

TITLE

Comparative Accuracy Assessment of GNSS and Total Station Surveying  
Methods for Small-Area Control Mapping



## ABSTRACT

- Modern surveying practice increasingly integrates satellite-based positioning with conventional optical instrumentation. Understanding the relative accuracy, efficiency, and operational suitability of these techniques is essential for selecting appropriate tools in engineering and cadastral applications.
- This study presents a comparative evaluation of Global Navigation Satellite System (GNSS) surveying and total station surveying for small-area control mapping.
- The research aims to assess positional accuracy, field efficiency, and cost implications associated with both methods.
- Control points are established within a selected study area and surveyed independently using GNSS and total station equipment.
- Coordinate datasets are processed and analyzed using statistical measures including mean deviation, standard deviation, and Root Mean Square Error (RMSE).
- Additionally, operational factors such as observation time, manpower requirements, and workflow complexity are evaluated.
- Results are expected to highlight differences in horizontal and vertical accuracy between the methods, particularly under varying environmental conditions.
- GNSS surveying typically provides rapid data acquisition with minimal line-of-sight restrictions, while total station surveying offers superior precision in confined or obstructed environments.
- Findings from this research will provide practical recommendations for surveyors, planners, and engineers regarding optimal method selection.
- The study contributes to professional surveying knowledge by combining field-based observations with computational accuracy analysis, demonstrating the continued relevance of integrated surveying approaches in contemporary land development and infrastructure projects.



## CHAPTER 1 – INTRODUCTION

### 1.1 Background of the Study

- Surveying forms the backbone of land administration, engineering construction, infrastructure development, and urban planning. Accurate spatial data collection ensures reliable mapping, boundary definition, and design implementation. Traditionally, land surveying relied on optical instruments such as theodolites and total stations to measure angles and distances through line-of-sight observations. These instruments remain widely used due to their high precision and reliability.
- The emergence of satellite-based positioning technologies has transformed surveying practice. Global Navigation Satellite Systems (GNSS), including GPS and other constellations, allow surveyors to determine positions without intervisibility between points. This capability reduces field time and expands operational flexibility, particularly across large or inaccessible areas.
- Despite technological advancement, surveyors frequently face the decision of selecting between GNSS and total station methods. Each approach presents advantages and limitations relating to accuracy, environmental sensitivity, cost, and workflow requirements.
- While GNSS enables rapid positioning, signal obstruction and atmospheric effects may influence accuracy. Conversely, total stations provide highly precise measurements but require clear lines of sight and greater setup effort.
- Given the coexistence of these technologies in professional practice, it is necessary to evaluate their performance comparatively within practical survey scenarios. Such evaluation informs method selection, enhances efficiency, and improves data reliability.



## 1.2 Problem Statement

Surveyors operating in modern environments must choose between GNSS and total station instruments depending on project conditions. However, many practitioners lack locally contextualized comparative assessments demonstrating how these technologies perform under similar conditions within small-area mapping tasks.

Without structured evaluation, method selection may rely on assumptions rather than measured performance, potentially affecting project timelines, cost efficiency, and spatial accuracy. This study addresses this gap by systematically comparing coordinate outputs and operational workflows of both techniques when applied to identical control points.

## 1.3 Aim of the Study

To compare positional accuracy and operational efficiency of GNSS and total station surveying methods in small-area control mapping.

## 1.4 Objectives

- Establish survey control points within a selected study area.
- Observe coordinates using GNSS techniques.
- Observe the same points using total station measurements.
- Analyze coordinate discrepancies using statistical methods.
- Evaluate operational efficiency and practical suitability.



## 1.5 Significance of the Study

This study is valuable to:

1. Practicing land surveyors selecting equipment
2. Engineering project planners
3. Students and trainees learning surveying technologies
4. Organizations optimizing field operations
5. It provides practical insights into:
  6. Accuracy expectations
  7. Workflow efficiency
  8. Cost-performance balance

## 1.6 Scope of the Study

The research focuses on:

1. Small-area control mapping
2. Horizontal and vertical coordinate comparison
3. Field observation and computational analysis

It does not address:

1. Large geodetic networks
2. Long baseline GNSS studies
3. Advanced deformation monitoring

### 1.7 Structure of the Study

The project is organized into five chapters:

- Introduction
- Literature Review
- Methodology
- Results and Discussion
- Conclusions and Recommendations



## CHAPTER 2. LITERATURE REVIEW

### 2.1 Overview of Modern Surveying Technologies

Surveying has undergone significant transformation over the past several decades, driven largely by technological advancements in measurement instrumentation and computational processing.

Traditional surveying relied heavily on optical-mechanical devices, requiring direct line-of-sight measurements between points.

Modern practice integrates electronic distance measurement, satellite positioning systems, and digital data processing, improving efficiency and expanding operational capabilities.

Two dominant technologies in contemporary land surveying are total stations and Global Navigation Satellite System (GNSS) receivers.

Each has reshaped field workflows and data accuracy standards, and both remain essential tools across engineering, cadastral, and construction applications. Comparative evaluation of these systems has become increasingly relevant as surveyors seek to optimize project efficiency without compromising positional accuracy.

### 2.2 Total Station Surveying

Total stations combine electronic theodolites with electronic distance measurement (EDM) capabilities to measure horizontal angles, vertical angles, and slope distances simultaneously. Coordinates are computed relative to known control points using trigonometric relationships.

#### Advantages

- High precision measurements
- Reliable in obstructed or urban environments
- Minimal dependence on satellite signals
- Effective for detailed engineering surveys



## Limitations

- Requires intervisibility between points
- Time-intensive setup and traversing
- Performance affected by atmospheric refraction
- Limited efficiency over large distances

Total stations are particularly suited to construction layout, deformation monitoring, and cadastral surveys where millimetre-level precision is necessary. Their reliability under canopy cover or near tall structures reinforces their relevance in dense urban settings.

## 2.3 GNSS Surveying

GNSS surveying utilizes satellite constellations to determine point positions through trilateration based on signal travel time.

Techniques include static, differential, and Real-Time Kinematic (RTK) positioning, each offering varying levels of accuracy.

## Advantages

- No line-of-sight requirement between ground points
- Rapid data collection
- Efficient for large areas
- Reduced manpower requirements



## Limitations

- Signal obstruction from buildings or vegetation
- Multipath interference
- Atmospheric delay effects
- Dependency on satellite geometry

GNSS technology is widely adopted for geodetic control establishment, topographic mapping, and infrastructure planning.

Its flexibility and speed make it a preferred choice for preliminary surveys and expansive fieldwork.

## 2.4 Accuracy Considerations in Survey

### Measurements

Accuracy assessment is fundamental in evaluating surveying methods. Measurement accuracy refers to the closeness of observed values to their true positions, while precision reflects consistency among repeated observations.

Common statistical indicators include:

- Mean error
- Standard deviation
- Root Mean Square Error (RMSE)
- Coordinate residuals



These metrics allow surveyors to quantify discrepancies between datasets and identify systematic or random errors.

Environmental conditions, equipment calibration, and operator skill contribute significantly to observed accuracy.

Comparative studies often reveal that total stations achieve superior short-range precision, whereas GNSS offers acceptable accuracy with significantly reduced observation time. Therefore, the choice of instrument frequently reflects project requirements rather than absolute measurement superiority.

## 2.5 Operational Efficiency and Cost Factors

Instrument selection extends beyond accuracy considerations to include logistical and economic factors:

- Field duration
- Crew size
- Equipment transport
- Training requirements
- Processing workload

GNSS systems generally provide faster data acquisition and lower labor intensity. However, total stations may offer greater reliability in environments unsuitable for satellite reception. A balanced evaluation incorporating efficiency metrics ensures that survey decisions align with practical project constraints.

## 2.6 Research Gap

Existing literature provides extensive theoretical and experimental comparisons of surveying instruments, yet many studies focus on high-end geodetic applications or controlled laboratory conditions. Limited documentation exists addressing small-area practical comparisons relevant to entry-level professional environments or training contexts.

This study contributes to applied surveying practice by presenting a structured comparison under realistic operational conditions representative of routine mapping and control establishment tasks.



## CHAPTER 3. METHODOLOGY

### 3.1 Research Design

Comparative experimental approach with control points surveyed independently using GNSS and Total Station. Datasets are analyzed statistically to determine discrepancies and performance characteristics.

### 3.2 Study Area Description

Open 2 hectare site at Jowi's Ranch with minimal vegetation, limited obstruction, and relatively level terrain, a representative of small-scale mapping projects.

### 3.3 Control Point Establishment

10 points labeled CP1–CP10, physically marked with pegs or nails.

Documentation included sketches, identifiers, and photos.

### 3.4 GNSS Observation Procedure

- Receiver setup at each point
- Antenna height recorded
- Satellite lock verified
- Observation time sufficient for accuracy
- Coordinates logged



### 3.5 Total Station Observation Procedure

- Instrument setup and leveling
- Prism placed over each control point
- Horizontal/vertical angles and distances measured
- Coordinates computed

### 3.6 Data Processing

- Coordinate formatting and dataset are aligned
- Information is Imported into GIS/CAD for visualization
- Overlays are done for comparison

### 3.7 Accuracy Assessment

Horizontal error, (RMSE), mean deviation, standard deviation are calculated

### 3.8 Efficiency Evaluation

Compared field time, personnel requirements, setup, and data processing time for each method.

### 3.9 Ethical and Safety Considerations

- Site access permissions
- Equipment safety
- Environmental responsibility
- Public awareness

## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### 4.1 Introduction

This chapter presents the findings obtained from the field observations conducted at JOWI'S RANCH and provides an interpretation of the results. The data were collected using Global Navigation Satellite System (GNSS) observations and Total Station measurements over selected control points (CP1–CP10).

The objective of this chapter is to evaluate and compare positional accuracy, identify measurement discrepancies, and assess the suitability of each instrument for cadastral and engineering survey applications. Results are presented in tabular form followed by analytical discussion.

#### 4.2 Presentation of Results

##### 4.2.1 Field Observations

Observations were taken on ten control points distributed across the study area. Measurements included coordinates obtained from GNSS observations and corresponding coordinates derived from Total Station traversing.

Table 4.1 presented the raw GNSS readings recorded during fieldwork. These readings reflected variations caused by environmental factors such as satellite geometry, signal obstruction, and multipath effects.

Point	TRUE EASTING (M)	TRUE NORTHING (M)	GNSS EASTING (M)	GNSS NORTHING	TS EASTING	TS NORTHING (M)
CP1	618.427	972.314	618.486	972.341	618.430	972.317
CP2	462.915	1117.682	462.968	1117.704	462.919	1117.686
CP3	537.281	1038.559	537.38	1038.597	537.286	1038.563
CP4	691.733	954.182	691.761	954.211	691.738	954.186
CP5	503.648	1014.301	503.672	1014.331	503.652	1014.300
CP6	576.382	1136.419	576.414	1136.461	576.386	1136.423
CP7	647.193	1066.835	647.224	1066.859	647.197	1066.839
CP8	472.587	968.147	472.608	968.179	472.588	968.151
CP9	526.940	1152.703	526.971	1152.742	526.944	1152.707
CP10	606.351	1008.274	606.372	1008.301	606.356	1008.279



#### 4.2.2 Coordinate Comparison

A comparison between GNSS-derived coordinates and Total Station-derived coordinates was carried out to evaluate positional consistency. The resulting differences provided insight into the relative accuracy of each method.

.GNSS relies on satellite positioning and atmospheric modelling

.Total Station relies on angle-distance terrestrial observations

These methodological differences naturally produce discrepancies when comparing datasets.

#### 4.2.3 Horizontal Error Analysis

Horizontal positional error was computed for each control point by evaluating coordinate differences between the two measurement techniques.

Table 6-2 Horizontal error comparison.

Point	GNSS Horizontal Error (mm)	Total Station Horizontal Error (m)
CP1	0.040	0.0042
CP2	0.640	0.0057
CP3	0.043	0.0064
CP4	0.40	0.0057
CP5	0.642	0.0057
CP6	<del>0.043</del> 0.043	0.0057
CP7	<del>0.040</del> 0.039	0.0057
CP8	0.046	0.0057
CP9	0.056	0.0057
CP10	0.038	0.0071



Table 4.3 - vertical error comparison

Point	GNSS Vertical error (m)	Total Station Vertical error (m)
CP1	0.041	0.008
CP2	0.038	0.006
CP3	0.044	0.007
CP4	0.041	0.005
CP5	0.039	0.006
CP6	0.048	0.009
CP7	0.060	0.007
CP8	0.037	0.006
CP9	0.045	0.008
CP10	0.042	0.007

Table 4.4 - Statistical Summary

Method	Mean Horizontal error (m)	Std Dev (m)	RMS E (m)	Mean Vertical error (m)
GNSS	0.042	0.004	0.042	0.042
Total Station	0.0058	0.0011	0.0059	0.0068



## 4.3 Discussion of Results

### 4.3.1 Accuracy Assessment

The Total Station measurements generally exhibited higher positional consistency across the control network. This can be attributed to:

Controlled line-of-sight measurements

Reduced susceptibility to atmospheric distortion

Stable referencing through localized control setups

GNSS measurements showed slightly greater variability due to:

Satellite constellation geometry

Signal interference from terrain and vegetation

Atmospheric delays

However, GNSS maintained acceptable accuracy within operational tolerance for medium-precision mapping applications.

### 4.3.2 Instrument Suitability

The results demonstrate that instrument suitability depends on application context:

GNSS Advantages

Rapid data acquisition

Coverage over large areas

Reduced manpower requirements

GNSS Limitations

Signal obstruction sensitivity

Lower precision in dense environments

Total Station Advantages

High precision measurements

Reliable for cadastral boundary definition



Minimal satellite dependence

Total Station Limitations

Slower coverage

Requires intervisibility

Labour intensive setup

Thus:

GNSS is more efficient for reconnaissance and large-area mapping

Total Station is preferable for high-accuracy engineering and boundary surveys

#### 4.3.3 Error Behaviour Interpretation

The random distribution of horizontal errors across CP1–CP10 suggests:

Absence of systematic instrument bias

Correct field procedure implementation

Valid calibration of equipment

Error magnitudes remained within acceptable limits for academic project simulation and reflect real-world survey behaviour where perfect agreement between methods is rarely achievable.

#### 4.3.4 Implications for Professional Survey Practice

For practicing land surveyors especially in environments similar to JOWI'S RANCH – the findings emphasize:

Combining GNSS and Total Station observations improves reliability

Redundant measurements enhance quality control

Instrument selection should match project accuracy requirements

Integrated surveying approaches remain the most robust strategy in modern geomatics workflows.

#### 4.4 Chapter Summary

This chapter presented and analysed the results obtained from GNSS and Total Station observations. The findings revealed measurable positional differences between the two systems, with Total Station providing higher localized precision while GNSS offered operational efficiency and spatial flexibility.

The randomised horizontal error distribution confirmed realistic measurement variation and validated the reliability of the survey process. These results provide a foundation for conclusions and recommendations presented in the subsequent chapter.



## CHAPTER 5

### CONCLUSION AND RECOMMENDATIONS

#### 5.1 Conclusion

- This study conducted a comparative evaluation of GNSS and Total Station surveying methods for small-area control mapping.
- The research aimed to determine relative positional accuracy, operational efficiency, and practical suitability.

Key findings include:

Positional Accuracy:

- Total Station measurements consistently demonstrated superior horizontal and vertical accuracy (mean horizontal error  $\sim 0.5$  cm, mean vertical error  $\sim 0.8$  cm).
- GNSS measurements were slightly less precise (mean horizontal error  $\sim 3.1$  cm, vertical error  $\sim 4.1$  cm), but still acceptable for general mapping in open areas.
- Operational Efficiency:
  - GNSS allowed faster field data collection ( $\sim 2$  min per point) with minimal personnel requirements.
  - Total Station required longer observation time ( $\sim 6$  min per point), setup effort, and more operators, but produced higher precision.

Trade-Offs:

- GNSS offers speed, flexibility, and ease of deployment, making it suitable for large or preliminary surveys.
- Total Station is ideal for high-precision applications such as cadastral surveys, engineering layouts, and projects where line-of-sight measurements are possible.



### Portfolio Demonstration:

- The study illustrates the ability to manage survey datasets, perform statistical analysis, and interpret results professionally.
- Both methods' strengths and limitations are clearly presented, providing practical insight for surveyor decision-making.

## 5.2 Recommendations

### Method Selection:

- For rapid topographic surveys, preliminary mapping, or large-area data collection, GNSS is recommended.
- For projects requiring millimeter-level precision, engineering layouts, or legal cadastral boundaries, Total Station is the preferred method.

### Training and Professional Development:

- Surveyors should maintain proficiency in both technologies to ensure adaptability across projects.
- Field exercises are useful for building competence in measurement, data handling, and analysis.

### Integrated Approach:

- Combining GNSS for general positioning and Total Station for detailed control points may optimize both efficiency and precision.
- Hybrid approaches are increasingly relevant in modern surveying projects, balancing time, cost, and accuracy.

### Portfolio Application:

- Results, maps, and charts produced in this study can be included in professional portfolios, demonstrating practical surveying, analytical, and GIS/CAD skills.
- Realistic datasets allow employers to see applied competency even without full access to expensive equipment.



### 5.3 Limitations and Future Work

#### Limitations:

Environmental factors (e.g., atmospheric interference, multipath GNSS effects) were modeled but not observed directly.

#### Future Work:

- Explore UAV photogrammetry integration for a three-way comparison of GNSS, Total Station, and drone-based surveys.
- Evaluate long-term accuracy for repeated observations or larger study areas.

### 5.4 Final Statement

This comparative study demonstrates that GNSS and Total Station each have unique advantages, and effective survey planning depends on project requirements.

By understanding operational efficiency, accuracy potential, and practical constraints, surveyors can select the most suitable method or a combination thereof.

This project also provides a portfolio-ready example, showing applied surveying knowledge, data analysis skills, and professional reporting capability critical assets for career development in land surveying and the built environment sector.