    mp12  mp21  mp15  mp51
SMP 23  5 22 10:08 23  5 22 16:12  0.15  0.20  0.09  0.09
      first epoch    last epoch    hrs   dt  #expt  #have   %   mp1   mp2
o/slps
SUM 23  5 22 10:08 23  5 22 16:12 6.066 .50     -  527923  -   0.15  0.20
357
```

A.4.TEQC results for data quality check TANZ

```
version: teqc  2019Feb25

 SV+|--------|--------|--------|--------|--------|--------|--------|------
--+ SV
  4|oLoLL
LLooooooooooooooLooooooooooooo|  4
  9|oooooooI
IMoooooooooooooooooooooooo|  9
 14|oooooooIL
ILoooooooooooo| 14
 17|ooooooooooooI
LLIILIooooooooooo| 17
  7|ooooooooooLoI
LLoooooooooooooooooooooo|  7
 19|ooooooooooooooooI
LIMIoooooo| 19
 30|ooooooooooooooLLLL
LIoooooooooooooooooo| 30
  6|ooooooooooooooooooI
.Looooooooooo|  6
 11|ooooooooooooooooooooooLI
LIoLoIM| 11
 20|ooooooooooooooooooooooooI
Looo| 20
```

```
  5|ooooooooooooooooooooooooooooII
LL|  5
 12|  LIooooooooooLIooooooooooooooooooooL
| 12
 13|  LLoooooooooooooooooooIIIL
| 13
 15|     LoooooooooooooooooooooooooooooL
| 15
 29|         LoooooooooooooooooooooooooooooooooL
| 29
 24|          LLoooooooooooooooooLLLII
| 24
 18|                IoooooooooooooooooIooLIoooooooooII
| 18
 23|                  .LoooooooooooooooooooooI
| 23
 25|                   IoooooooooooooooooLLI
| 25
 10|                       ILoooooooooooooooooooooII---LIIII
| 10
 28|                        LoooooooooooooooooooooooooooooIL
| 28
 32|                         2IIoooooooooooooooooooooII
| 32
 31|                            IoooooooooooooooooooooooooooooL
| 31
  2|                            IILLLIILLLLLMoooooooooooooooooooIL
|  2
 26|                             LLoooooooooooooooooooooooooooooLI
| 26
 16|                                 LLoooooooooooooooooooooooooIoIoIL
| 16
 27|                                     LooooooooooooooooooooILLII
| 27
  3|                                        2ILLLooLL-I-
1oooooooooooooooooooL|  3
  8|                                         LoooooooooooooooooooooooooooLI
|  8
 21|                                             MoooooooooooooooooooIL
| 21
  1|                                                LooooooooooooooooooooII
|  1
Obs|bbddddddccddbbbabaabbbbbcdbbddddddddbbccbcccccddddcededdeededdddddccccdd
cc|Obs
Clk|
|Clk
   +|--------|--------|--------|--------|--------|--------|--------|------
--+
00:00:00.000
23:59:45.000
2023 May 22                                                              2023
May 22

********************
```

```
QC of RINEX  file(s) : tanz1420.23o
*********************

4-character ID          : TANZ
Receiver type           : Trimble NetR9 (# = 5145K79596) (fw = 4.60)
Antenna type            : TRM55971.00     NONE (# = 31050706)

Time of start of window : 2023 May 22  00:00:00.000
Time of  end  of window : 2023 May 22  23:59:45.000
Time line window length : 24.00 hour(s), ticked every 3.0 hour(s)
Observation interval    : 15.0000 seconds
Total satellites w/ obs : 31
NAVSTAR GPS SVs w/o OBS : 22
Rx tracking capability  : unknown
Poss. # of obs epochs   :   5760
Epochs w/ observations  :   5760
Epochs repeated         :      0  (0.00%)
Complete observations   :  65925
 Deleted observations   :   1977
Obs w/ SV duplication   :      0  (within non-repeated epochs)
Moving average MP12     : 0.703910 m
Moving average MP21     : 0.548337 m
Points in MP moving avg : 50
Mean S1                 : 42.52 (sd=4.32 n=67902)
Mean S2                 : 33.73 (sd=9.13 n=65925)
No. of Rx clock offsets : 0
Total Rx clock drift    :  0.000000 ms
Rate of Rx clock drift  :  0.000 ms/hr
Avg time between resets : Inf minute(s)
Freq no. and timecode   : 2 15842 ffffff
Report gap > than       : 10.00 minute(s)
       but < than       : 90.00 minute(s)
epochs w/ msec clk slip : 0
other msec mp events    : 0 (: 284)   {expect ~= 1:50}
IOD signifying a slip   : >400.0 cm/minute
IOD slips               :    130
IOD or MP slips         :    144
      first epoch    last epoch    sn1   sn2
SSN 23  5 22 00:00 23  5 22 23:59 42.52 33.73
      first epoch    last epoch    hrs   dt  #expt  #have   %   mp1   mp2
o/slps
SUM 23  5 22 00:00 23  5 22 23:59 24.00  15     -   65925  -   0.70  0.55
458
```

A.5 GPS OBERVATION LOGSHEET FOR T07D

GPS SURVEY LOGSHEET **Date: ___________________**

Observer's Name/s: ____

Point ID: ________________ Antenna Height: _________ Antenna Offset: __________

Receiver Type: ____________________ Receiver S/N: _________________

Battery Capacity: Battery 1: ________ Battery 2: __________External_________

Controller Type: _______________ Controller SN: _______________

Latitude: _________________ Longitude: ____________________ Height: _________

Location: ________________ District: ______________ Region: __________________

Start Time (Local): ___________________ End Time (Local): __________________

Start Time (UTC): ____________________ End Time (UTC): __________________

LOCATION SKETCH

A.6 GPS OBERVATION LOGSHEET FOR T08D

GPS SURVEY LOGSHEET **Date: ___________________**

Observer's Name/s: ____

Point ID: ________________ Antenna Height: _________ Antenna Offset: __________

Receiver Type: ____________________ Receiver S/N: _________________

Battery Capacity: Battery 1: ________ Battery 2: __________External_________

Controller Type: _______________ Controller SN: _______________

Latitude: _________________ Longitude: ____________________ Height: _________

Location: ________________ District: ______________ Region: __________________

Start Time (Local): ___________________ End Time (Local): __________________

Start Time (UTC): ____________________ End Time (UTC): __________________

LOCATION SKETCH

A.7 GPS OBERVATION LOGSHEET FOR T14D

GPS SURVEY LOGSHEET **Date: ____________________**

Observer's Name/s: ____

Point ID: _________________ Antenna Height: __________ Antenna Offset: ___________

Receiver Type: _____________________ Receiver S/N: __________________

Battery Capacity: Battery 1: _________ Battery 2: ___________External__________

Controller Type: ________________ Controller SN: ________________

Latitude: __________________ Longitude: _____________________ Height: __________

Location: _________________ District: _______________ Region: ___________________

Start Time (Local): ____________________ End Time (Local): ___________________

Start Time (UTC): _____________________ End Time (UTC): ___________________

LOCATION SKETCH