KATHMANDU UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF GEOMATICS ENGINEERING

REPORT ON SURVEYING WITH DGPS, RTK-GNSS AND TS: A COMPARATIVE STUDY

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ABSTRACT

In high-precision land surveying related projects, accurate surveying equipment plays a crucial role. Among the most precise surveying tools currently used are Differential Global Positioning System (DGPS) and Total Stations (TS). The aim of this project is to compare the precision of three surveying methods: DGPS, RTK GNSS, and TS. We seek to determine which method provides the highest level of accuracy via measuring of 8 control points. Furthermore, subsidiary points were established in field to compare the area and perimeter of plots obtained using RTK and TS. By analyzing and interpreting the obtained coordinates using three different methods we come to conclude that the Root Mean Square Error (RMSE) between DGPS and Total Station (TS) measurements was 0.185329781, while the RMSE between RTK and TS was 0.175212807. The Standard Deviation of the Area and Perimeter measurements between the TS and RTK parcel data was 0.416231645 and 0.006708369, respectively. These results indicate that both DGPS and RTK methods provided measurements that were highly correlated with the Total Station data, with the RTK method showing slightly lower RMSE values compared to DGPS. The low Standard Deviation for the area and perimeter measurements further confirm the strong agreement between the TS and RTK-GNSS survey techniques.

Keywords: TS, DGPS, RTK GNSS, Parcel, Analysis, Traverse

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DGPS	Differential Global Positioning System
EDM	Electronic Distance Measurement
EGM96	Earth Gravitational Model 1996
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
PDOP	Position Dilution of Precision
ppm	Parts Per Million
QZSS	Quasi-Zenith Satellite System
RTK	Real-Time Kinematic
RTK-GNSS	Real-Time Kinematic Global Navigation Satellite System
TS	Total Station
UHF	Ultra-High Frequency
WGS84	World Geodetic System 1984

1. INTRODUCTION

1.1 Background

Surveying is the scientific and artistic discipline dedicated to making all necessary measurements that involve measuring elevation, directions, and distances to ascertain many aspects of the earth's surface, including its dimensions, contours, and three-dimensional characteristics (McCormac, 2004). It is a basic necessity in the arranging and execution of almost every type of structure. A control survey is a part of a survey where highly accurate instruments and techniques are employed to establish precise reference points, ensuring the reliability and accuracy of subsequent surveying operations (Megrahi, 2020). In surveying, specifically in the area of engineering projects, more sophisticated instruments are employed to improve efficiency and accuracy. In the present day, the most commonly utilized surveying devices are the Differential Global Positioning System (DGPS) and the Total Station (TS) for land Surveying in Nepal (Oli, 2023).

DGPS is a surveying device that is used to enhance the accuracy of position information from the Global Navigation Satellite System (GNSS), including GPS, GLONASS, Galileo, BeiDou, and others. The accuracy of such positioning varies depending on the number of satellites and the value of PDOP (Position Dilution of Precision) (M.Bakula, 2007).DGPS can use a combination of pseudorange and carrier phase measurements to achieve the best possible accuracy (Raquet, 2012). DGPS operates through two main methods: Static method and Real Time Kinematic (RTK) method.

Static systems include a range of survey styles from rapid static surveys to static surveys. Rapid static surveys are designed to gather a moderate quantity of points using reduced observation durations. Typically, rapid static surveys are 15 minutes to 2 hours. Static surveys offer the second highest precision of static surveys by occupying a single location for occupation times ranging from 2 to 48 hours. The satellite observations are post-processed using a variety of techniques to receive a position (Lauer, 2018).

RTK is a dynamic positioning technique that uses short observation times to achieve high positioning accuracy (down to decimeters or centimeter levels) in real-time. It involves two systems: a base station (reference point) and a rover (positioning device).

The main tools used in RTK include a base and receiver, UHF radio antenna, battery, controller, tribrach, tripod, pole mount, GPS cradle, and meter (Safrel, 2018).

Another commonly used surveying instrument is TS. The telescope in TS has a built-in electronic theodolite that measures the horizontal and vertical angles and the slope distance from the instrument to the target. It is an electronic transit theodolite integrated with EDM which can store data on the instrument, allowing the analysis of data (Amirthavarshini. K, 2019).

A closed-loop traverse is a closed shape consisting of both measurement angles and distance, if all angles and lengths are corrected, the algebraic summation of departure and latitude departure will be zero. The angular measurements are never obtained without error, the difference between the theoretical total (zero) and the measured amount of the cumulative error of the survey is angular misclosure (Andersen H. E., 2009). This project aims to evaluate the general comparison of RTK, DGPS, and Total Station by measuring eight ground points in the form of a close polygon traverse and uses the Bowditch rule for traverse adjustment for the data obtained with TS. Apart from this, we have included parcel points for comparing the areas and perimeters generated by TS and RTK through computational and visual analysis of parcel areas.

1.1 Problem Statement

Surveying is the scientific method of determining the precise three-dimensional locations of points, distances, and angles between them. This field employs various techniques, including DGPS, RTK, and total stations. In this project, only these instruments have been used.

The latest GNSS receivers are improving the accuracy of positioning information, but the satellite availability, signal blocking problem, multipath, etc. can degrade the required accuracy. Also, for Static and RTK GNSS time taken for data acquisition is a crucial factor affecting the accuracy of positioning. Total Station can accurately measure single-point coordinates, but the accuracy of these measurements is affected by the angle and distance of sight, as well as weather conditions (Chekole, 2014).

Considering those limitations, this project evaluates and compares the accuracy, and precision of these three surveying methods (DGPS, RTK, and total station).

1.2 Objectives

1.2.1 Primary Objectives

- The primary objective of this project is to evaluate and compare the accuracy of three different surveying methods: Static DGPS, RTK GNSS, and Total Station.

1.2.2 Secondary Objectives

- To learn about instrument handling i.e. proper use, maintenance, and care of instruments to ensure accurate and reliable measurements.
- To compare the area and perimeter of the parcel using different surveying methods i.e. RTK GNSS and Total Station.
- Establishing control points for further detailing.
- Learn to apply different mathematical and map visualization techniques.

1.3 Scope

The scope of this study encompasses a comprehensive evaluation and comparative analysis of the accuracy of three distinct surveying methods: Static DGPS, RTK GNSS, and Total Station. The primary aim is to provide users with valuable insights for selecting the most appropriate method for specific surveying needs.

Furthermore, this project not only facilitates informed decision-making but also establishes a robust control point for ensuring thorough detailing of various features. Additionally, the project undertakes comparative analyses of parameters such as the area and perimeter of parcels using RTK and Total Station, contributing further to the practical understanding and application of surveying methodologies.

Therefore, this study serves as a crucial point for exploration and advancement in the field of land surveying. It benefits both current practitioners and future researchers looking to enhance their understanding and skills in surveying methods and applications.

1.4 Terms and Terminologies

1. GNSS

Global Navigation Satellite System (GNSS) is a group of satellites strategically placed to generate and relay positioning, timing, and navigation data from space to connected sensors on the earth- that are usually embedded in Internet of Things (IoT) devices. There are several GNSS currently available (EUSPA, n.d.). Some of them are:

- Galileo (EU)
- GPS (USA)
- GLONASS (Russia)
- BeiDou (China)

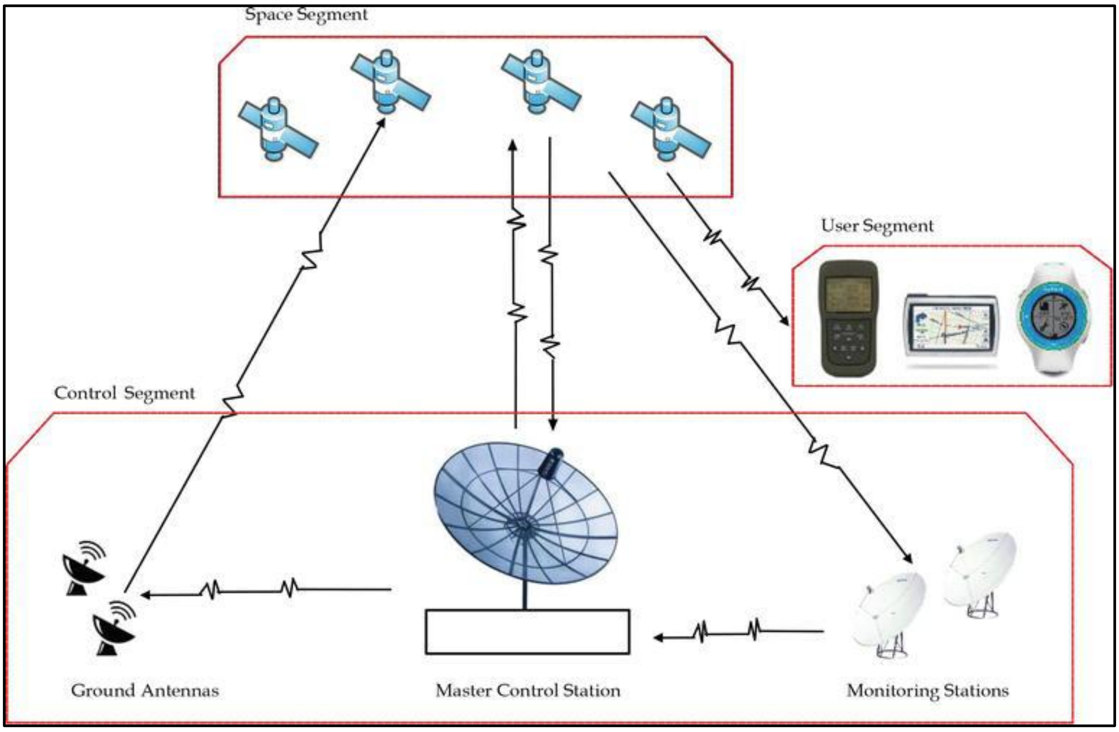

Figure 1:GNSS System

Source: https://www.spiceworks.com

2. Base and Rover

Two receivers are used in RTK. One of them is stationery, and another moves freely. They are called base stations and rovers. The base's mission is to stay in one place and send corrections to a moving receiver. Rover uses that data to achieve a centimeter precise position (GGS, n.d.).

3. Static

In the context of GNSS receivers, "static" refers to a survey method where a single receiver and antenna combination records satellite observations over a prolonged period, typically several hours or days, to achieve high accuracy and precision in determining the receiver's position (GETSI, n.d.).

4. Real-time

In the context of GNSS receivers, "real-time" refers to the ability of the receiver to process and provide accurate position, velocity, and time information continuously and immediately, without any significant delay or post-processing (GETSI, n.d.).

5. Datalink

In GNSS (Global Navigation Satellite System), a data link refers to the communication channel used to transmit data between a base station and a rover receiver. The data link enables the transfer of essential information such as correction signals from the base station to the rover, improving the accuracy of positioning.

6. Pseudo-range and Carrier-phase

Pseudorange is the difference in time between when a GPS signal was transmitted and when it was received and is used for basic GPS positioning. The carrier phase is the difference in phase between the transmitting and receiving oscillators and is used for high-precision applications such as surveying and navigation (Nijia Qian, 2019).

7. PDOP

PDOP (Position Dilution of Precision) in GPS refers to the geometric measure of satellite positioning relative to a receiver. It indicates how satellite geometry affects positional accuracy. A lower PDOP value signifies better accuracy due to satellites being spread widely across the sky, reducing errors from poor geometric configuration (Nijia Qian, 2019).

8. Elevation Mask

The signal path by the satellites which are near the horizon bends due to refraction. Due to this, errors creep into the solution given by the GPS. To avoid this, an elevation mask of 15° is applied and the satellites below the set value are disregarded for the position calculation. This is called an elevation mask (Yadav, GA, 2023).

9. Logging time

Logging time refers to the duration during which a GNSS receiver collects and stores Position, Velocity, and Time (PVT) information derived from satellite signals. This data is typically logged at regular intervals and can span from seconds to hours, days, or even longer, depending on the logging capabilities of the receiver and the requirements of the application (Yadav, GNss, n.d.).

10. Ellipsoid

It is a mathematical representation of the Earth's shape, resembling an oblate spheroid. The ellipsoid assumes the Earth's shape is smooth and symmetric, making it useful for geodetic purposes such as mapping and satellite navigation (Esri, n.d.).

11. Geoid

A geoid is an irregularly shaped model that approximates the Earth's mean sea level. It represents the shape the ocean surface would take under the influence of gravity and rotation alone, without tides or currents. The geoid is used as a reference for measuring elevations and sea level changes, critical for applications like satellite altimetry and oceanography (Esri, n.d.).

12. Projection System

A projected coordinate system is a two-dimensional system used to represent locations on a flat surface, such as a map or a computer screen. Unlike geographic coordinate systems which use spherical coordinates (latitude, longitude), projected coordinate systems employ Cartesian coordinates (x, y, and sometimes z) that are adjusted to minimize distortions caused by projecting the Earth’s curved surface onto a flat plane surface (Esri, n.d.).

13. Control Points

Control Points refers to a set of permanently monumented points, also known as "stations," whose coordinates are established by surveying methods.

14. DAT and RINEX format

DAT format is a binary format specific to certain GNSS receivers like Stonex or Trimble. It contains raw satellite data. RINEX stands for Receiver Independent

Exchange Format, a standardized ASCII format widely used for GNSS data exchange and processing. It includes satellite observation data (OBS) and navigation messages (NAV) (Gurtner, 2009).

15. Post-processing

It is an approach where raw data measurements logged on to a receiver are processed after the data acquisition activity. For this project, TBC was used for processing DGPS data (Gurtner, 2009).

16. Digital Theodolite

TS is integrated with digital theodolite for angular measurement. A digital theodolite is a surveying instrument that combines a telescope with electronic sensors to measure precise angles horizontally and vertically (GGS, n.d.).

17. EDM

Electronic distance measurement (EDM) Electronic distance measurement (EDM) is a method of determining the length between two points using electromagnetic waves. EDM instruments are highly reliable and convenient pieces of surveying equipment and can be used to measure distances of up to 100 kilometers. EDM instruments emit electromagnetic waves toward a target reflector and measure the time it takes for the waves to return. This time measurement, combined with the known speed of electromagnetic waves in air, calculates the distance (GGS, n.d.).

18. Microprocessor

A microprocessor is the component of TS which takes care of recording, reading, and the necessary computations. The microprocessor unit processes data for computations such as horizontal distances, point coordinates, and elevation levels. It integrates with the instrument's electronic theodolite and distance meter to facilitate precise measurements and data management (GGS, n.d.).

19. Data Collector

A data collector in TS typically refers to software or hardware used in surveying and geospatial applications to gather, manage, and process field data from Total Stations (TS) and other survey instruments (GGS, n.d.).

20. Reflector

The reflectors used with total stations aid in measuring distances and angles by reflecting electromagnetic waves to the instrument. This setup enables efficient surveying tasks by automating data collection and computation processes (GGS, n.d.).

21. Levelling and Centering

Levelling is the method that ensures that the instrument is horizontally aligned. It's achieved using levelling screws to adjust the instrument's base until a bubble in a spirit level is centered. Centering is the method that ensures the instrument is positioned directly above a point. This involves aligning the instrument's plumb line with a marked point on the ground. Optical plummets or plumbing forks are often used for precise centering. It is done for both DGPS and the total station (J. Paul Guyer, 2018).

22. Line of Sight

The line of sight is the path from the instrument's optics to the target point or prism. In Total Station surveying, "line of sight" refers to the straight path along which the instrument measures angles and distances. This line extends from the instrument's optical center through the target point or prism. It's crucial for accurate measurements because deviations can introduce errors in positioning (J. Paul Guyer, 2018).

23. Prism Constant

A prism constant in Total Station surveying refers to the offset distance between the true center of a survey prism and the point where the instrument's line of sight intersects with the prism. This constant is essential for accurate measurements in distance and angle calculations during surveying tasks (J. Paul Guyer, 2018).

2. LITERATURE REVIEW

This section provides an overview of related work to give a concise understanding of the concepts of accuracy associated with DGPS, RTK, and Total Station.

According to the work by Mekik and Arslanoglu, (2009), it compares the performance of Real-Time Kinematic GPS with static GPS and traditional conventional methods for Geographic Information System (GIS) applications. In the test, RTK GPS was compared with static GPS and conventional terrestrial method i.e. TS. The results indicate that RTK GPS achieves accuracies comparable to those of static GPS and conventional terrestrial method, with root mean square error (RMSE) values below 3 cm. This is significant because it means that RTK GPS can produce reliable results in a shorter time frame and with fewer field staff.

Megrahi, (2020), the study compares the accuracy of instruments by adjusting the 6 points closed traverse. RMSE and standard deviation (SD) were used to evaluate the accuracy and precision of the measurements obtained from RTK and TS. The RTK device demonstrated superior accuracy compared to the TS device, with absolute errors of 0.057 m and RMSE values of 0.018 m for East and 0.021 m for North, along with an SD of 2.53. Unlike TS, RTK can measure points without requiring a line of sight. Furthermore, RTK-based surveys are not only practical and efficient but also timesaving and more efficient in terms of human resources.

Ameen, Tais, and Ajaj, (2020) tested the accuracy of between RTK GNSS and Total Station through an eleven-point closed polygon traverse, the northing and easting errors for DGPS were 0.0098 m and 0.0126 m, while for the Total Station, they were 0.092 m and -0.056 m. The absolute errors were 0.0159 m for DGPS and 0.1077 m for the Total Station. Notably, the separation distances differed, especially at points R8, R9, and R10 compared to T8, T9, and T10. This assessment used the close polygon traverse equations and Mapcheck tool to compute misclosure errors for both devices.

To evaluate the compatibility of the RTK method with the Total Station method, Ahmed (2012) tested both on an existing network. The study aimed to determine RTK's achievable accuracy, repeatability under different satellite configurations, and performance in urban areas. RTK accuracy and repeatability were assessed by comparing its point coordinates with those determined by the Total Station. Results showed a coordinate difference of 2 cm horizontally and 3 cm vertically. In comparison, this thesis found the coordinate differences between RTK and Total Station to be 1.8 cm for both horizontal and vertical coordinates.

Lin's study in 2004 compared the accuracy of GPS Real-Time Kinematic (RTK) and total station methods. The results indicated that GPS RTK achieved a positional accuracy of 14 mm, whereas the total station method yielded an accuracy of 16 mm.

According to the studies conducted by Jonsson, et al (2003), RTK measurement was applied to test the accuracy of different GPS instruments (Leica, Topcon, and Trimble). A network of nine control points was established using total stations. Then, the authors performed RTK measurements on the same network and compared results with different instruments. Results obtained from RTK measurement have shown a horizontal and vertical accuracy of 10 mm and 2 cm respectively. When comparing this result with the result of the thesis, better accuracy was achieved in both horizontal and vertical coordinates.

Chekole, (2014), in this study the reference network points measured with TS were determined with 1 mm precision for both horizontal and vertical coordinates. When using the RTK method on the same reference network points, 9 mm in horizontal and 1.5 cm accuracy in vertical coordinates has been achieved. The RTK measurements, which were measured five times, were determined with a maximum standard deviation of 8 mm (point I) and 1.5 cm (point A) for horizontal and vertical coordinates respectively. The precision of the remaining control points is below these levels.

Abdulmajed and Abbak, (2019), this study tested the RTK (Real-Time Kinematic) method, using GPS+GLONASS provided better positioning accuracy compared to using GPS only. In the unobstructed open sky area, the position accuracy was about 1 cm with GPS+GLONASS, which was at least 1 cm better than using GPS only. In the obstructed area, the position accuracy with GPS+GLONASS was about 2-3 cm, which was at least 3 cm better than using GPS only. The combined GPS+GLONASS system had better satellite availability, with up to 14 satellites available compared to only 4-5 satellites for GPS only and reduced the chances of signal loss and multipath errors. For the static method, using GPS+GLONASS provided a position quality of around 3-5 mm, which was 1-2 mm better than using GPS only in the open sky area. The combined GPS+GLONASS system increased the number of available satellites and improved the satellite geometry, leading to higher accuracy.

3. METHODOLOGY

3.1 Study Area

The study area was located between the Land Management Training Centre (LMTC) and Dhulikhel Hospital, situated in the southeastern part of Dhulikhel Municipality Ward No. 4, Nepal. The coordinates of Dhulikhel Municipality Ward No.4 are 27.620687° latitude and 85.541706° longitude. The study area covered approximately 51092.5495 square meters, with a perimeter of about 859.058 meters. It is close to the Kathmandu University premises.

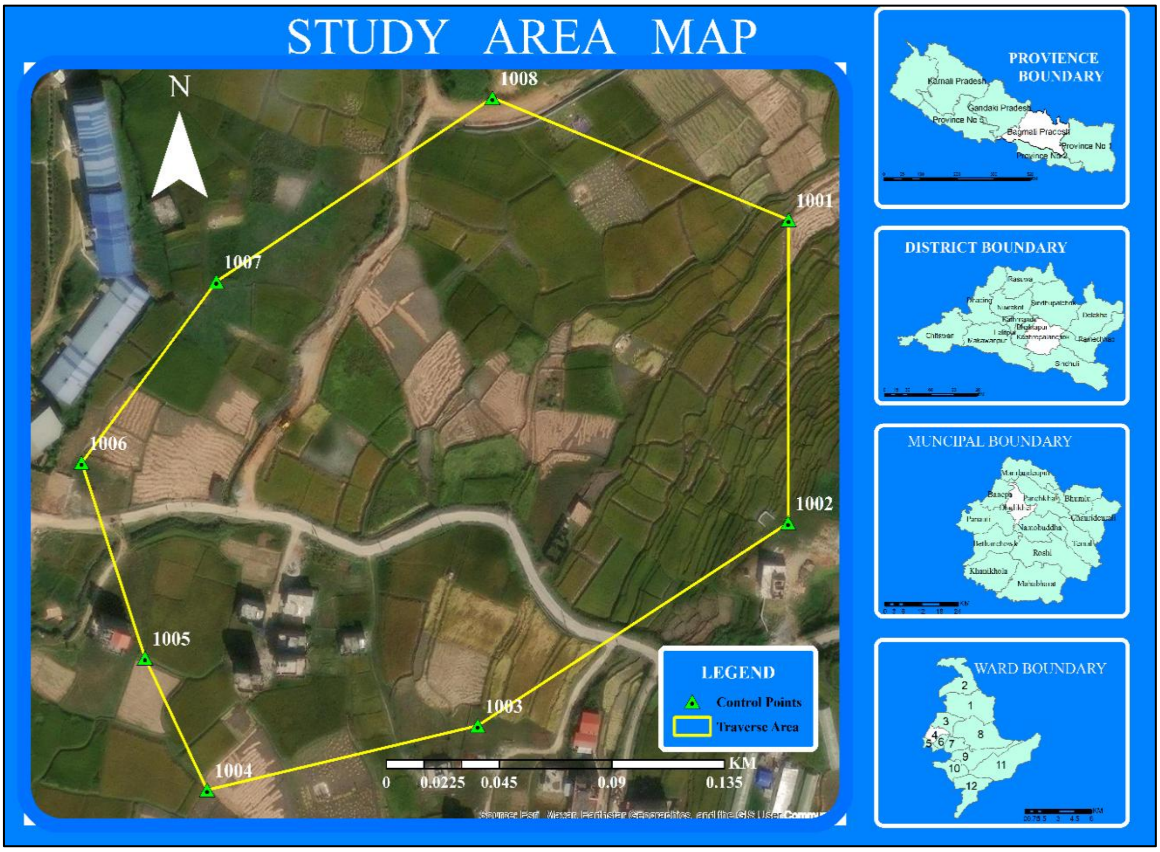

Figure 2: Study Area

3.2 Instruments and Software Used

3.2.1 Instrument Used

1. DGPS and RTK GNSS

We have employed two distinct methods of DGPS, namely static and RTK, for the purpose of evaluation.

In static DGPS data collection, the base station is placed at a fixed position throughout the survey, typically at a known control point, and continuously tracks GNSS satellite signals to record carrier phase and pseudorange measurements. The rover receiver is then placed at the points to be positioned, and remains stationary for an extended period, usually 2 to 48 hours, to record similar measurements. The base station data is used to calculate its precise coordinates, while the rover's data is post-processed together with the base station data to determine the precise 3D coordinates of the rover's position, achieving centimeter-level or even millimeter-level accuracy (Patil, 2018).

This high-precision static DGPS approach is commonly used for establishing control networks, conducting deformation monitoring studies, and performing other surveying and mapping applications that require the utmost positional accuracy, though it comes at the cost of longer data collection times compared to Real-Time Kinematic (RTK) methods.

Figure 3: Stonex DGPS

Source: https://globalgpssystems.com

The DGPS used in static data collection has the following specifications:

Table 1: DGPS Specifications

Name	STONEX S8 PLUS GPS
Satellite Tracked	GPS, GLONASS, Galileo, QZSS and BeiDou
Antenna Type	STXS8PX003A
Logging Time	5 sec
Acceptance Criteria Horizontal accuracy Vertical accuracy	 0.0500 m + 1.000 ppm 0.1000 m + 1.000 ppm
Cutoff angle/Elevation Mask	15º
Coordinate System	Universal Transverse Mercator
Zone	45_N
Scale Factor	0.9996000000
Ellipsoid	World Geodetic System 1984
Geoid	EGM96(Global)
PDOP	1.412

Real-Time Kinematic (RTK) positioning is a high-precision GPS technique that utilizes real-time corrections from a fixed base station to achieve centimeter-level accuracy. The system involves a base station, which is set up at a known location and continuously collects satellite data. This base station calculates the positional errors due to atmospheric conditions and other factors and then transmits these corrections via a UHF radio antenna. The rover, also receiving satellite signals, applies real-time corrections to enhance its positional accuracy (SBG, 2024).

Figure 4: Trimble RTK-GNSS

Source: https://www.instadrone.fr

The DGPS used in RTK data collection has the following specifications:

Table 2: RTK Specifications

Name	Trimble R4s GNSS system
Satellite Tracked	GPS, GLONASS, Galileo, QZSS and BeiDou
Antenna Type	R4s Internal
Logging Time	<3 sec
High precision static surveying Horizontal accuracy Vertical accuracy	 3 mm + 0.1 ppm 3.5 mm + 0.4 ppm
High precision RTK surveying Horizontal accuracy Vertical accuracy	 8 mm + 1 ppm 15 mm + 1 ppm
Cutoff angle/Elevation Mask	15º
PDOP	05
Coordinate System	Universal Transverse Mercator
Zone	45_N
Scale Factor	0.9996000000
Ellipsoid	World Geodetic System 1984
Geoid	EGM96(global)

2. Total Station

The total station was used for the data collection process from the field. The Total Station is a very precise instrument in terms of liner and angular measurement in short distances. The Total Station used was the Nikon N series and has the following specifications and parameter sets. A total station is a sophisticated surveying instrument that combines an electronic theodolite and an electronic distance meter. It works by emitting modulated signals that are reflected, allowing it to calculate the slope distance and then use trigonometry to compute the horizontal and vertical angles as well as 3D coordinates of the target relative to the instrument's position. The onboard microprocessor performs all calculations and stores the survey data, which can be transferred to a computer, making the total station an essential tool in modern surveying and construction applications due to its ability to quickly and accurately measure angles, distances, and 3D coordinates in an integrated manner (Rick, 2018).

Figure 5: Nikon TS

Source: *https://www.capitalsurveyingsupplies.com*

The specification of Total Station used during the survey is shown in table below:

Table 3:TS Specification

Model number	D471487
Method	Single prism
Single prism	3000m
Magnification	3X
Display	Graphics LCD/240*96 pixels
Data clock	Yes
Laser pointer	Yes
Reflector less	500m
Angular accuracy	±1”
Linear accuracy	±1.0 mm + 1 ppm
Measuring Range	10,000 meters
Prism Constant	-30mm
Distance Speed	150 m/s
Mode	Precise 0.1 mm

3.2.2 Software Used

1. Trimble Business Center

Trimble Business Center (TBC) is a software suite designed for processing and managing survey data, including Differential Global Positioning System (DGPS) data. It supports static data processing, network adjustments, and generates detailed adjustment reports. TBC allows efficient data management, improves accuracy, and offers flexibility and customization options. It is a comprehensive tool for surveyors and geospatial professionals to achieve high accuracy and precision in projects (Sisnroy, 2020).

Table 4: Trimble Software Details

Source	Department of Geomatics Engineering
Version	5.9
License	Yes

2. Trimble Access

Trimble Access is a field software designed to work with the Trimble R4s GNSS receiver, providing essential tools for real-time kinematic (RTK) surveying. It offers features such as real-time data processing, RTK correction services, and seamless integration with the receiver, ensuring efficient and accurate data collection. The software's importance lies in its ability to facilitate high-quality, productive workflows and data exchange, making it a crucial component for surveyors and geospatial professionals. It enhances the capabilities of the R4s receiver by providing advanced data processing and real-time correction services, allowing users to collect and analyze data quickly and accurately in the field.

3. Arc GIS

ArcGIS is a comprehensive mapping and analytics software platform provided by Esri. It offers a range of capabilities, including spatial analysis, data science, field operations, 3D GIS, and imagery/remote sensing. Feature layers are a key component of ArcGIS, grouping similar geographic features like buildings, parcels, roads, etc. There are several types of feature layers, including hosted feature layers, hosted Indoors Spaces feature layers, ArcGIS Server feature layers, streaming feature layers, and feature collections. Feature layers support editing, labeling, filtering, analysis, and more, with hosted feature layers offering the most robust set of features and editing capabilities. We have used Arc GIS version 10.8 for the survey data visualization.

4. Total Station File Transfer

The Total Station File Transfer app, developed by NIKON-TRIMBLE CO., LTD., is a mobile application that allows users to communicate with a total station over Bluetooth. The app enables users to send coordinate data stored on their smartphone to the total station instrument, as well as receive observation and coordinate data from the instrument and share it via email**.**

The app is available for IOS and Android devices, and it allows for seamless data communication between the mobile device and the total station. This can be useful for surveyors and geospatial professionals who need to efficiently transfer data between their field equipment and mobile devices (Whitt, Quick Setup Guide for R8s / R10 RTK Survey using Trimble Access, 2020).

5. MS Excel

MS Excel is a commonly used Microsoft Office application. It is a spreadsheet program that allows users to store, organize, and analyze numerical data in a tabular format. It's designed to help users manage and manipulate data, create charts and graphs, and perform calculations and analysis. Excel allows users to perform complex calculations using built-in formulas and functions, which can automate tasks like summing columns, averaging data, and more. Excel offers tools to create various charts and graphs, helping users to visualize data trends and patterns. Advanced features like PivotTables and conditional formatting make Excel a powerful tool for analyzing large datasets, enabling users to sort, filter, and summarize information quickly. Excel is extensively used in business, finance, education, and personal data management due to its versatility and robust functionality.

3.3 Workflow Diagram

Any project has to have a suitable and acceptable working methodology created before it can be completed. If not, we might not succeed in that project's goal. So, the overall methodological workflow to be followed during this project is shown below with the help of a workflow diagram.

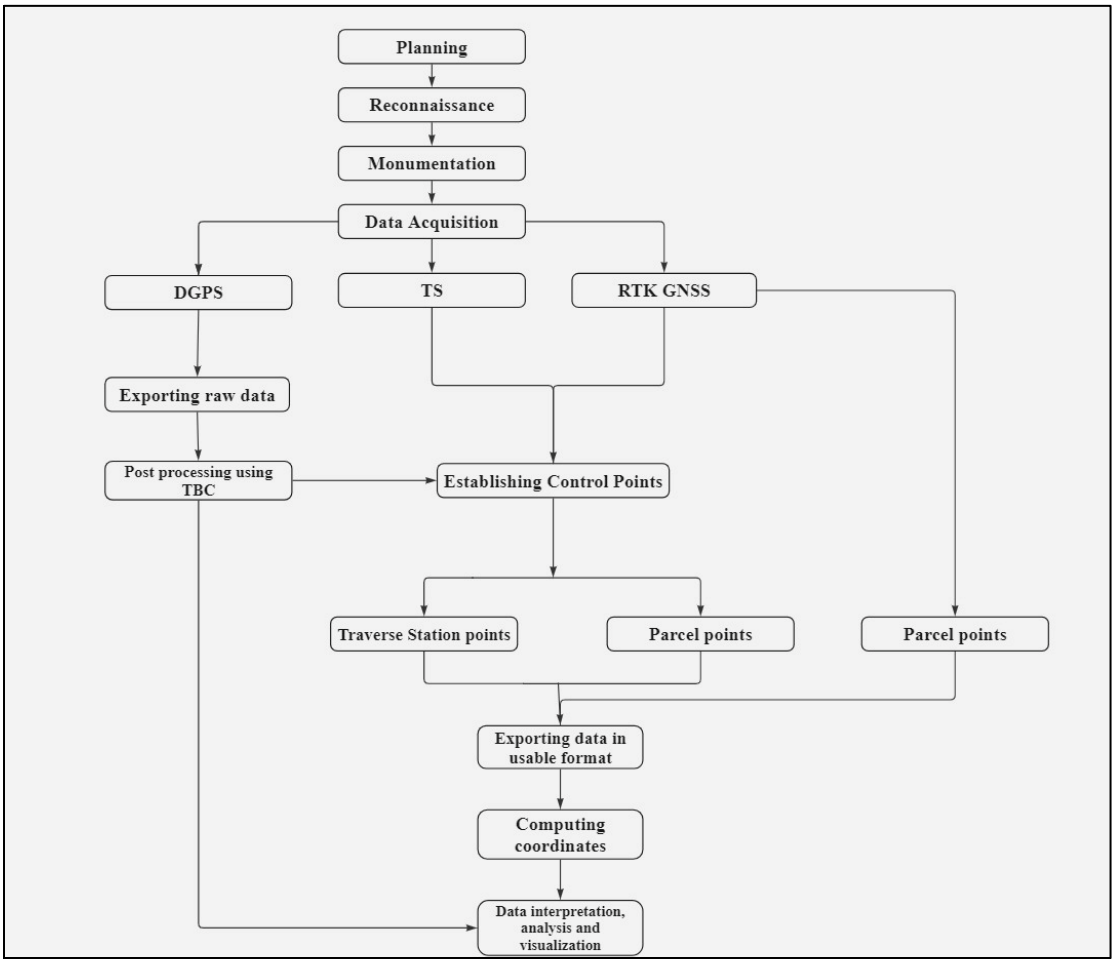

Figure 6: Workflow Diagram

3.3.1 Planning and Reconnaissance

Planning refers to the systematic process of organizing and preparing the surveying works that lead to the successful completion of the project. We collected data, documents and some research papers relevant to the project. Selection and identification of survey sites were done such that there was clear visibility of the sky and minimal obstructions to ensure the accuracy of the signals received by the RTK, Total Station, and DGPS. Then we scrupulously managed the instruments, assuring that they were in good operating condition.

A reconnaissance survey, or initial assessment of the study area to confirm that it matched our intended objectives, was carried out before the actual survey work started. Considerations like the topography of the planned area, careful observations of the obstructions such as electric poles or any electric appliances that may cause disturbance of the signals from the satellite, and climatic conditions for the proper execution of the work were done.

3.3.2 Monumentation

Monumentation refers to the placement of physical markers on surveyed land to define the key points. It helps to indicate the location of a specific station. Wooden pegs were used for the monumentation of those control points such that they provide accurate horizontal and vertical control points throughout the working time. Eight control points were established. The major 8 CPs (Control Points) were named as 1001 to 1008 whereas the Base Station was named as 1000. The survey data's accuracy and dependability were enhanced by the control points, which were affixed to the ground following monumentation.

3.3.3 Data Acquisition

For this project, we employed three methodologies for data acquisition. The first involved using a Differential Global Positioning System (DGPS), the second utilized an RTK-GNSS (Real-Time Kinematic Global Navigation Satellite System) with a Base and Rover set., and the third employed a Total Station. These varied approaches allowed us to capture data using different surveying technologies, each with their unique advantages and applications. The DGPS is known for its precision in horizontal coordinates as well as vertical coordinates, RTK-GNSS ensures accurate positioning with real-time correction data, and Total Station is known for its precision in the measurement of short distance. The combination of these methodologies aimed to gather comprehensive and precise data for the project's objectives.

1. DGPS

The data collection process using DGPS in static mode was conducted using static technique. This method involves collecting data over a time ranging from 15 minutes to 2 hours. It took us two days to collect overall data for 8 stations.

The base receiver was set up at Base Station (i.e.1000) and remained stationary for a data acquisition duration of 1 hour and 30 minutes for the initial epoch. Then, Rover 1 was placed at Station 1001; after completing 45 minutes out of the total data acquisition duration of 1 hour 30 minutes for Rover 1, Rover 2 was then placed at Station 1002 for the same data acquisition duration. This process was repeated, with each rover being placed at a new station after the previous rover had completed 45 minutes of data acquisition, thus accomplishing the total data acquisition duration of 1 hour 30 minutes. After that, Rover 1 was replaced at Station 1003 and Rover 2 at Station 1004, following the same pattern. Finally, the base receiver was kept stationary for an additional data acquisition duration of 1 hour 30 minutes, after collecting all data for the given time frame. Considering this, the base receiver remained stationary in a fixed position for approximately 6 hours 30 minutes each day.

Following were the data obtained with DGPS in static mode:

Table 5: DGPS Data

	DGPS		
Stations	***Easting (m)***	***Northing (m)***	***Elevation (m)***
1000	356530.6140	3056009.1090	1471.390
1001	356564.5360	3055918.2750	1470.077
1002	356564.3710	3055800.9630	1479.877
1003	356440.4080	3055722.5010	1469.587
1004	356332.3930	3055697.5850	1462.900
1005	356307.5750	3055748.6530	1464.006
1006	356282.2800	3055824.2810	1465.458
1007	356336.0740	3055894.4120	1465.964
1008	356446.3000	3055965.5090	1472.723

2. RTK

RTK computes the coordinates of points at Real-Time. This system continuously receives real-time corrections from the base station to maintain accuracy.

In this study, the base station was placed at the Base station (i.e.- 1000), whose coordinates were previously established using the static DGPS method through post-processing of the DGPS data. For the RTK data collection, the base station was set up at Station 1000 and the rover was connected to the base station using a data link. Base station coordinates were entered into the RTK system as the reference, and the RTK method then computes and corrects the coordinates of the other stations.

Along with the collection of data for the stations, parcel points were also collected for the purpose of evaluating and comparing the area and perimeter of the parcel with TS.

The following were data obtained with RTK GNSS:

Table 6: RTK Data

	RTK		
Stations	***Easting (m)***	***Northing (m)***	***Elevation (m)***
1000	356530.6140	3056009.1090	1471.390
1001	356564.514	3055918.263	1470.35
1002	356564.361	3055800.968	1480.255
1003	356440.423	3055722.497	1469.939
1004	356332.361	3055697.571	1462.972
1005	356307.572	3055748.637	1464.308
1006	356282.258	3055824.279	1465.81
1007	356336.051	3055894.421	1466.329
1008	356446.312	3055965.488	1473.13

3. Total Station

For collecting data using the TS, two known points, 1000 and 1001, were considered. The coordinates of these points were obtained from the post-processing of static DGPS data and were used to compute the bearing of the initial line. Subsequently, angular and linear measurements were made for 8 control points in a closed traverse. In this process, exterior angles were measured, and distances were measured in two directions, with the meaning of these values being taken. Using the bearing of initial line 1000-1001, the bearing of all other legs was calculated. Then, coordinates were computed for all other stations with the help of known coordinates, and bearings and distances of traverse leg.

Following were the data obtained with TS after applying correction:

Table 7: TS Data

	TS		
Stations	***Easting (m)***	***Northing (m)***	***Elevation (m)***
1000	356530.6140	3056009.1090	1471.390
1001	356564.5360	3055918.2750	1470.077
1002	356564.3795	3055800.8680	1479.872
1003	356440.3284	3055722.3100	1469.559
1004	356332.2111	3055697.3720	1462.8662
1005	356307.3534	3055748.5010	1463.9678
1006	356282.0391	3055824.2180	1465.4428
1007	356335.8914	3055894.4290	1465.9495
1008	356446.2100	3055965.5620	1472.7415

Following were errors and accuracy obtained in traverse calculation.

Table 8: Errors and Accuracy for Traverse

Parameters	***Result***
Angular Error	41"
Closing Error	0.0611 m
Linear Accuracy	1:14100

Overall Data:

Table 9: Data From TS, RTK, and DGPS

	TS			RTK			DGPS		
Stations	**Easting (m)**	**Northing (m)**	**Elevation (m)**	**Easting (m)**	**Northing (m)**	**Elevation (m)**	**Easting (m)**	**Northing (m)**	**Elevation (m)**
1000	356530.6140	3056009.1090	1471.390	356530.6140	3056009.1090	1471.390	356530.6140	3056009.1090	1471.390
1001	356564.5360	3055918.2750	1470.077	356564.514	3055918.263	1470.35	356564.5360	3055918.2750	1470.077
1002	356564.3795	3055800.8680	1479.872	356564.361	3055800.968	1480.255	356564.3710	3055800.9630	1479.877
1003	356440.3284	3055722.3100	1469.559	356440.423	3055722.497	1469.939	356440.4080	3055722.5010	1469.587
1004	356332.2111	3055697.3720	1462.8662	356332.361	3055697.571	1462.972	356332.3930	3055697.5850	1462.900
1005	356307.3534	3055748.5010	1463.9678	356307.572	3055748.637	1464.308	356307.5750	3055748.6530	1464.006
1006	356282.0391	3055824.2180	1465.4428	356282.258	3055824.279	1465.81	356282.2800	3055824.2810	1465.458
1007	356335.8914	3055894.4290	1465.9495	356336.051	3055894.421	1466.329	356336.0740	3055894.4120	1465.964
1008	356446.2100	3055965.5620	1472.7415	356446.312	3055965.488	1473.13	356446.3000	3055965.5090	1472.723

4. RESULTS AND DISCUSSION

4.1 Comparisons and Results

The core part of this project is to analyze and compare the data collected from field surveys and present them in charts, tables, and maps following certain mathematical models and visualization techniques. These outcomes and results are shown in sub-topics below:

4.1.1 Assessment of Control Points

While carrying out the field survey for this project, we selected 8 CPs (Control Points) and one independent Base station. The CP was named from 1001 to 1008 in clockwise chronology whereas the Base station was 1000. For two known precise coordinates, Base station (i.e. - 1000) and CP 1001 obtained from DGPS survey were selected.

Calculation of RMSE:

Root Mean Square Error (RMSE) is a commonly used measure to evaluate the accuracy of a model's predictions. It is calculated by taking the square root of the average of the squared differences between the observed and actual values. RMSE is particularly useful because it provides a single number that can be used to compare the performance of different models.

Here's the formula:

$$RMSE = \sqrt{[(1/n) * \Sigma (y\_true - y\_obs)^2]}$$

Where:

- y_true is the actual value
- y_obs is the observed value
- n is the number of data points.

1. *DGPS vs TS*

The Root Mean Square Error (RMSE) obtained is 18.53 cm.

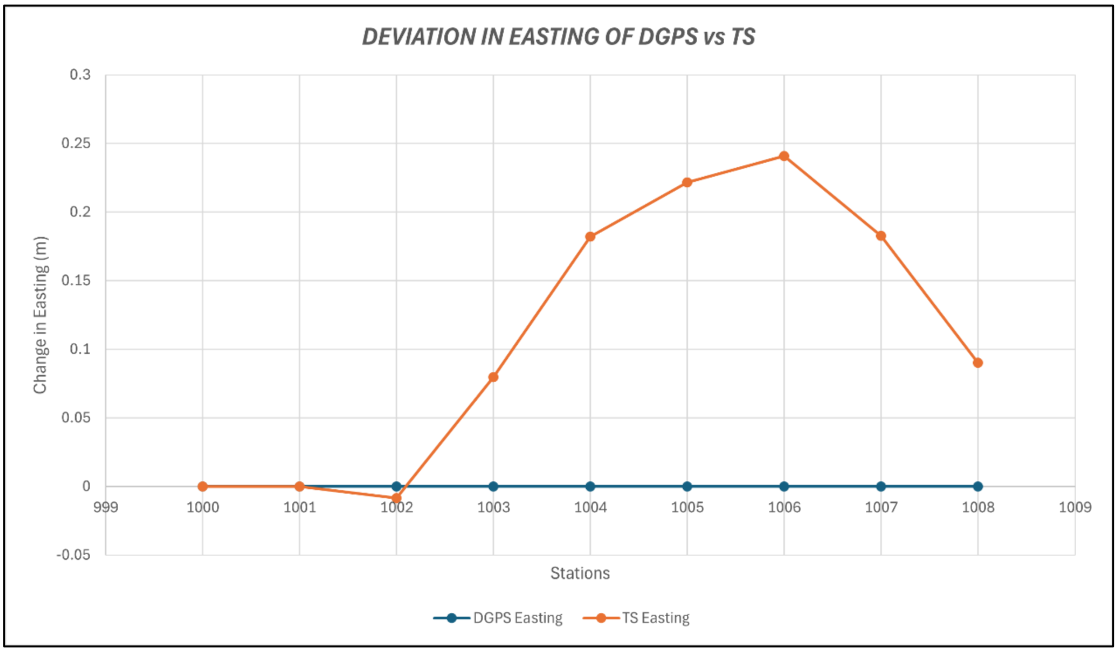

Figure 7: Deviation in Easting of DGPS vs TS

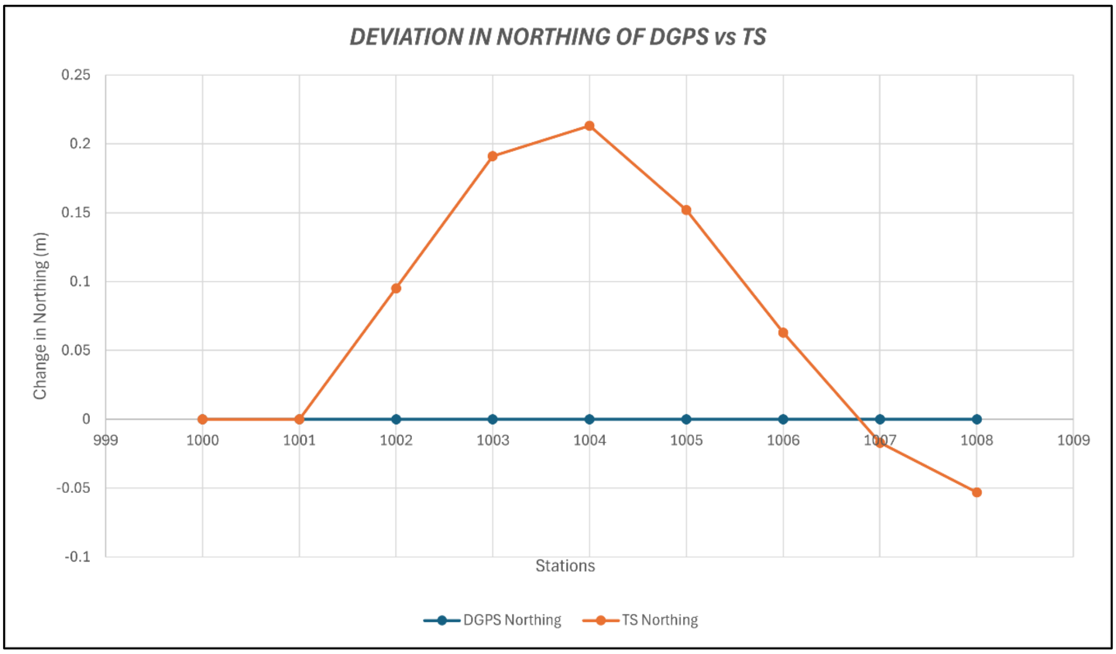

Figure 8: Deviation in Northing of DGPS vs TS

2. *DGPS vs RTK*

The Root Mean Square Error (RMSE) obtained is 2.15 cm.

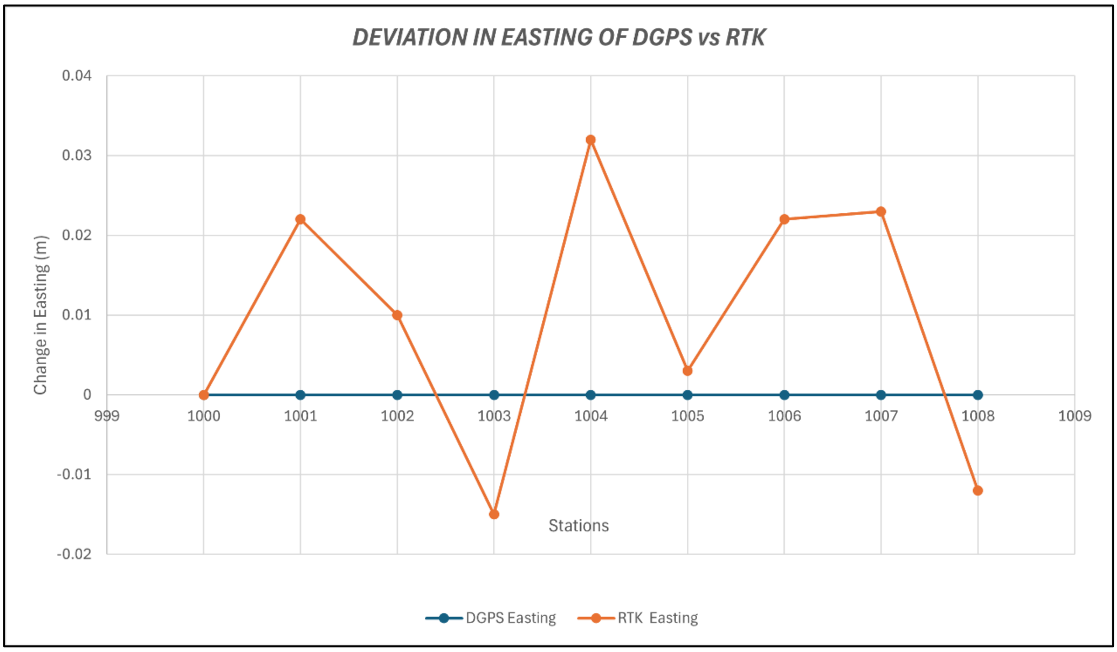

Figure 9: Deviation in Easting of DGPS vs RTK

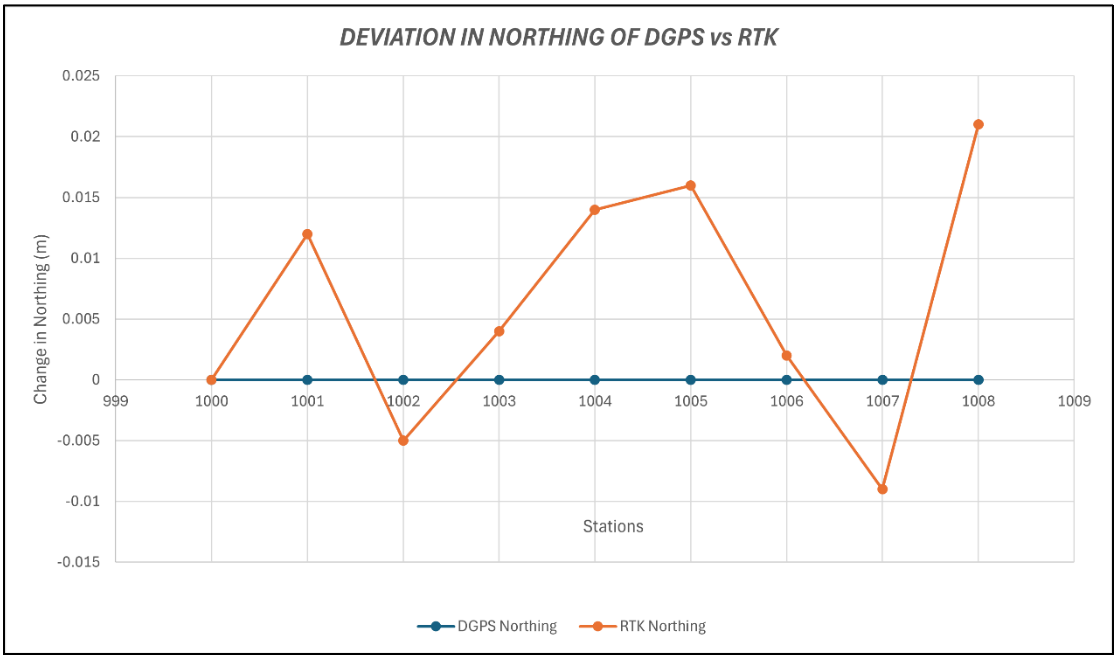

Figure 10: Deviation in Northing of DGPS and RTK

For the proper visualization of difference in values of easting and northing obtained by TS, RTK and DGPS; following graphs are shown below:

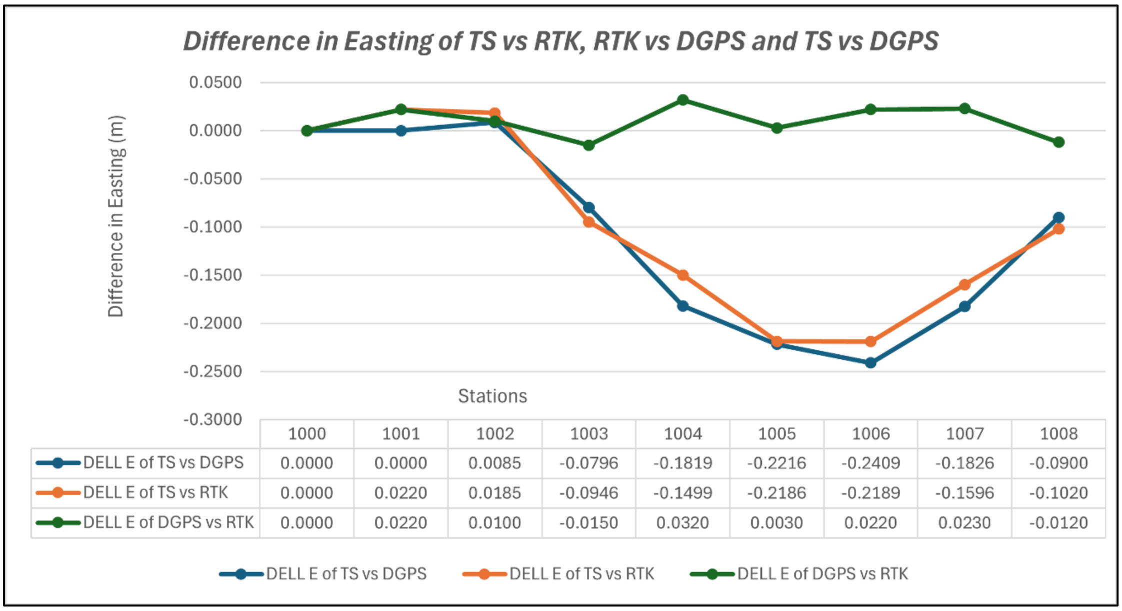

Figure 11: Difference in Easting of TS vs RTK, RTK vs DGPS and TS vs DGPS

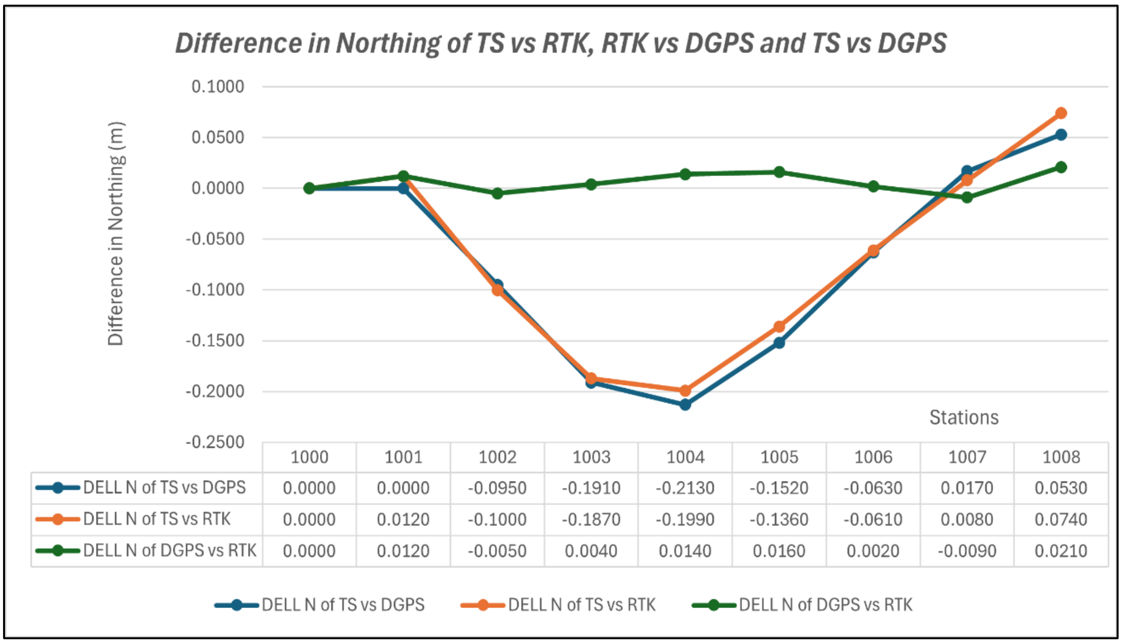

Figure 12: Difference in Northing of TS vs RTK, RTK vs DGPS and TS vs DGPS

The above figure shows that the differences in values of Easting and Northing taken by DGPS and RTK are very similar to each other and almost tend to zero. This shows that data given by RTK-GNSS and DGPS are close to one another. But on the other hand, the differences in values of Easting and Northing taken by TS & RTK and RTK & DGPS show visible deviations.

4.1.2 Assessment of Area and Perimeter of Parcels

Altogether 16 parcels were created, 2 parcels around each Control Point. And the naming of parcels made by Total Station is T1, T2, …, and T16 whereas R1, R2, …, and R16 are the names for parcels made by RTK. The table below shows the data of the area and perimeter of parcels after processing field data obtained by the Total Station and Real-Time Kinematics survey.

Table 10:Area and Perimeter of Parcels

Parcels by Total Station			***Parcels by RTK***		
Parcel No	***Area***	***Perimeter***	***Parcel No***	***Area***	***Perimeter***
T1	1369.369818	164.842	**R1**	1364.3913	164.533
T2	1179.996984	146.876	**R2**	1172.6155	146.448
T3	954.545313	129.674	**R3**	953.1035	129.569
T4	947.241631	134.646	**R4**	942.3718	134.295
T5	1454.605019	161.396	**R5**	1458.833	161.537
T6	1736.229943	171.568	**R6**	1726.3911	171.182
T7	1154.721951	147.017	**R7**	1160.6064	147.205
T8	1126.863655	148.161	**R8**	1123.1211	148.23
T9	659.729293	112.279	**R9**	658.4146	112.123
T10	881.883386	124.368	**R10**	879.7457	124.179
T11	757.135113	117.788	**R11**	757.0243	117.693
T12	214.991631	60.3671	**R12**	215.1279	60.3782
T13	1669.453775	177.249	**R13**	1672.102	177.249
T14	2012.290592	203.72	**R14**	2007.9733	203.534
T15	974.857479	130.088	**R15**	971.6574	129.964
T16	820.880165	118.537	**R16**	810.7743	117.974

Now, the Standard Deviation between the area and perimeter of the parcels calculated are shown in the table below:

Table 11:Difference in SD between TS vs RTK

Difference between TS Parcel vs RTK Parcel	
Difference in SD of Area	0.416231645 m^2
Difference in SD of Perimeter	0.006708369 m
RMSE of Area	5.078928442 m^2
RMSE of Perimeter	0.257150152 m
Maximum Deviation in Area	10.105865 m^2
Maximum Deviation in Perimeter	0.563 m

These datasets were analyzed in MS Excel to show deviations in area and perimeter among the parcels made by Total Station and Real-Time Kinematics as follows:

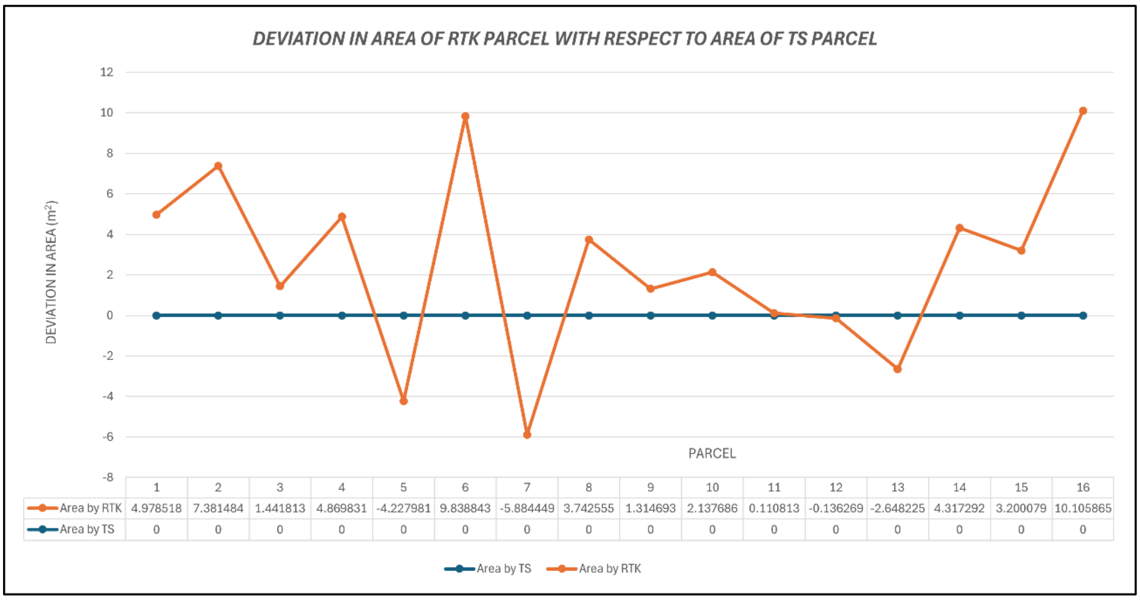

Figure 14: Deviation in area of RTK parcel with respect to area of TS parcel

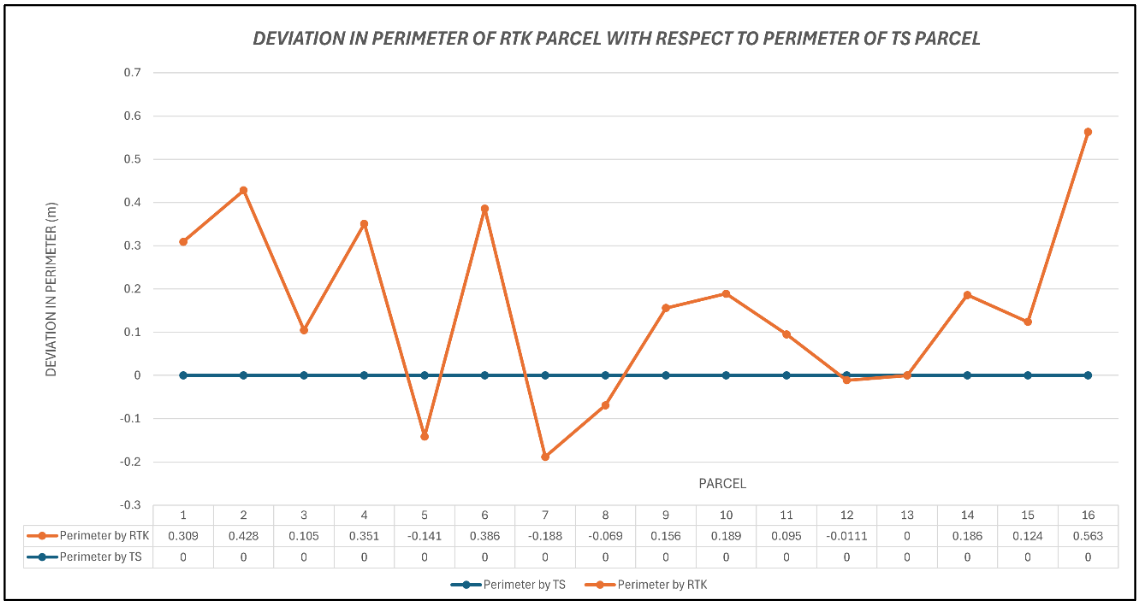

Figure 13: Deviation in area of RTK parcel with respect to perimeter of TS parcel

4.1.3 Assessment of Area and Perimeter of Closed Traverse

There were 8 major Control Points around the study area whose data were recorded by various surveying techniques including Total Station, Real-Time Kinematics, and Differential Global Positioning System. These data show certain deviations among themselves. For this reason, the analysis of the area and perimeter enclosing the traverse control points is done whose outcome is shown in the figures below:

Table 12: Area and Perimeter from DGPS, RTK, and TS

Instrument	***Traverse Area (m^2)***	***Traverse Perimeter (m)***
TS	51092.5495	859.058
DGPS	50995.2884	858.271
RTK	50996.05479	858.276

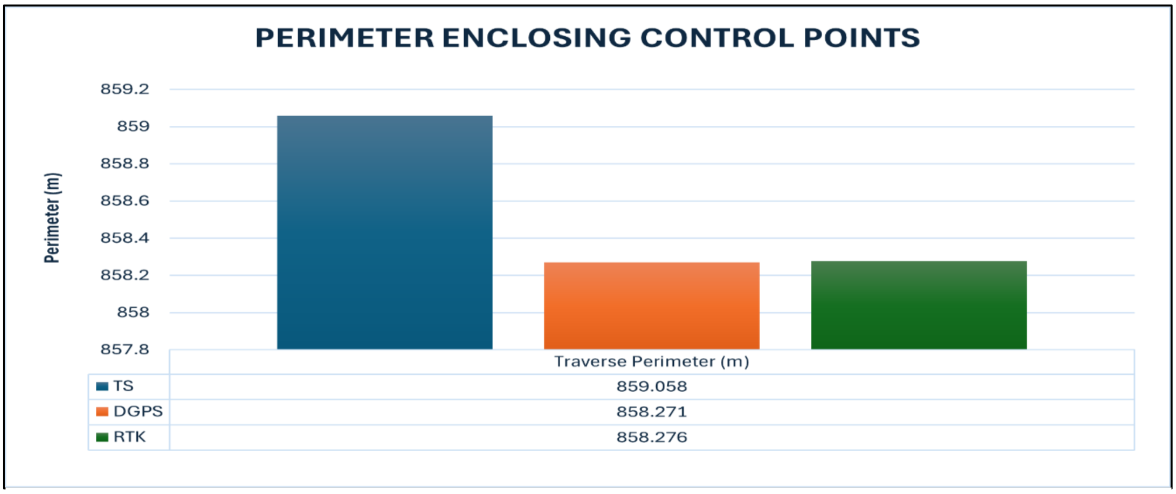

Figure 15: Perimeter enclosing control points

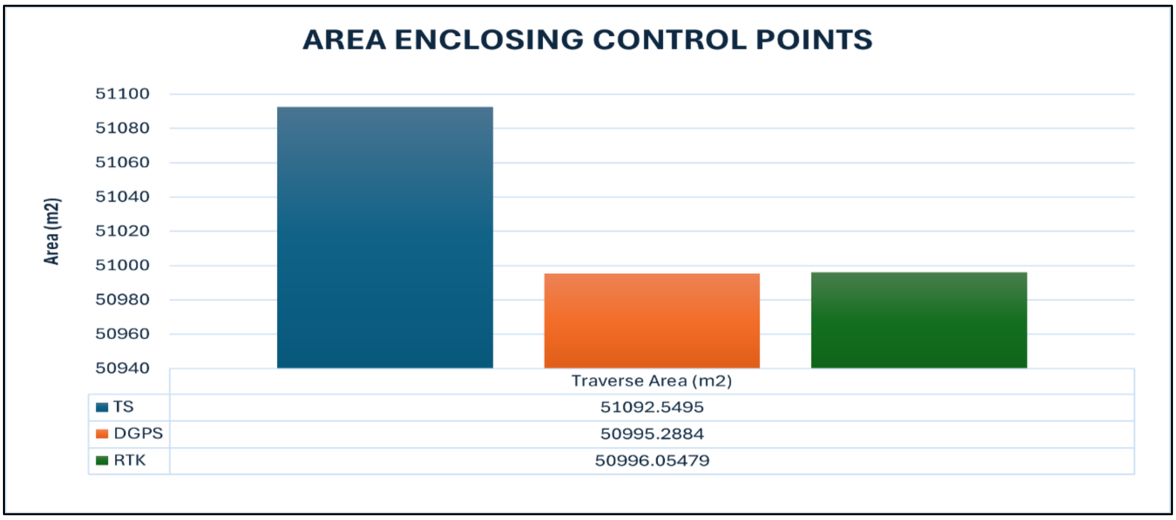

Figure 16: Area enclosing control points

4.2 Output Maps

The best way for visualization of data and to interpret their outcome is via Map. Maps allow the viewer to easily understand the key components of the project. The map-making art is directly related to cartography which provides the fundamentals of map design, its layout, and overall visualization.

For the visualization of parcels made by surveying techniques like TS and RTK, a total of 8 maps showing 2 parcels on each were prepared which shows the variation in area and perimeter of those parcels.

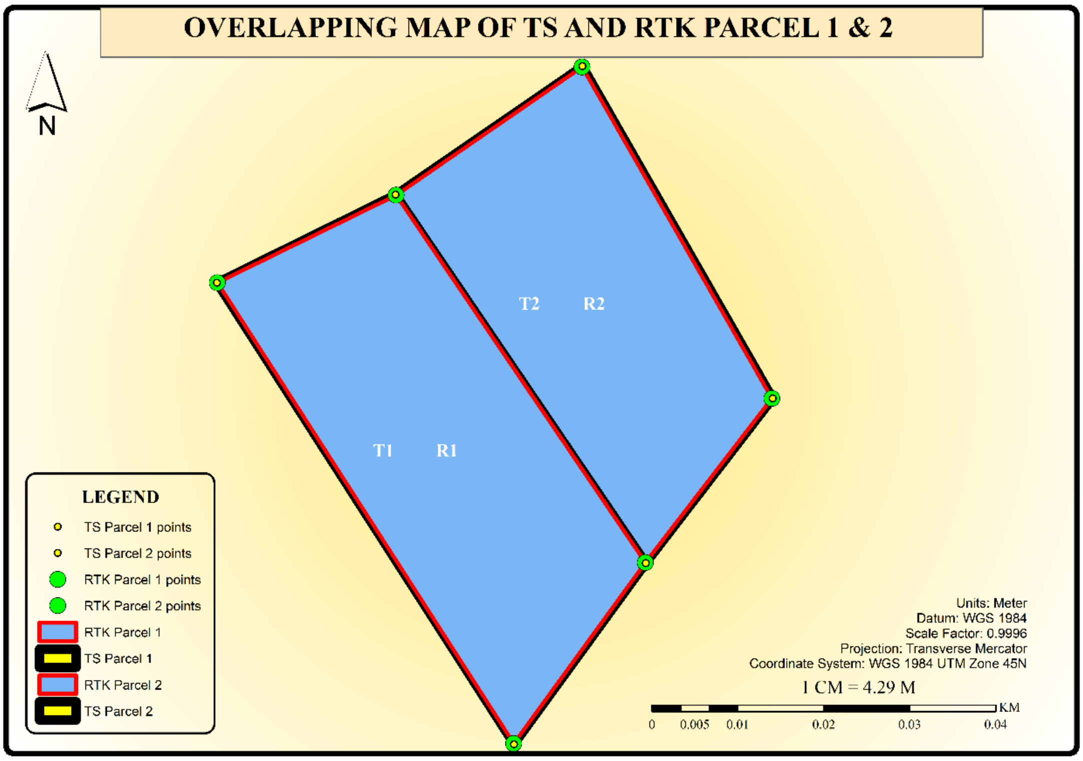

Figure 18: Overlapping map of TS and RTK parcel 1 & 2

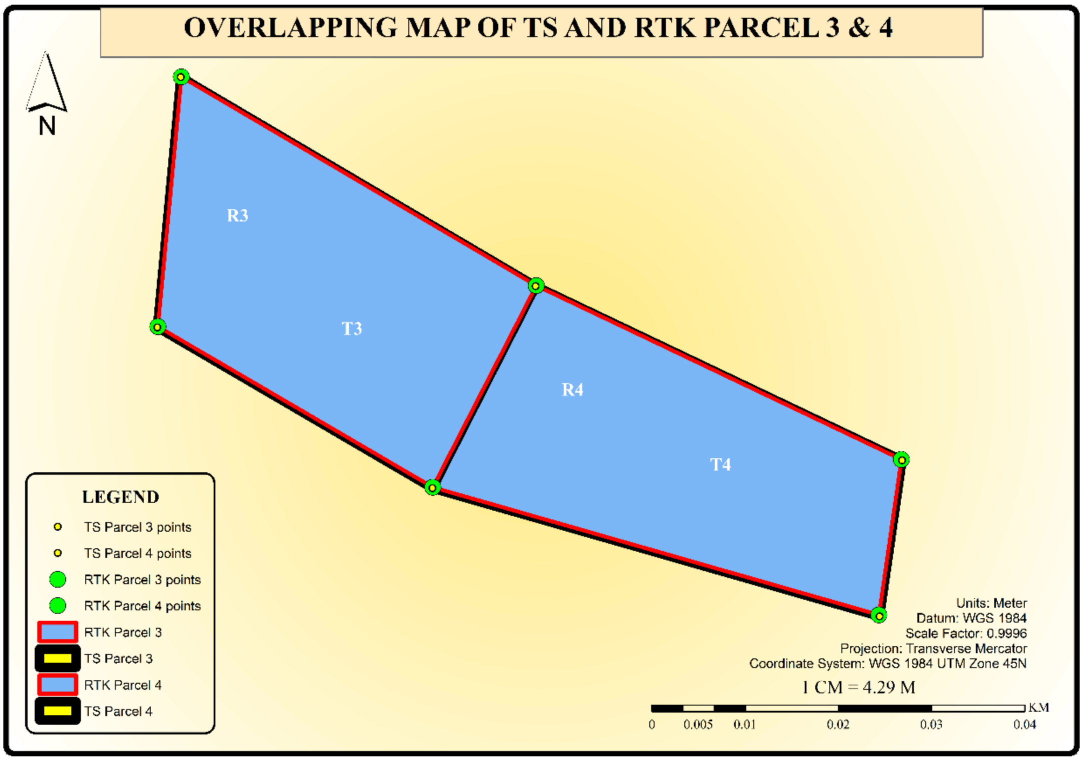

Figure 17: Overlapping map of TS and RTK parcel 3 & 4

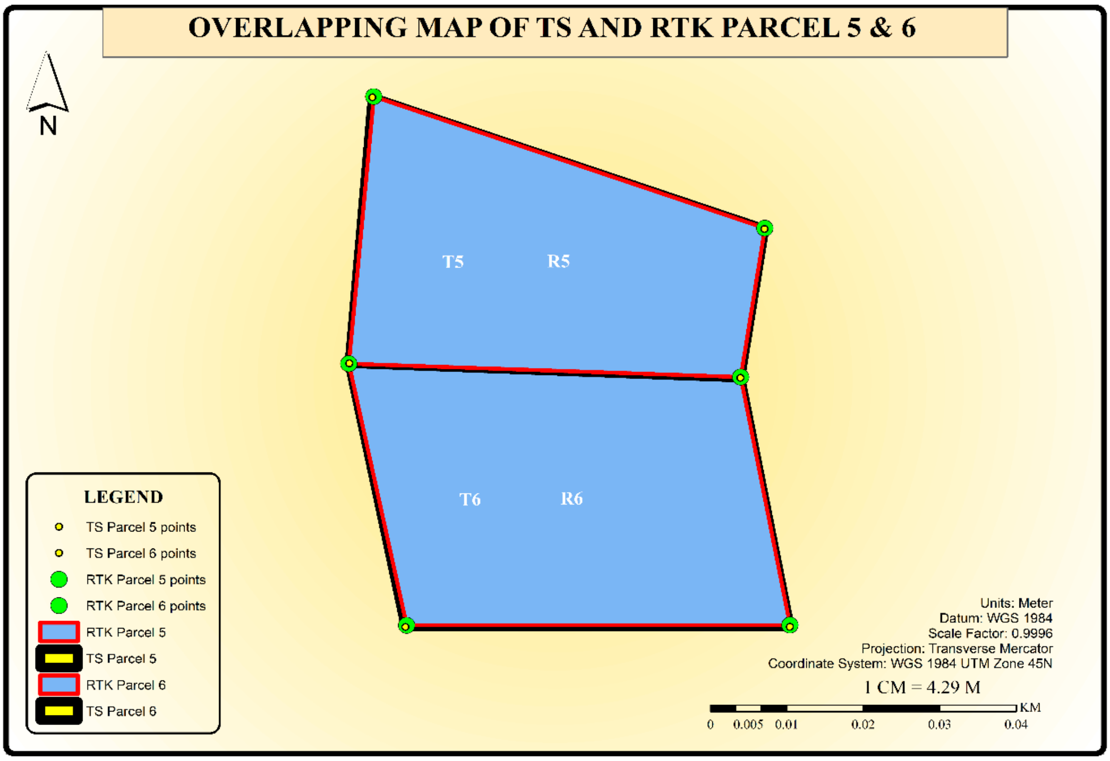

Figure 19: Overlapping map of TS and RTK parcel 5 & 6

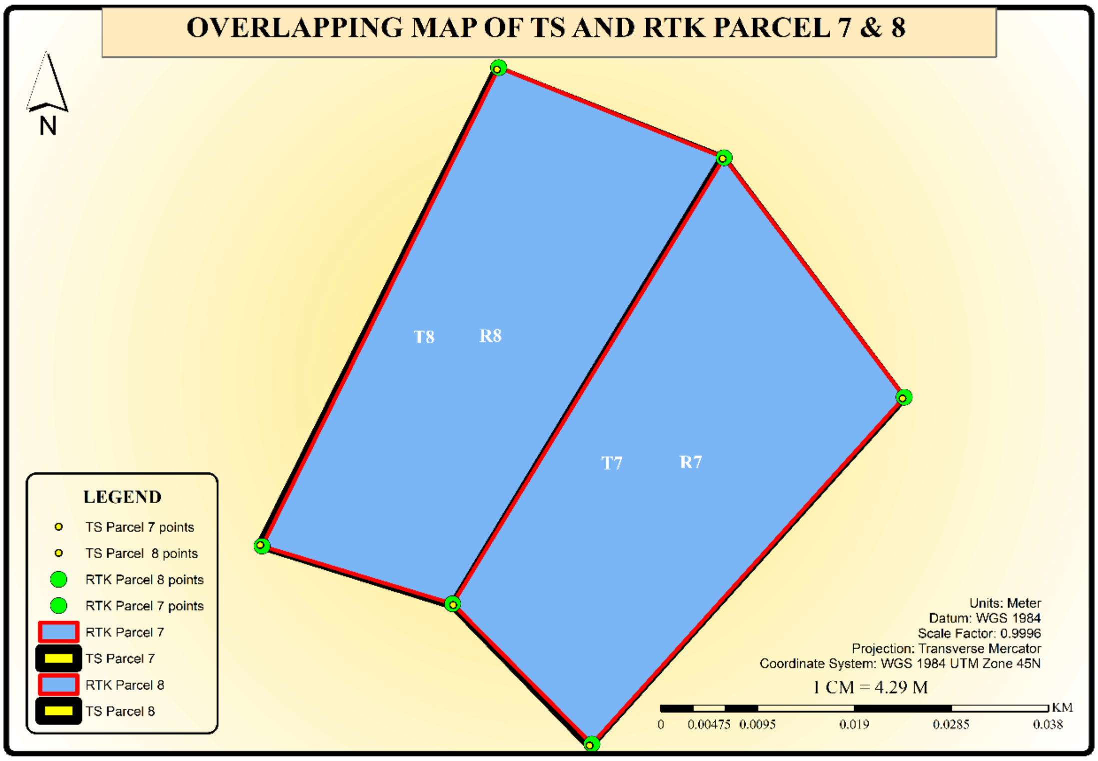

Figure 20: Overlapping map of TS and RTK parcel 7 & 8

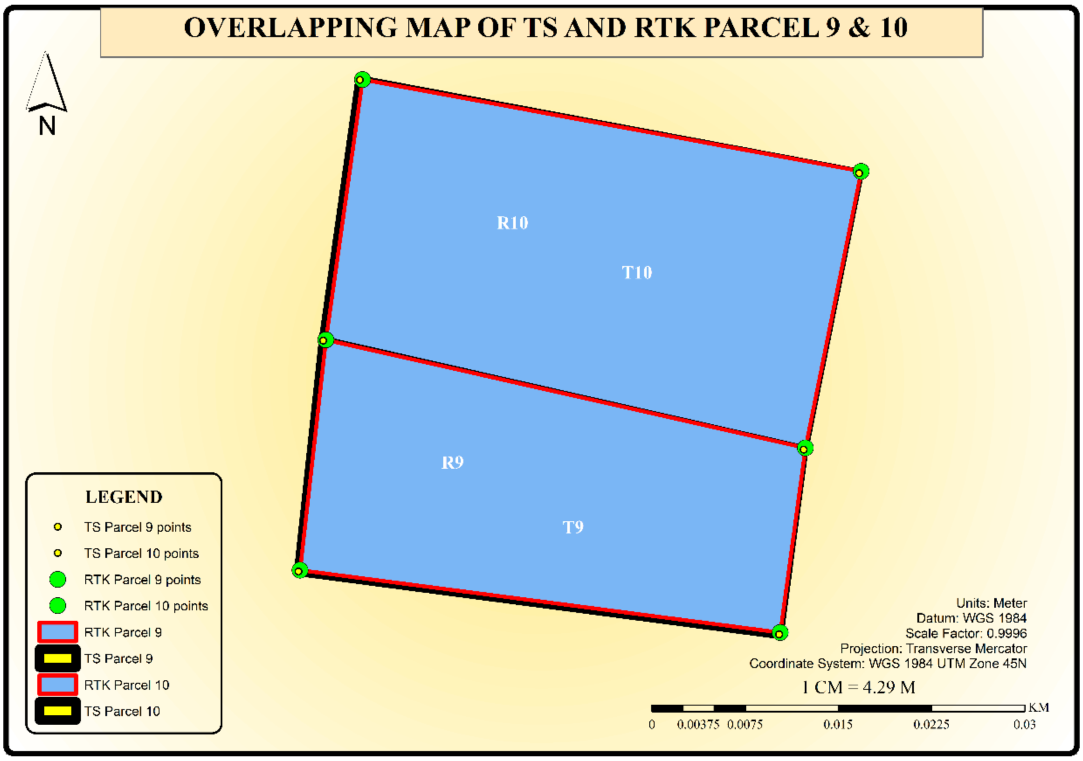

Figure 22:Overlapping map of TS and RTK parcel 9 & 10

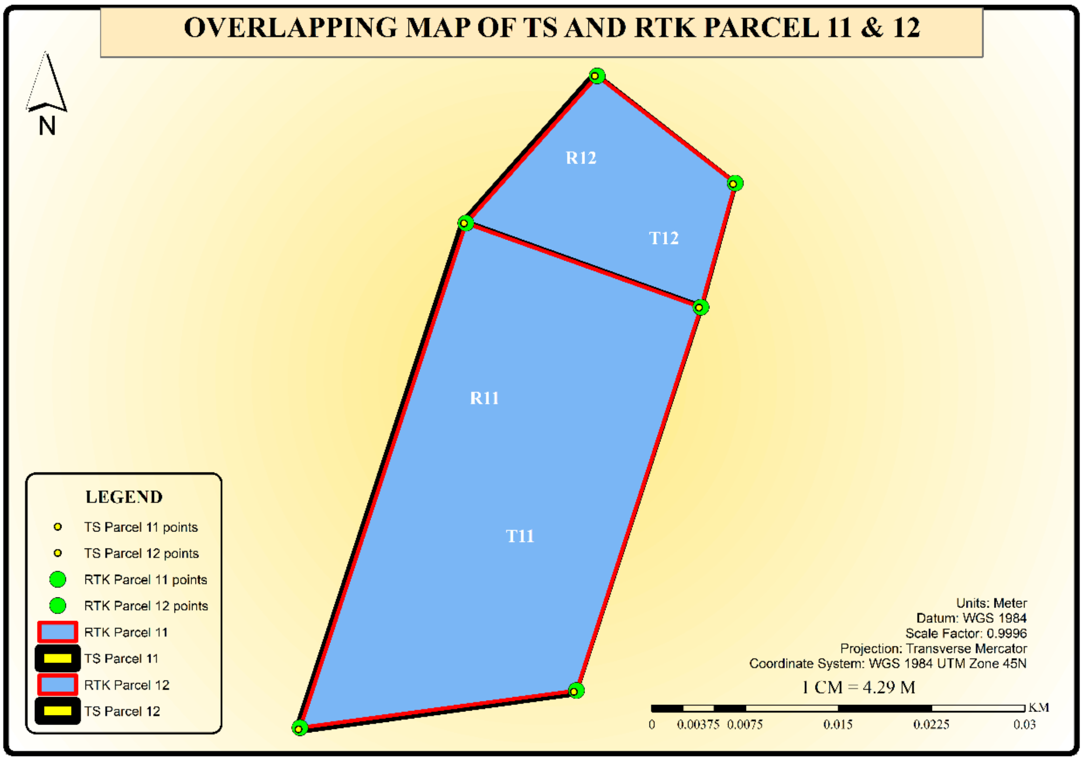

Figure 21: Overlapping map of TS and RTK parcel 11 & 12

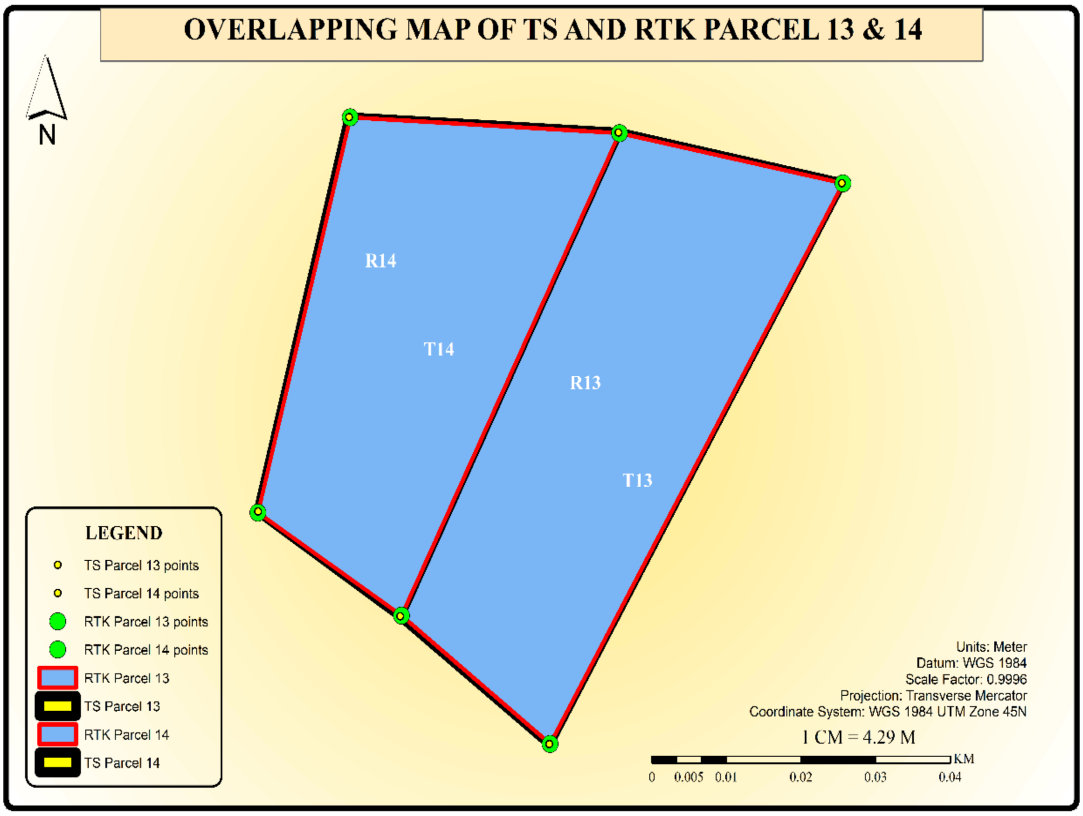

Figure 23: Overlapping map of TS and RTK parcel 13 & 14

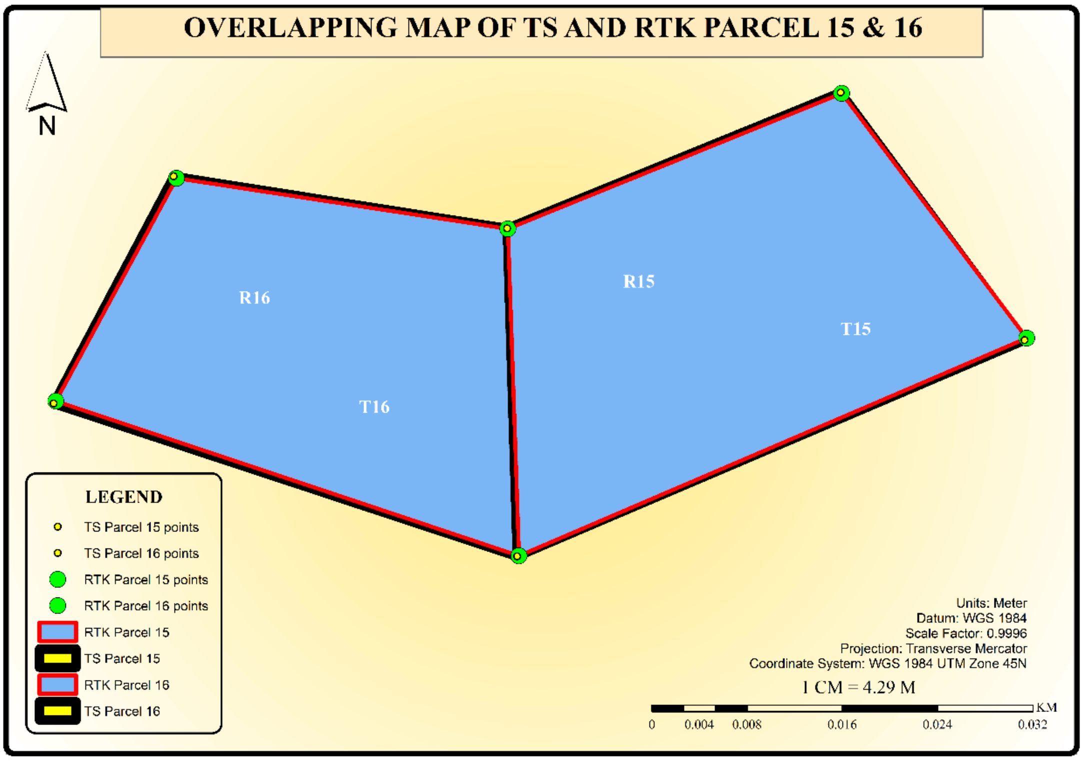

Figure 24:Overlapping map of TS and RTK parcel 15 & 16

4.3 Limitations

Determining and evaluating the accuracy of the measurement needs quite stable weather conditions and carefulness. Limitations for this project are:

- Accuracy can be affected by weather conditions.
- There may be signal obstructions during the GNSS data acquisition.
- Accuracy can be impacted by atmospheric conditions such as temperature and humidity.
- Potential for human error during instrument setup and data recording.
- Complexities in post-processing of data for static DGPS.

5. PROJECT SCHEDULE

For the completion of this project, a total of 15 weeks was required where the activities along with their duration are shown in the timeline below:

Table 13: Project Schedule

S. N	***ACTIVITIES***	***WEEK***														
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***
1.	Literature review	■	■	■	■	■	■	■	■	■	■	■	■			
2.	Concept Paper submission	■														
3.	Site Selection		■	■												
4.	Proposal Submission and Defense				■											
5.	Data Collection by DGPS					■	■									
6.	Processing of DGPS data							■								
7.	Data collection by TS								■	■						
8	Data collection by RTK										■					
8.	Data organizing and analysis											■	■			
9.	Final Report Preparation								■	■	■	■	■	■	■	
10.	Report Submission and Final Defense															■

6. OUTCOMES

After the analysis and comparison of data, the outcome of this project is shown in the table below:

Table 14: Outcomes

Criteria	***Total Station***	***RTK-GNSS***	***DGPS***
Time for data collection	Requires more time than compared to DGPS and RTK GNSS	Faster than Total Station and DGPS.	Takes a medium time range between TS and RTK
Operational Skills	Skilled Personnel	Skilled Personnel	Skilled Personnel
Portability of Instrument	Hard to carry the whole instrument set required for the TS survey	Most easy to carry	Less heavy than TS but still harder to carry than RTK
Accuracy	Highly accurate for ground surveys	Highest level of accuracy	Less accurate than RTK
Integration with GIS	CSV obtained can be directly integrated into GIS	Gives CSV directly so easily integrable	Can be integrated only after post-processing
Data Type	Point data	Point data	Point data
Data Processing Method	The manual method of Traverse Computation using Bowditch Rule	Real-time or rapid Processing	Post-processing using TBC software

7. CONCLUSION

The primary objective of this project is to evaluate and compare the accuracy of three different surveying methods: Static DGPS, RTK GNSS and Total Station around an area with minor undulations.

In static DGPS, longer observation time helps to average out the errors which generally lead to higher accuracy. For the assessment of Control Points, static DGPS is taken as standard value. RTK method is closer to static DGPS with RMSE error of 2.15 cm compared to TS with RMSE error of 18.53 cm. Thus, we can conclude that RTK method is better than TS.

For the assessment of parcels, the dataset of TS was taken as standard value, and it was compared to RTK parcel dataset. The evaluation shows RMSE error in area of 5.078 m^2 and RMSE error in perimeter of 25.72 cm whereas SD in area of 41.62 cm^2 and SD in perimeter of 6.7mm. We can conclude that the parcels obtained by TS and RTK survey shows less deviation and shift from each other.

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9. ANNEXES

COORDINATES OF CONTROL POINTS

	DGPS				TS				RTK		
Station No	Easting	Northing	Elevation	Station No	Easting	Northing	Elevation	Station No	Easting	Northing	Elevation
1000	356530.6140	3056009.1090	1471.390	1000	356530.6140	3056009.1090	1471.390	1000	356530.6140	3056009.1090	1471.390
1001	356564.5360	3055918.2750	1470.077	1001	356564.536	3055918.275	1470.077	1001	356564.514	3055918.263	1470.35
1002	356564.3710	3055800.9630	1479.877	1002	356564.3795	3055800.868	1479.872	1002	356564.361	3055800.968	1480.255
1003	356440.4080	3055722.5010	1469.587	1003	356440.3284	3055722.310	1469.559	1003	356440.423	3055722.497	1469.939
1004	356332.3930	3055697.5850	1462.900	1004	356332.2111	3055697.372	1462.8662	1004	356332.361	3055697.571	1462.972
1005	356307.5750	3055748.6530	1464.006	1005	356307.3534	3055748.501	1463.9678	1005	356307.572	3055748.637	1464.308
1006	356282.2800	3055824.2810	1465.458	1006	356282.0391	3055824.218	1465.4428	1006	356282.258	3055824.279	1465.81
1007	356336.0740	3055894.4120	1465.964	1007	356335.8914	3055894.429	1465.9495	1007	356336.051	3055894.421	1466.329
1008	356446.3000	3055965.5090	1472.723	1008	356446.21	3055965.562	1472.7415	1008	356446.312	3055965.488	1473.13

TS vs DGPS			TS vs RTK			DGPS vs RTK		
Dell E	Dell N	Dell RL	Dell E	Dell N	Dell RL	Dell E	Dell N	Dell RL
0.0000	0.0000	0.000	0.0000	0.0000	0.000	0.0000	0.0000	0.000
0.0000	0.0000	0.000	0.0220	0.0120	-0.273	0.0220	0.0120	-0.273
0.0085	-0.0950	-0.005	0.0185	-0.1000	-0.383	0.0100	-0.0050	-0.378
-0.0796	-0.1910	-0.028	-0.0946	-0.1870	-0.380	-0.0150	0.0040	-0.352
-0.1819	-0.2130	-0.034	-0.1499	-0.1990	-0.106	0.0320	0.0140	-0.072
-0.2216	-0.1520	-0.038	-0.2186	-0.1360	-0.340	0.0030	0.0160	-0.302
-0.2409	-0.0630	-0.015	-0.2189	-0.0610	-0.367	0.0220	0.0020	-0.352
-0.1826	0.0170	-0.014	-0.1596	0.0080	-0.380	0.0230	-0.0090	-0.365
-0.0900	0.0530	0.019	-0.1020	0.0740	-0.389	-0.0120	0.0210	-0.407
max error E:-24cm/N:-21cm			max error E:-21cm/N:-19cm			max error E:-3cm/N:-2cm		

DGPS Easting		DGPS Northing	
Mean	356409.2421	Mean	3055821.522
Standard Error	39.69542555	Standard Error	34.41139383
Median	356388.241	Median	3055812.622
Mode	#N/A	Mode	#N/A
Standard Deviation	112.2756184	Standard Deviation	97.3301197
Sample Variance	12605.81448	Sample Variance	9473.152201
Kurtosis	-1.461314555	Kurtosis	-1.438062598
Skewness	0.486707687	Skewness	0.208206621
Range	282.256	Range	267.924
Minimum	356282.28	Minimum	3055697.585
Maximum	356564.536	Maximum	3055965.509
Sum	2851273.937	Sum	24446572.18
Count	8	Count	8

TS Easting		TS Northing	
Mean	356409.1186	Mean	3055821.442
Standard Error	39.72959505	Standard Error	34.44618212
Median	356388.1099	Median	3055812.543
Mode	#N/A	Mode	#N/A
Standard Deviation	112.3722643	Standard Deviation	97.42851586
Sample Variance	12627.52578	Sample Variance	9492.315702
Kurtosis	-1.461491288	Kurtosis	-1.438360891
Skewness	0.486531791	Skewness	0.207907026
Range	282.4969	Range	268.19
Minimum	356282.0391	Minimum	3055697.372
Maximum	356564.536	Maximum	3055965.562
Sum	2851272.949	Sum	24446571.54
Count	8	Count	8

RTK Easting		RTK Northing	
Mean	356409.2315	Mean	3055821.516
Standard Error	39.69685862	Standard Error	34.41121763
Median	356388.237	Median	3055812.624
Mode	#N/A	Mode	#N/A
Standard Deviation	112.2796717	Standard Deviation	97.32962133
Sample Variance	12606.72467	Sample Variance	9473.055188
Kurtosis	-1.461884501	Kurtosis	-1.438395886
Skewness	0.486452982	Skewness	0.207973632
Range	282.256	Range	267.917
Minimum	356282.258	Minimum	3055697.571
Maximum	356564.514	Maximum	3055965.488
Sum	2851273.852	Sum	24446572.12
Count	8	Count	8

Difference in Two Methods : TS vs RTK

Column1	Easting	Northing	Elevation
∆ SD	0.092592612	0.098894528	-0.04664387

Difference in Two Methods : TS vs DGPS

Column1	Easting	Northing	Elevation
∆ SD	0.096645936	0.098396154	0.012130615

DGPS Elevation	
Mean	1468.824
Standard Error	1.970041896
Median	1467.7755
Mode	#N/A
Standard Deviation	5.572119935
Sample Variance	31.04852057
Kurtosis	1.190564017
Skewness	1.134834868
Range	16.977
Minimum	1462.9
Maximum	1479.877
Sum	11750.592
Count	8

TS Elevation	
Mean	1468.809475
Standard Error	1.974330716
Median	1467.75425
Mode	#N/A
Standard Deviation	5.58425055
Sample Variance	31.1838542
Kurtosis	1.168282116
Skewness	1.128925393
Range	17.0058
Minimum	1462.8662
Maximum	1479.872
Sum	11750.4758
Count	8

RTK Elevation	
Mean	1469.136625
Standard Error	1.990821815
Median	1468.134
Mode	#N/A
Standard Deviation	5.630894421
Sample Variance	31.70697198
Kurtosis	1.140063026
Skewness	1.103797361
Range	17.283
Minimum	1462.972
Maximum	1480.255
Sum	11753.093
Count	8

Difference in Two Methods : DGPS vs RTK

Column1	Easting	Northing	Elevation
∆ SD	-0.004053324	0.000498374	-0.05877449

	DGPS		
Station No	Easting	Northing	Elevation
1000	356530.6140	3056009.1090	1471.390
1001	356564.5360	3055918.2750	1470.077
1002	356564.3710	3055800.9630	1479.877
1003	356440.4080	3055722.5010	1469.587
1004	356332.3930	3055697.5850	1462.900
1005	356307.5750	3055748.6530	1464.006
1006	356282.2800	3055824.2810	1465.458
1007	356336.0740	3055894.4120	1465.964
1008	356446.3000	3055965.5090	1472.723

	TS		
Station No	Easting	Northing	Elevation
1000	356530.6140	3056009.1090	1471.390
1001	356564.536	3055918.275	1470.077
1002	356564.3795	3055800.868	1479.872
1003	356440.3284	3055722.310	1469.559
1004	356332.2111	3055697.372	1462.8662
1005	356307.3534	3055748.501	1463.9678
1006	356282.0391	3055824.218	1465.4428
1007	356335.8914	3055894.429	1465.9495
1008	356446.21	3055965.562	1472.7415

TS is used as Standard data

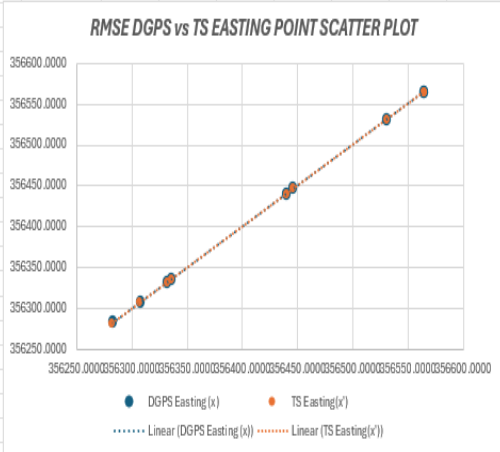
	RTK		
Station No	Easting	Northing	Elevation
1000	356530.6140	3056009.1090	1471.390
1001	356564.514	3055918.263	1470.35
1002	356564.361	3055800.968	1480.255
1003	356440.423	3055722.497	1469.939
1004	356332.361	3055697.571	1462.972
1005	356307.572	3055748.637	1464.308
1006	356282.258	3055824.279	1465.81
1007	356336.051	3055894.421	1466.329
1008	356446.312	3055965.488	1473.13

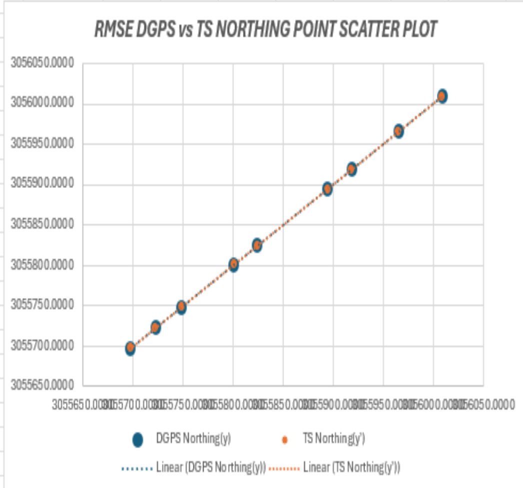
RMSE CALCULATION OF DGPS - TS

Station	x-x'	y-y'	z-z'	(x-x')sq	(y-y')sq	(z-z')sq
1000	0.0000	0.0000	0.000	0	0	0
1001	0.0000	0.0000	0.000	0	0	0
1002	-0.0085	0.0950	0.005	7.225E-05	0.009025	2.5E-05
1003	0.0796	0.1910	0.028	0.00633616	0.036481	0.000784
1004	0.1819	0.2130	0.034	0.03308761	0.045369	0.00114244
1005	0.2216	0.1520	0.038	0.04910656	0.023104	0.00145924
1006	0.2409	0.0630	0.015	0.05803281	0.003969	0.00023104
1007	0.1826	-0.0170	0.014	0.03334276	0.000289	0.00021025
1008	0.0900	-0.0530	-0.019	0.0081	0.002809	0.00034225
			Sum	0.18807815	0.121046	0.00419422
			N	9		
			RMSE	0.144559926	0.115972219	0.021587599
			MSE=	0.020897572	0.013449556	0.000466024
			RMSE check	0.144559926	0.115972219	0.021587599
			COMBINED RMSE	0.185329781		

RMSE CALCULATION OF RTK - TS

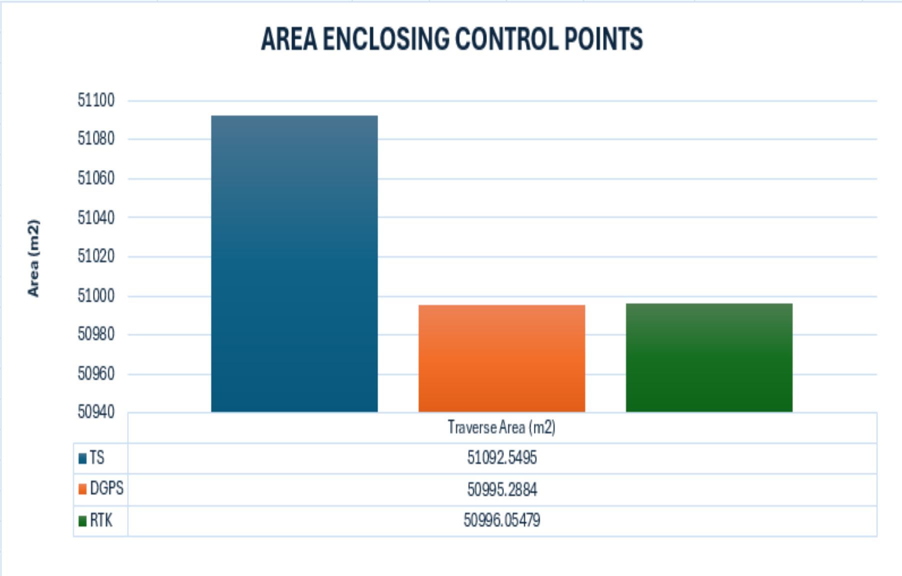
Station	x-x'	y-y'	z-z'	(x-x')sq	(y-y')sq	(z-z')sq
1000	0.0000	0.0000	0.000	0	0	0
1001	-0.0220	-0.0120	0.273	0.000484	0.000144	0.074529
1002	-0.0185	0.1000	0.383	0.00034225	0.01	0.146689
1003	0.0946	0.1870	0.380	0.00894916	0.034969	0.1444
1004	0.1499	0.1990	0.106	0.02247001	0.039601	0.01119364
1005	0.2186	0.1360	0.340	0.04778596	0.018496	0.11573604
1006	0.2189	0.0610	0.367	0.04791721	0.003721	0.13483584
1007	0.1596	-0.0080	0.380	0.02547216	6.4E-05	0.14402025
1008	0.1020	-0.0740	0.389	0.010404	0.005476	0.15093225
			Sum	0.16382475	0.112471	0.92233602
			N	9		
			RMSE	0.134917567	0.111788988	0.320127756
			MSE=	0.01820275	0.012496778	0.10248178
			RMSE check	0.134917567	0.111788988	0.320127756
			COMBINED RMSE	0.175212807		

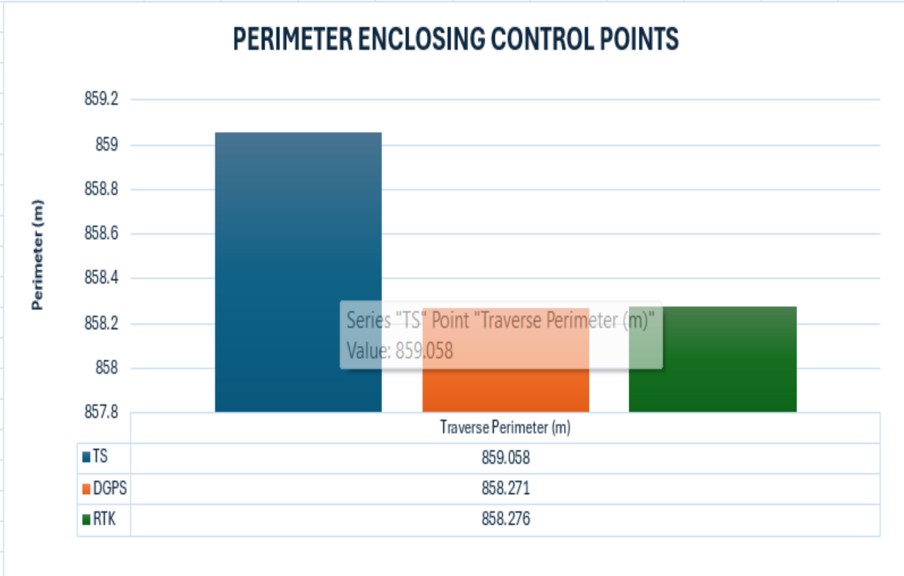




ANALYSIS OF TRAVERSE CONTROL POINT AREA AND PERIMETER

Instrument	Traverse Area (m^2)	Traverse Perimeter (m)
TS	51092.5495	859.058
DGPS	50995.2884	858.271
RTK	50996.05479	858.276





Parcels by Total Station

Parcel No	Area	Perimeter
T1	1369.369818	164.842
T2	1179.996984	146.876
T3	954.545313	129.674
T4	947.241631	134.646
T5	1454.605019	161.396
T6	1736.229943	171.568
T7	1154.721951	147.017
T8	1126.863655	148.161
T9	659.729293	112.279
T10	881.883386	124.368
T11	757.135113	117.788
T12	214.991631	60.3671
T13	1669.453775	177.249
T14	2012.290592	203.72
T15	974.857479	130.088
T16	820.880165	118.537

Parcels by RTK

Parcel No	Area	Perimeter
R1	1364.3913	164.533
R2	1172.6155	146.448
R3	953.1035	129.569
R4	942.3718	134.295
R5	1458.833	161.537
R6	1726.3911	171.182
R7	1160.6064	147.205
R8	1123.1211	148.23
R9	658.4146	112.123
R10	879.7457	124.179
R11	757.0243	117.693
R12	215.1279	60.3782
R13	1672.102	177.249
R14	2007.9733	203.534
R15	971.6574	129.964
R16	810.7743	117.974

Deviations

Dell Area	Dell Perimeter
4.978518	0.309
7.381484	0.428
1.441813	0.105
4.869831	0.351
-4.227981	-0.141
9.838843	0.386
-5.884449	-0.188
3.742555	-0.069
1.314693	0.156
2.137686	0.189
0.110813	0.095
-0.136269	-0.0111
-2.648225	0
4.317292	0.186
3.200079	0.124
10.105865	0.563

max deviation = 10.1058msq

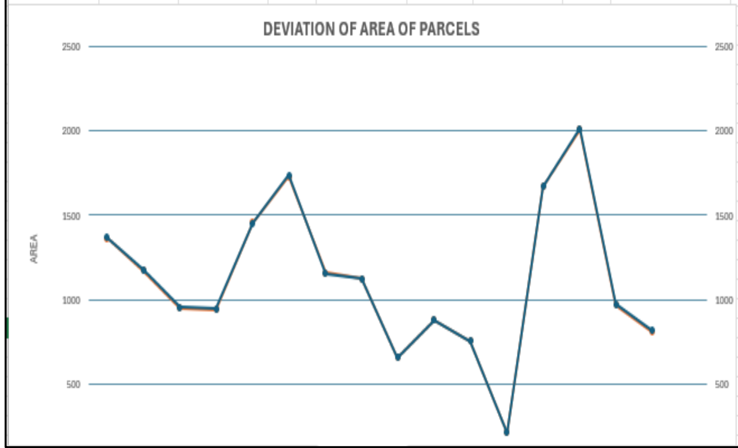
Deviation in SD betwn TS vs RTK

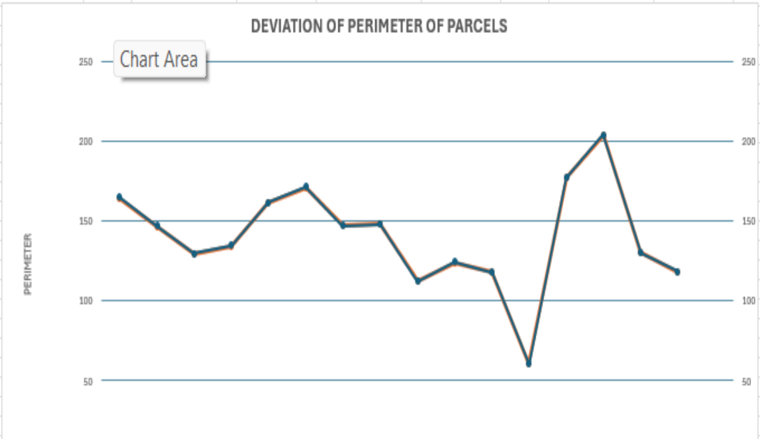
Diff. in SD of Area	0.416231645
Diff. in SD of Perimeter	0.006708369

Parcel Area by TS		***Parcel Perimeter by TS***	
Mean	1119.674734	Mean	140.5360063
Standard Error	112.6172952	Standard Error	8.220778102
Median	1050.860567	Median	140.761
Mode	#N/A	Mode	#N/A
Standard Deviation	450.4691808	Standard Deviation	32.88311241
Sample Variance	202922.4828	Sample Variance	1081.299082
Kurtosis	0.240767347	Kurtosis	1.554824879
Skewness	0.189186617	Skewness	-0.45227002
Range	1797.298961	Range	143.3529
Minimum	214.991631	Minimum	60.3671
Maximum	2012.290592	Maximum	203.72
Sum	17914.79575	Sum	2248.5761
Count	16	Count	16

Parcel Area by RTK		***Parcel Perimeter by RTK***	
Mean	1117.140825	Mean	140.380825
Standard Error	112.5132373	Standard Error	8.21910101
Median	1047.38925	Median	140.3715
Mode	#N/A	Mode	#N/A
Standard Deviation	450.0529491	Standard Deviation	32.87640404
Sample Variance	202547.657	Sample Variance	1080.857942
Kurtosis	0.218133334	Kurtosis	1.529201032
Skewness	0.189876126	Skewness	-0.447309571
Range	1792.8454	Range	143.1558
Minimum	215.1279	Minimum	60.3782
Maximum	2007.9733	Maximum	203.534
Sum	17874.2532	Sum	2246.0932
Count	16	Count	16

Par	a-a'	p-p'	(a-a')sq	(p-p')sq
1	-4.9785	-0.3090	24.78564148	0.095481
2	-7.3815	-0.4280	54.48630604	0.183184
3	-1.4418	-0.1050	2.078824727	0.011025
4	-4.8698	-0.3510	23.71525397	0.123201
5	4.2280	0.1410	17.87582334	0.019881
6	-9.8388	-0.3860	96.80283158	0.148996
7	5.8844	0.1880	34.62674003	0.035344
8	-3.7426	0.0690	14.00671793	0.004761
9	-1.3147	-0.1560	1.728417684	0.024336
10	-2.1377	-0.1890	4.569701435	0.035721
11	-0.1108	-0.0950	0.012279521	0.009025
12	0.1363	0.0111	0.01856924	0.00012321
13	2.6482	0.0000	7.013095651	0
14	-4.3173	-0.1860	18.63901021	0.034596
15	-3.2001	-0.1240	10.24050561	0.015376
16	-10.1059	-0.5630	102.1285074	0.316969
		Sum	412.7282258	1.05801921
		n	16	
		RMSE	5.078928442	0.257150152
		MSE	25.79551411	0.066126201
		PMSE recheck	5.078928442	0.257150152





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Time zone:	Mountain Standard Time	Geoid:	EGM96 (Global)
Reference number:		Vertical datum:	
Description:		Calibrated site:	
Comment 1:			
Comment 2:			
Comment 3:			

Point List

ID	Easting (Meter)	Northing (Meter)	Elevation (Meter)	Feature Code
1001	356564.536	3055918.275	1470.077	
1002	356564.371	3055800.963	1479.877	
1003	356440.408	3055722.501	1469.587	
1004	356332.393	3055697.585	1462.900	
Base	356530.614	3056009.109	1471.390	

5/27/2024 1:55:04 PM		Trimble Business Center