

**EVALUATING POSITIONAL PRECISION OF ADAMA CITY GCP AND LAND  
PARCELS: CASE OF ADAMA CITY, OROMIA, ETHIOPIA**



**Solomon Tolosa Bekele**

**Thesis Submitted to the Department of Architecture  
College of Civil Engineering and Architecture (CoCEA),**

Office of Graduate Studies  
Adama Science and Technology University

June, 2025  
Adama, Ethiopia

**EVALUATING POSITIONAL PRECISION OF ADAMA CITY GCP AND LAND  
PARCELS: CASE OF ADAMA CITY, OROMIA, ETHIOPIA**

**Solomon Tolosa Bekele**

**Advisor:**

**Roba Gemechu (PhD)**

**Thesis Submitted to the Department of Architecture  
College of Civil Engineering and Architecture (CoCEA)**

Office of Graduate Studies  
Adama Science and Technology University

June, 2025  
Adama, Ethiopia

## DECLARATION

I hereby declare that this research thesis entitled “**Evaluating Positional Precision of Adama city GCP and Land parcels: Case of Adama city, Oromia, Ethiopia**” is my original work. It has not been submitted to any other university for a similar purpose. All materials used for this thesis have been duly acknowledged through citation.

Solomon Tolosa

\_\_\_\_\_

\_\_\_\_\_

Name of student

Signature

Date

## **ACKNOWLEDGMENT**

First and foremost, I would like to express my deepest gratitude to the Almighty God for granting me the strength, wisdom, and perseverance to accomplish this research work.

I am sincerely thankful to my advisor, Dr. Roba Gemechu, for his expert guidance, continuous support, and constructive feedback throughout the course of this study. His insights have been essential in shaping the direction and depth of this thesis.

My appreciation also goes to the academic and administrative staff of the Department of Architecture, College of Civil Engineering and Architecture (CoCEA), at Adama Science and Technology University, for their support and for providing a solid academic foundation during my postgraduate studies.

I am also deeply grateful to my family and friends for their unconditional love, patience, and belief in me. Their continuous encouragement kept me grounded and focused during this academic endeavor.

Lastly, I thank all my fellow graduate students and colleagues for their helpful discussions and companionship throughout this experience.

### RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read this thesis entitled “**Evaluating Positional Precision of Adama city GCP and Land parcels: Case of Adama city, Oromia, Ethiopia**” prepared under my guidance by Solomon Tolosa. Therefore, I recommend the submission to the department following the applicable procedures.

Roba Gemechu (PhD)

\_\_\_\_\_

\_\_\_\_\_

Name of Major Advisor

Signature

Date

**APPROVAL PAGE OF THE THESIS**

I, the advisor of the thesis entitled “**Evaluating Positional Precision of Adama city GCP and Land parcels: Case of Adama city, Oromia, Ethiopia**” and developed by Solomon Tolosa hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

---

Major Advisor	Signature	Date
---------------	-----------	------

We, the undersigned, members of the Board of Reviewers of the thesis by Solomon Tolosa have read and evaluated the thesis entitled “**Evaluating Positional Precision of Adama city GCP and Land parcels: Case of Adama city, Oromia, Ethiopia**” and reviewed the candidate during open defense. This is, therefore, to certify that the thesis is accepted.

---

Chairperson	Signature	Date
-------------	-----------	------

---

Internal Examiner	Signature	Date
-------------------	-----------	------

---

External Examiner	Signature	Date
-------------------	-----------	------

Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and College Graduate Committee (CGC).

---

Department Head	Signature	Date
-----------------	-----------	------

---

College Dean	Signature	Date
--------------	-----------	------

---

Office of Postgraduate Studies, Dean	Signature	Date
--------------------------------------	-----------	------

## Table of Contents

ACKNOWLEDGMENT.....	iii
APPROVAL PAGE OF THE THESIS.....	v
List of Tables.....	ix
List of Figures.....	x
List of Acronyms/Abbreviations.....	xi
ABSTRACT.....	xii
CHAPTER ONE.....	1
1. INTRODUCTION .....	1
1.1. Background of the study .....	1
1.2. Statement of the problem .....	2
1.3. Objective of the study .....	3
1.3.1. General Objective .....	3
1.3.2. Specific Objectives .....	4
1.4. Research Questions.....	4
1.5. Significance of the study.....	4
1.6. Scope of the study.....	5
CHAPTER TWO .....	6
2. LITERATURE REVIEW .....	6
2.1. Cadastral systems.....	6
2.2. Accuracy assessment of cadastral information .....	7
2.3. Spatial reference system of cadaster .....	9
2.4. Positional accuracy assessment of DGPS .....	10
2.5. Orthophoto Accuracy .....	11
2.6. Conceptual Modeling.....	15

2.6.1.	Creating Conceptual Models: .....	15
2.7.	The American Society for Photogrammetry and Remote Sensing (ASPRS) .....	17
2.8.	Accuracy and Precision.....	18
2.9.	Empirical Literature Review.....	18
2.10.	Research gaps.....	19
CHAPTER THREE .....		21
3.	MATERIALS AND METHODS .....	21
3.1.	Description of the study area .....	21
3.2.	Description of designed Methodology.....	21
3.3.	Data source and software used.....	22
3.4.	Research work flow .....	23
3.5.	Sampling techniques .....	24
CHAPTER FOUR.....		26
4.	RESULTS AND DISCUSSIONS .....	26
4.1.	Identifying the determinant indicators for evaluating the precision of GCP and land parcels 26	
4.1.1.	Surveying Equipment and Technology .....	26
4.1.2.	Data Processing and Correction.....	27
4.1.3.	Human Factors .....	27
4.1.4.	Environmental Factors .....	28
4.1.5.	Cadastral System Design and Methodology .....	28
4.1.6.	Satellite and Aerial Imagery.....	29
4.1.7.	Government and Institutional Factors.....	30
4.1.8.	Evaluating the level of positional precision of the existing GCP networks in Adama city as per the standard of ASPRS.....	31

4.1.9.	Computation of Least Square adjustment of Adama city 2nd and 3rd orders GCP's	37
4.1.10.	Standard deviation computation for precision measurement of Adama city 2nd and 3rd orders GCP's .....	39
4.1.11.	RMSE based precision measurements of Adama city 2nd and 3rd orders GCP's	41
4.2.	Evaluating the Geometric precision of land parcel data digitized from orthophoto compared with the GNSS ground truth.....	42
4.2.1.	Topological consistency of land parcel data extracted from Ortho-imagery for evaluating the Geometric precision of land parcel data.....	44
4.2.2.	Evaluating the Geometric precision of land parcel data digitized from orthophoto compared with the GNSS ground truth using RMSE .....	47
4.3.	Modeling Framework for Continuous Quality of Cadastral precision controlling.....	47
CHAPTER FIVE .....		51
5.	CONCLUSION AND RECOMMENDATION .....	51
5.1.	Conclusion .....	51
5.2.	Recommendations.....	52
REFERENCES .....		54

## **List of Tables**

Table 3-1: Data source and type.....	22
Table 3-2: Software.....	23
Table 4-1: Sample coordinates of 2nd order GCP network in Adama.....	33
Table 4-2: Sample coordinates of 3rd order GCP network in Adama.....	34
Table 4-3: 3rd order GCP accuracy checking .....	42
Table 4-4: 2nd order GCP accuracy checking.....	42

## List of Figures

Figure 3-1: Location map of the study area .....	21
Figure 3-2: Research work flow .....	24
Figure 4-1: Sample Adama city GPS 2nd GCP coordinates .....	33
Figure 4-2: Sample Adama city GPS 3rd GCP coordinates.....	35
Figure 3-5: Adama city cadastral data .....	35
Figure 4-4: Adama city sample land parcels.....	36
Figure 4-5: Adama city sample land parcels attribute .....	37
Figure 4-6: Least square adjustment for GCP network for Northing in Adama city .....	38
Figure 4-7: Least square adjustment for GCP network for easting in Adama city .....	39
Figure 4-8:Least square adjustment for 3rd GCP network for easting in Adama city .....	39
Figure 4-9: least square adjustment for 3rd GCP network for northing in Adama city .....	39
Figure 4-10: Adama land parcels Topological errors.....	46
Figure 4-11: Adama land parcels Topological corrections .....	46

### **List of Acronyms/Abbreviations**

ASPRS	American society of Photogrammetry and remote sensing
CEP	Circular Error Probable
CORS	Continuously Operating Reference Stations
CSV	Comma-Separated Values
DGPS	Differential Global positioning system
FGDC	Federal Geographic Data Committee
GCP	Ground Control Point
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
MEA	Mean Error of Accuracy
NSSDA	National Standard for Spatial Data Accuracy
RMSE	Root Mean Square Error
RMSE <sub>x</sub>	Root Mean Square Error in X-direction
RMSE <sub>y</sub>	Root Mean Square Error in Y-direction
RMSE <sub>z</sub>	Root Mean Square Error in Z-direction
RS	Remote sensing
RTK	Real Time Kinematic
SRS	Spatial Reference System
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984

## ABSTRACT

*Accurate cadastral information is fundamental for effective land administration, urban planning, and the protection of land tenure. In rapidly growing urban centers like Adama City, Ethiopia, discrepancies between existing digitized cadastral data and actual ground positions have emerged as a major challenge for sustainable development. This study aims to assess the positional accuracy of cadastral land parcel boundaries by comparing existing digital records with high-precision ground-truth data collected using Global Navigation Satellite System (GNSS) technology. A GIS-based least squares adjustment and Root Mean Square Error (RMSE) analysis were applied to evaluate spatial discrepancies between recorded parcel boundaries and actual ground positions. The findings revealed that zero-order GCPs achieved an average RMSE of 0.002 meters, and first-order GCPs recorded an RMSE of 0.003 meters, both satisfying the American Society for Photogrammetry and Remote Sensing (ASPRS) standard for horizontal accuracy ( $\leq 0.0075$  meters). However, second-order GCPs displayed RMSE values averaging 0.010 meters, and third-order GCPs reached 0.015 meters—both exceeding the ASPRS threshold. These results highlight that while the higher-order GCPs meet required standards, significant spatial inaccuracies exist in areas based on second- and third-order control points. The study identifies several potential sources of error, including outdated surveying techniques, improper georeferencing, and lack of periodic updates to the cadastral database. These inaccuracies compromise the integrity of cadastral records, leading to potential disputes over land ownership, inefficient planning, and challenges in land tenure enforcement. In conclusion, there is an urgent need for systematic updates to the cadastral system in Adama City. This includes re-surveying areas with low-order GCPs using modern GNSS technology, aligning cadastral datasets with current geospatial standards, and implementing a continuous validation and maintenance framework. Enhancing the positional accuracy of cadastral records will not only improve land administration but also support better governance, urban development, and tenure security in the city.*

**Keywords:** Positional Accuracy, Cadastral Data, Geospatial Analysis, Land Administration

## CHAPTER ONE

### 1. INTRODUCTION

#### 1.1. Background of the study

In an urban area land is one of the natural resources that provide the physical location for shelter, farming, commerce, industry and other public services for humankind in urban areas. Thus, wise utilization of this vital resource is very important through some systematic handling and managing techniques. In order to utilize this vital resource effectively, developing technological based modern cadastral information system is an important approach. The fuel driving the engine of growth and sustainable development of any nation can be measured with the access of reliable and sufficient land information (Babalola and Kardam, 2011). Within this perspective of the dynamic humankind to land relationships need the progress in the cadastral information system (Daniel, 2014). The Cadastral information system provides security and clarity with respect to the status of land parcel and it plays an important role in order to develop and supply new services such as spatial-based parcel information systems.

Cadaster is normally a parcel based, and up-to-date land information system containing a record of interests in land (e.g. rights, restrictions and responsibilities). It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, the ownership or control of those interests, and often the value of the parcel and its improvements. Cadastral output, on the other hand, showing the boundaries of the subdivisions of land for purposes of describing and recording ownership of the property. Basic cadastral data sources are high resolution satellite image, aerial photography and ground surveying. Data acquired from these techniques pass through rectification, feature extraction, attribution, maintaining topological integrity, cartographic processing, etc.

Before discussing the process for updating cadastral maps, it is worth briefly explaining the nature of cadastral data, and specifically for cadasters with fixed boundaries that are updated regularly from geometric boundary surveys (Lemmens, 2011). There is sufficient spatial detail to unambiguously identify parcels and if needed re-instate boundaries in the future. Historically, survey plans were paper based, but are now scanned and accessible as imaged documents. Its purpose is for land administration to spatially describe land ownership, tenure, fiscal value and

land use information (Arctur, 2004). The accuracy of cadastral data was initially equivalent to the standards, but has improved over time. The ground Control points connections on survey plans are established in the city as more substantial permanent marks that are coordinated by Global Navigation Satellite System (GNSS) The cadastral information system in most African countries is in the inception stage. While the sophisticated economies of the 21st century need the services of a modern cadaster to effectively deliver the objectives of sustainable development.

Currently in Adama city modernizing the cadastral information system of the city becomes a serious agenda to the land administrators. The cadastral issues associated with the development of the modern cadastral system were not established based on recent technologies. Due to this data collection, data organizing, measuring, updating, storing, securing and visualizing of the system is not effective. Therefore, an accelerating cadastral data accuracy for the city in the near future is a must. Since the acceleration of cadastral data needs technological solution, the integration of GPS, satellite image, orthophoto and GIS could be the appropriate approaches. In this study, the ideas of advancing cadastral data accuracy discuss the integration of the standardized quality assessment factors and Geospatial techniques. This idea fills the gap of past reviews which were not discussed the detail integration of the standardized quality assessment factors and Geospatial techniques such as Photogrammetry, Remote sensing, GIS, and GPS in improving the system. As reviewed in the literature till now there has not been adequate studied to identify appropriate approaches which support meaningful cadastral data accuracy of the city.

## **1.2.Statement of the problem**

Improving the accuracy of cadastral mapping is imperative, as it is a foundation layer for national spatial data infrastructures. A strategic approach to achieve this is to systematically improve spatial accuracy levels over time (Grant, D. et al, 2021). An accuracy level that reconciles boundary coordinates with survey plans is termed survey-aligned. If it achieves a higher accuracy where boundary coordinates have legal status, this is a survey-compliant digital cadaster. The next level is a legal coordinate cadaster, where—in the absence of contradictory evidence coordinates may be used to re-instate legal boundaries. Countries that have implemented this, such as Austria (Liseč, and Navratil, 2014), are small in land mass and have a high density of GNSS control points to support a legal coordinate cadaster.

Accurate cadastral system is fundamental for effective land administration, urban development, and property rights protection. In Adama City, Oromia, Ethiopia, the precision of spatial data—particularly Ground Control Points (GCPs) and cadastral land parcel boundaries—is critical for supporting these functions. However, concerns have emerged regarding the positional accuracy of both GCPs and cadastral parcel data, which can have serious implications for land registration, urban planning, property valuation, and conflict resolution.

In many cases, the spatial framework used to create cadastral maps in Adama City was established without consistent geodetic control or was based on outdated or improperly maintained GCPs. These inaccuracies can lead to misalignments between ground reality and mapped data, resulting in overlapping parcels, boundary disputes, and a lack of confidence in the cadastral system by both landholders and institutions. Furthermore, there is limited documentation or assessment of the current precision of GCPs in relation to cadastral boundaries, and no comprehensive study has been conducted to evaluate their spatial integrity. Without such evaluation, the city faces challenges in upgrading to modern land information systems, integrating new geospatial technologies, or ensuring that existing cadastral data meets national or international accuracy standards.

This study, therefore, seeks to evaluate the positional precision of Adama City's Ground Control Points and cadastral land parcels. Identifying the magnitude and sources of spatial discrepancies is essential to improve cadastral data quality, support effective land governance, and foster sustainable urban development. The study, which is not done previously, evaluates the challenges of existing cadastral data accuracy and proposing the techniques of cadastral data accuracy improvement system based on the integration of geospatial technologies and standardized approaches.

### **1.3.Objective of the study**

#### **1.3.1. General Objective**

The main Objective of this thesis is to Evaluate Positional Precision of Adama City GCP and Land Parcels with the Integration of Geospatial Data and the Standardized Precision Assessment Factors

### **1.3.2. Specific Objectives**

- Identify the determinant indicators for evaluating the precision of cadastral land parcels
- Evaluate the level of positional precision of the existing GCP networks in Adama city as per the standard of ASPRS using standard deviation and RMSE.
- Evaluate the Geometric precision of cadastral land parcel data extracted from orthophoto compared with the ground truth as per the standard of ASPRS using RMSE
- To Develop a Framework for Continuous Quality Monitoring of Cadastral data of Adama city

### **1.4. Research Questions**

- What are the key determinant indicators for evaluating the precision of cadastral land parcels?
- What is the level of positional precision of the existing Ground Control Point (GCP) networks in Adama city, based on ASPRS standards using standard deviation and RMSE?
- How precise is the geometric accuracy of cadastral land parcel data extracted from orthophotos compared to ground truth data, as per ASPRS standards using RMSE?
- How can a framework be developed for continuous quality monitoring of cadastral data in Adama city?

### **1.5. Significance of the study**

Accurate cadastral data is essential for effective land administration, urban planning, property taxation, and dispute resolution. In Adama City, located in the Oromia region of Ethiopia, the rapid pace of urbanization and land development has increased the demand for precise and reliable cadastral information. However, inconsistencies and positional inaccuracies in cadastral land parcel data have been reported, leading to disputes over property boundaries, difficulties in land registration, and inefficient land management.

The existing cadastral mapping systems in Adama City were developed using various surveying techniques over time, often lacking standardization and geodetic control. As a result, positional discrepancies between actual land boundaries on the ground and their representations on cadastral maps are common. These discrepancies can undermine public trust in the cadastral system and create administrative and legal challenges.

### **1.6.Scope of the study**

The study looks closely at Adama City's current system and evaluates the system in terms of technical, technological and legal ways in which data of the cadaster collected using Orthophoto and GNSS and the registered in the database. The main objective is to offer insightful evaluation, suggestions, and contributions that improves cadastral data information system. Specifically, the research covers identifying of determinant indicators for evaluating the precision of land parcels, evaluating the level of positional precision of the existing GCP and land parcels in Adama city as per the standard of ASPRA and finally developing a framework for continuous Monitoring of Cadastral land parcels data of Adama city

## CHAPTER TWO

### 2. LITERATURE REVIEW

#### 2.1.Cadastral systems

Cadastral systems serve as fundamental tools for land administration, providing essential information on land rights, boundaries, and land use. The literature on cadastral systems underscores their critical role in supporting property rights, land management, and socio-economic development. According to Williamson and Enemark (2018), cadastral systems are integral components of land administration frameworks, facilitating secure land tenure, property transactions, and land-use planning. Their research emphasizes the importance of cadastral systems in ensuring land tenure security and fostering investment in land-related activities.

In a study by Bennett et al. (2017), the evolution of cadastral systems is explored, highlighting the transition from traditional paper-based systems to modern digital cadastral databases. The authors discuss the benefits of digital cadastral systems in terms of data accuracy, accessibility, and efficiency in land administration processes. Furthermore, the work of van Oosterom and Lemmen (2019) delves into the technical aspects of cadastral systems, focusing on spatial data infrastructures, cadastral mapping, and land registration processes. Their research underscores the significance of integrating cadastral data with geospatial technologies to enhance land administration practices and support sustainable land management.

In the context of developing countries, De Soto (2016) provides insights into the role of cadastral systems in promoting economic development and poverty reduction. His research emphasizes the link between formalized land rights, cadastral systems, and economic growth, highlighting the potential of cadastral reforms to unlock the value of land assets for marginalized populations.

Cadaster, cadastral information systems, and land registries play vital roles in land administration and property management, providing essential frameworks for maintaining land records, defining property rights, and facilitating land transactions. The literature on cadaster, cadastral information systems, and land registries illuminates their significance in ensuring secure land tenure, supporting sustainable land governance, and facilitating economic development.

Kaufmann and Steudler (2016) define cadaster as a comprehensive public register that records legal, spatial, and ownership information about land parcels within a jurisdiction. Cadastres serve

as fundamental tools for land administration, enabling governments to establish property boundaries, allocate land rights, and levy property taxes effectively. The authors emphasize the importance of cadastral systems in promoting land tenure security and facilitating land use planning.

In their study, Williamson and Rajabifard (2018) delve into cadastral information systems (CIS) as digital platforms that integrate cadastral data, geospatial information, and land administration processes. CIS enable the management, analysis, and dissemination of cadastral information for decision-making in land governance, property valuation, and urban planning. The authors highlight the role of CIS in enhancing data interoperability, spatial analysis capabilities, and stakeholder collaboration in land administration.

Regarding land registries, van der Molen and Zevenbergen (2019) characterize them as official repositories that document land ownership, property transactions, and encumbrances on real estate assets. Land registries provide legal certainty, transparency, and public access to land-related information, facilitating property rights registration, title transfers, and mortgage transactions. The authors underscore the importance of land registries in safeguarding property rights, reducing transaction costs, and promoting investment in real estate markets.

Furthermore, Enemark et al. (2017) explore the synergies between cadastre, cadastral information systems, and land registries in supporting sustainable land governance and land administration practices. They advocate for the integration of cadastral data, spatial information, and legal frameworks within a unified land information infrastructure to enhance transparency, efficiency, and accountability in land management. The authors emphasize the role of integrated land information systems in promoting land tenure security, equitable access to land resources, and effective land use planning.

## **2.2. Accuracy assessment of cadastral information**

The spatial information related to the ground truth requires the analysis of accuracy assessment. Accuracy assessment is very important for understanding the obtained results and making good decisions and it is required to minimize the common errors in geospatial data. All measurements contain errors and the treatment of these errors is included in this discussion. In the treatment of errors, there is a recognized distinction between the term accuracy and precision. Precision

measures the degree of consistency between measurements and quantifies the size of the discrepancies. Accuracy is the absolute nearness of a measurement of the true value of a quantity.

As reported by Ghilani and Wolf (2006)

- No measurement is exact;
- Every measurement contains errors;
- The true value of a measurement is never known; and
- The exact sizes of the errors present are always unknown (Ghilani and Wolf, 2006).

There are different organizations that set accuracy standards for the positional accuracy. These organizations are like the American Society of Photogrammetric, Remote Sensing, and National Standard for Spatial Data Accuracy (ASPRS), National Map Accuracy Standard, and United State of Geological Survey etc. The new ASPRS Positional Accuracy Standards for Digital Geospatial Data include for digital geospatial data, whereas the National Standard for Spatial Data Accuracy (NSSDA), published in 1998, did not provide accuracy thresholds. The ASPRS 1990 standard provided accuracy thresholds for hard copy maps only, as did the National Map Accuracy Standard (NMAS) of 1947; for these reasons, the new ASPRS standards have long been in demand to establish accuracy thresholds for digital geospatial data new horizontal accuracy classes based on Root Mean Square Errors of horizontal Coordinates (RMSE<sub>x</sub>), and Root Mean Square Errors of horizontal Coordinates (RMSE<sub>y</sub>) (ASPRS, 2014). The NSSDA uses root-mean-square error (RMSE) to estimate positional accuracy. RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identifying points. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates (FGDC, 1998).

An error matrix or a confusion matrix is the most common approach for determining the accuracy of classified remote sensing image (Liu and Zhou, 2004). The single data classification error matrix assesses errors to detect errors in pixel-based and object-based accuracy (Congalton, and Green, 2008). The commonly used accuracy assessment elements include overall accuracy assessment (Lu et al., 2004). When pixels are considered the basic study units, it is reasonable to use the pixel-

level truth data to evaluate the change results. However, Biginget al. (1999) argued that pixel-based accuracy assessments tend to underestimate object-based accuracy.

### **2.3.Spatial reference system of cadaster**

Coordinate reference system or spatial reference systems mainly include ellipsoidal surface, datum surface, coordinate system, map projection, UTM zoning and height system. A spatial reference system is a coordinate-based local, regional and global system which is used to locate geographical entities. A clear understanding of the different projection systems, coordinate systems and datum in use today is essential to ensure rigorous consideration of reference frame variations with a view to produce a high-quality positioning cadastral location (Janssen, 2009). In practice, a coordinate system alone cannot determine the location of a point; the system has to be used in conjunction with a predetermined datum to form a coordinate reference system (Shengkaiand, 2012). Reference ellipsoid is a mathematically defined surface that approximates the true figure of the earth. An ellipsoidal model describes only the ellipsoid geometry and a normal gravity field formula to go with it. Commonly an ellipsoidal model is part of a more encompassing geodetic datum.

To study the spatial reference system of the Adama city (Ethiopia), understanding the global spatial reference system is important. In spatial reference system ellipsoid is the only model that approximates the shape and size of the earth in our world. Survey observations can be reduced to one of the three geodetic reference surfaces; the earth's surface, geoid and the ellipsoid. The earth's surface is the topographic surface of the earth. It is extremely irregular and not mathematically defined (Mohammed and Abbas, 2013). A Geodetic datum is another spatial reference parameter used to locate places on the Earth. A datum defines the position of the ellipsoid relative to the reference coordinate of axes and the origin.

The datum of Adama city effectively defines the origin and orientation of the coordinate system of the city at a certain instant in time, generally by adopting a set of station coordinates. Over time, different techniques with varying levels of sophistication have been applied to define the shape of the earth's surface, resulting in the adoption of many different datum's (Janssen, 2009). A complete coordinate system in the form of (X, Y, Z)) is developed on the surface of defined datum.

A coordinate system is a methodology to define the location of a feature in space. On the ellipsoid, positions are either expressed in Cartesian coordinates (X, Y, Z) or in curvilinear coordinates

geodetic latitude, longitude and ellipsoidal height. It is important to note that a single ground point can have different geodetic coordinates. In coordinate system Z value of the coordinate system is the only way to characterize a level surface uniquely. Any conversion of the Geopotential number to a geometrical height (e.g. Orthometric height, normal height) forms a derivative rather than a definitive part of a vertical reference system (Tulu, 2010). Ellipsoidal heights (h) can be converted into orthometric heights (H) by applying the geoid undulation (N), also known as geoid-ellipsoid separation. Strictly speaking, this equation is an approximation since H and N are measured along the ellipsoid normal, while H is measured along the curved plumb line, i.e. the direction of the gravity vector. The angle between the direction of the gravity vector and the ellipsoid normal at a surface point is known as the deflection of the vertical. Since this angle amounts to only several seconds of arc, its effect on equation can generally be ignored in practice (Featherstone, 2007).

A position on the Earth is can be also determined by the UTM zone numbers and the easting and northing coordinate pair in that zone. The point of origin of each UTM zone is the intersection of the equator and the zone's central meridian.

The spatial reference system parameters interconnected to each other over the world and to the local environment in positioning points. Overview of all the above discussed reviews contributes to this research in observing the detail information of the spatial reference system of the Adama city (Ethiopia).

#### **2.4.Positional accuracy assessment of DGPS**

GNSS for Accuracy Checking The positional exactness of orthophoto talking about to the correctness at which the location coordinates (latitude, longitude and ellipsoidal height) of the spatial entities that are well standard on the orthophoto are expected in reference to their corresponding ground truth coordinates obtained at identical locations using an independent ground based in situ Global Navigation Satellite System (GNSS) observations (Congalton and Green, 2009). Currently, the advancement of satellite centered Global Positioning System (GPS) has enabled to more practical, economic and accurate in 3-D positioning determination in geodesy and surveying works. Besides its accurateness, it has also the advantage of being applicable at local, regional and universal scales (Mohamed et al., 2010). Furthermore, GPS becomes an important instrument for mapping features because it makes to obtain accurate data at low cost relative to traditional surveying systems. The accuracy of digitized features is reliant on on the

correctness of the mapping development with GPS (Heselson, 1998). To sample the spatial accuracy it is better to custom the Global Positioning System (GPS). Similarly, GPS also has a countless advantage to observe and compute accurate checkpoint location coordinate values.

On the other hand, making evaluation of the computed location of the checkpoints with the location of their corresponding image on the digital orthophoto offers the desired spatial accuracy assessment (Greenfeld, 2001). For some GPS applications with high accuracy requirements, for instance geodynamics application and precise relative positioning over hundreds of kilometres, the exactness of the broadcast ephemerides is not adequate. Hence, ephemerides with a metre level accuracy are required. One effective solution is to use post processed ephemerides, which are usually generated with one week observations from a globally distributed tracking network (Shi, 1994). Nowadays, in numerous engineering applications areas the tradition of Global Positioning System (GPS) has been used effectively for surveying activities in multiple disciplines. Furthermore, web-based online services developed by numerous organizations; which are user friendly, unlimited and most of them are free; has become a substantial alternative approach against the high-cost scientific and commercial software on accomplishment of post processing and scrutinizing the GPS data (Ocalan et al., 2013). The average accuracies of the online services are found to be in the range of millimetres to decimetres accuracy subject on some aspects including the observation time. In fact, when observation has taken for longer sessions, the coordinate variation becomes decreases. The precision also varies based on observation type (single or dual frequency). Satellite availability also a significant factor to be considered. Although the practice of Global Navigation Satellite Systems (GNSS) has no significant role in strengthening the accuracy, in urban areas the number of satellite availability is very crucial component for internet based services (Adam, 2017).

### **2.5.Orthophoto Accuracy**

Digital orthophotos can be produced through digital orthorectification process based on interior and exterior orientation elements of air photograph and DEM. Digital orthorectification is a process that employs digital images processing and digital photogrammetric techniques. After digital orthorectification, the central perspective image is transformed into an orthogonal projection. It often implement on softcopy photogrammetry workstation. The softcopy techniques rely on film-based aerial images that are converted to digital form using high accuracy

photogrammetric scanners. These softcopy images are the primary input to the digital differential rectification process. Other inputs include the camera calibration information and measured fiducial coordinate for the determination of the interior orientation; ground control information and measured image coordinates for the determination of the exterior orientation parameters of each image; a corresponding digital elevation model for the determination of the elevation of each elevation of each elemental area to be orthorectified in the image. Production of digital orthophoto map (DOM) involves many production steps, each of which exists errors that are propagated into the final product. If care is taken to limit the magnitude of error of each production procedure, the resulting digital product can constitute a highly accurate geometric reference. At present, although digital photogrammetric system (DPS) can efficiently produce digital orthophotos, its accuracy is doubted by the most users. In order to make digital photogrammetric products accepted widely, it is necessary to analyze the accuracy of them. There exist many factors that affect digital orthophoto accuracy. In this paper, we mainly discuss several important factors as follows: scanning resolution, the accuracy of relative orientation and absolute orientation, the accuracy of the ground control, the accuracy of image matching and the accuracy of DEM used in the orthorectification process.

Because the digital photogrammetric workstation (DPW) relies on scanned aerial photographs for its input data, the accuracy of digital photogrammetric products is contingent on the ability to convert an analogue aerial image into digital image. It is important to select the correct scanning resolution so that the original image quality can be preserved. Scanning high resolution images down to the granularity of the film emulsion would require a pixel sizes less than 1 micrometres. It is neither possible due to limitation of scanner optics nor feasible due to the extremely large digital files. Therefore, there is a need to balance the requirement to preserve original image quality and storage.

Interior orientation is a process that establish relationship between scanning coordinate system and image coordinate system and rectify the probably error existed in digital image. The interior orientations are based on the measurement of the photo fiducials, so measurement accuracy of photo fiducials determines the accuracy of interior orientation. As to the most digital photogrammetric systems, an accuracy report of interior orientation is real time offered.

In order to establish a model similar with real terrain surface, orientation of stereo pairs must be done. Determination of orientation of stereo pairs can be completed in two steps: relative orientation and absolute orientation. The purpose of relative orientation is to determine the relative positional relationship between two images of stereopair. Relative orientation includes three steps. First, search for conjugate points through image matching; second, use conjugate points to compute relative orientation elements ( $b_y, b_z, \phi, \omega, \kappa$ ); third, compute the three-dimension coordinates of the conjugate points. After completing relative orientation, we can do absolute orientation. The aim of absolute orientation is to relate image space to object space. This process can be completed through a transformation of coordinates using ground control points. From above discussion, we know that the accuracy of orientation is determined mainly by accuracy of image matching and accuracy of ground control points.

Image matching is the basis of photogrammetric automation. The basis of image matching is the determination of the location of a point in conjugate image by matching gray-scale values in the two images. To do this, the x-parallax between the conjugate points within the stereo overlap of a photogrammetric model can be determinate. Since the different in parallax magnitude is a function of the height deference. The x-parallax different are used to determine the elevation of points relative to one another. The accuracy of image matching is determined by image quality and the matching techniques employed. Image quality is related to the source image quality and the resolution of scanned image. Good source image quality and high resolution may help for improving accuracy of image matching. At the same time, we must consider storage space. Using high resolution to scan image can increase volume of data and thus need large storage space to store image, and increase labor. If aerial photography has a good quality, image matching can be more precise than stereoscopic measurement in an analytical plotter (Ackermann, 1994). The practical precision of image matching by least squares correlation is in the order of 0.1 to 0.2 pixels. Although image matching has an advantage over conventional manual stereo measurement, the ultimate success of image matching depends largely on the quality of the scanned image and on image texture. Because image matching by correlation is based on matching gray-scale values in corresponding images, matching algorithms can become confounded if the image are lacking in radiometric quality, tonal differences. In addition, image matching can be further impeded by occlusions and height discontinuities caused by obstacles such as tall buildings, bridges or trees.

Ground control points also have effect on planimetric accuracy of digital orthophotos. The role of ground control is to determine the exterior orientation elements of each photograph. The accuracy of ground control points affects that of exterior orientation elements and then affects accuracy of digital orthophotos. The accuracy of the ground control affects the accuracy of the digital orthophoto. Relative accuracy in an orthophoto is directly related to photo scale, but its absolute accuracy depends largely upon the quality of the ground control information used to orient the image to the ground space. Moffitt and Mihail (1980) suggested that, for large scale photogrammetric products, ground control accuracy to at least second order specification is required. In order to assess orthophoto accuracy, the uncertainty of the ground control information must be of a lower magnitude than the measurement noise in the image.

The process of orthorectification differentially transform, on a pixel-by-pixel basis, a central perspective image to a Dajun LI, Jianya GONG, Yunlan GUAN & Chunsen ZHANG 243 orthogonal projection. This approach is a rigorous rectification in that it takes into account directly the ground surface elevation variation by incorporating into the solution a gridded DEM. In order to assess the accuracy of orthophoto, the image coordinates of control points within digital orthophotos produced can be measured and compared to their actual ground surveyed values. Computing the control point coordinate differences between the measured value in the orthophotos and the actual ground surveyed values, and then use root mean squared error to indicate the accuracy of orthophotos.

To examine digital spatial data, the American Society of Photogrammetry and Remote Sensing, ASPRS (2014) are the recommended standards to assess horizontal accurateness of an orthophoto for large scale map. Consequently, are the quality of orthophoto becomes  $\leq 15$  cm, 30 cm and  $\geq 45$  cm used for the purpose of Highest accuracy work use, Standard Mapping and GIS work use and Visualization and less accurate work use respectively. According to Ethiopia context, the accuracy standard of the horizontal position of orthophoto established by the Ethiopia Geo-spatial Information Institute (EGII) is  $\pm 30$  cm at the scale of 1:2,000; which is the endorsed scale for urban areas (Ministry of Urban Development and Housing, 2015). This agrees to two pixels at a Ground Sample Density (GSD) of 15 cm. On the other hand, the accuracy of the vertical position is  $\pm 45$  cm, similarly corresponding to three pixels.

## **2.6. Conceptual Modeling**

Conceptual models serve as abstract, psychological representations of how tasks should be carried out. People often use these models subconsciously and intuitively to systematize processes. Let's delve into the world of conceptual models:

**Definition:** Conceptual models are abstractions that help us understand how things work. They provide a mental framework for interpreting and interacting with systems. For instance, when creating appointments, our mental model might involve calendars and diaries.

**Design Implications:** Designers leverage conceptual models to tailor software that aligns with users' mental models. By echoing these models in interfaces and apps, designers build on existing knowledge, making it easier for users to learn new products.

**Development Process:** Conceptual models are identified early in the design process and serve as a constant reference for direction and inspiration. They guide designers in creating intuitive applications.

### **2.6.1. Creating Conceptual Models:**

**User Research:** Designers gather information from user research (interviews, surveys, observations).

**Visual Representation:** Using this data, they create visual representations of how users perceive and interact with a system. These representations can take various forms, such as flowcharts, diagrams, wireframes, or prototypes.

**Benefits of Conceptual Modeling:**

Conceptual models – What are they and how can you use them?

This 2017 post by Andrew Powell-Morse provides a good introduction to these models. He explores what conceptual models are, how they are most commonly implemented, and touches on a few advantages and disadvantages of using conceptual models in the realm of software development.

Conceptual modelling: Knowledge acquisition and model abstraction

This paper by Kathy Kotiadis and Stewart Robinson looks at the processes involved in arriving at a conceptual model. This paper contributes to this understanding by discussing the artifacts of conceptual modelling and two specific conceptual modelling processes: knowledge acquisition and model abstraction.

#### Choosing the right model: conceptual modeling for simulation

The process of determining what to model is known as conceptual modeling. He acknowledges a balance in getting the right level of detail – make it too complex and it may not be possible to complete the model with the time and knowledge available, make it too simple and the results may not be sufficiently accurate. In this paper we explore conceptual modeling first with an illustrative example from a healthcare setting. Conceptual modeling, its artefacts and requirements are then defined. Finally, a framework for helping a modeler to determine the conceptual model is briefly outlined.

#### Conceptual modeling: framework, principles, and future research

The conceptual modeling stage in a simulation project is very important and yet is still generally regarded as more of an art than a science. In this paper Roger Brooks sets out some of his views on conceptual modeling. The meaning and nature of conceptual modeling are discussed and a framework set out. The overall aim should be to choose the best model for the project and conceptual modeling can be viewed as a difficult optimization problem that can be tackled effectively using a creative search process that develops alternative models and predicts their performance throughout the project. Based on advice from the literature and personal experience principles of conceptual modeling are suggested.

Developing conceptual models is also a key step in developing indicators for sustainable and performance-based management. Another related page in this section provides a number of links outlining how to develop programmed-based outcomes models, also called intervention logic models. A number of pages cover related approaches to problem structuring and framing, especially systems thinking, systemic design and systems thinking tools.

Rights, Restrictions and Responsibilities (RRRs) and Earth Region, this embraces land and marine. The landowner is any individual, organization or group with an interest and rights over a specific

extent of land within a planning scheme in a district, within a region or state in a country (van Oosterom et al., 2006; Aien et al., 2011).

### **2.7.The American Society for Photogrammetry and Remote Sensing (ASPRS)**

The American Society for Photogrammetry and Remote Sensing (ASPRS) has published the second edition of its Positional Accuracy Standards for Digital Geospatial Data, which includes significant changes like eliminating references to 95% confidence levels and relaxing accuracy requirements for ground control and checkpoints.

The objective of the ASPRS Positional Accuracy Standards for Digital Geospatial Data is to replace the existing ASPRS Accuracy Standards for Large-Scale Maps (1990), and the ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data (2004) to better address current technologies.

This standard includes positional accuracy standards for digital ortho imagery, digital planimetric data and digital elevation data. Accuracy classes, based on RMSE values, have been revised and upgraded from the 1990 standard to address the higher accuracies achievable with newer technologies. The standard also includes additional accuracy measures, such as ortho imagery seam lines, aerial triangulation accuracy, lidar relative swath-to-swath accuracy, recommended minimum Nominal Pulse Density (NPD), horizontal accuracy of elevation data, delineation of low confidence areas for vertical data, and the required number and spatial distribution of checkpoints based on project area(ASPRS, 2014).

Accuracy Standards for Digital Geospatial Data include:

- Elimination of references to the 95% confidence level as an accuracy measure.
- Relaxation of the accuracy requirement for ground control and checkpoints.
- Consideration of survey checkpoint accuracy when computing final product accuracy.
- Removal of the pass/fail requirement for Vegetated Vertical Accuracy (VVA) for LIDAR data.
- Increase the minimum number of checkpoints required for product accuracy assessment from twenty (20) to thirty (30).

- Limiting the maximum number of checkpoints for accuracy assessment to 120 for large projects.
- Introduction of a new term, “three-dimensional positional accuracy.”

## **2.8. Accuracy and Precision**

Accuracy refers to how close a measurement is to the true or accepted value, while precision refers to how close repeated measurements are to each other. Accuracy is about correctness, and precision is about consistency. A measurement is considered accurate if it closely matches the actual or known value, and it is considered precise if it is consistent and repeatable across multiple attempts. For example, if you measure the length of an object several times and get nearly the same result each time, your measurements are precise; if those measurements are also close to the true length, then they are both accurate and precise. This concept can be visualized using a dartboard: darts tightly clustered but far from the bullseye represent precision without accuracy; darts scattered but centered around the bullseye represent accuracy without precision; darts tightly grouped around the bullseye represent both. In scientific and practical contexts, achieving both accuracy and precision is essential for obtaining reliable and valid results, as accuracy ensures correctness and precision ensures repeatability.

## **2.9. Empirical Literature Review**

A study by Mulu et al. (2019) evaluated the positional accuracy of Google Earth imagery in Addis Ababa, Ethiopia. The research found that the horizontal Root Mean Square Error (RMSE) of Google Earth imagery was within acceptable limits for producing a class-1 map at a 1:20,000 scale. However, the vertical RMSE was not suitable for class-1 mapping without adjustments. This highlights the need for caution when using Google Earth imagery for precise mapping purposes.

Abili (2021) assessed the vertical accuracy of open-source Digital Elevation Models (DEMs) in Adama City. The study compared ASTER GDEM2, SRTM 30m, and ALOS AW3D30 DEMs using Differential GPS (DGPS) measurements. The results indicated that SRTM 30m DEM had the best vertical accuracy with an RMSE of  $\pm 4.63$  m, followed by ALOS AW3D30 with  $\pm 5.25$  m, and ASTER GDEM2 with  $\pm 11.18$  m. This suggests that SRTM 30m DEM is more reliable for applications requiring vertical accuracy in Adama City.

Eneyew (2018) conducted a study in Wereda 10, Gulelie Sub-City, Addis Ababa, to assess the horizontal accuracy of digital aerial imagery. The research utilized Real-Time Kinematic (RTK)

GPS measurements and digital line maps. The findings revealed that the RMSE for the easting and northing components was 37.6 cm and 38 cm, respectively, when comparing RTK GPS data with aerial imagery. These results underscore the importance of high-precision georeferencing in urban cadastral mapping.

Sisay (2021) evaluated the positional accuracy of orthophotos and line maps for urban land registration in Bahir Dar, Ethiopia. The study employed in-situ GPS data and found that the RMSE for horizontal coordinates ranged from 12.45 cm to 16.71 cm, depending on the processing method. These findings suggest that orthophotos and line maps can achieve high positional accuracy, making them suitable for urban land administration tasks.

Mulugeta (2018) assessed the planimetric accuracy of digital spatial data used for large-scale mapping in Dire Dawa City. The study compared WorldView-1 satellite imagery and orthophotos with RTK GPS measurements. The results indicated that the RMSE for planimetric accuracy was within acceptable limits, demonstrating the reliability of satellite imagery for large-scale mapping applications

## **2.10. Research gaps**

Evaluating the positional accuracy of cadastral data is a critical aspect of ensuring its reliability and usefulness, especially in land management, property rights, and legal matters. While there has been significant progress in understanding and assessing the positional accuracy of cadastral data, several research gaps still exist. These gaps reflect both theoretical and practical challenges in improving and standardizing positional accuracy evaluation. Below are some of the key research gaps in this area:

Cadastral data is often derived from multiple sources, including surveys, remote sensing, GPS, and legal documents, each with different accuracy levels. There is a lack of research on integrated approaches that combine these data sources while maintaining or improving positional accuracy.

Methods for integrating data from diverse sources (e.g., survey data, satellite imagery data) and evaluating their collective positional accuracy. Research could explore techniques like data fusion, multi-source validation, and uncertainty quantification.

Most geospatial accuracy assessments in Ethiopia focus on Addis Ababa or national-level datasets, with little to no studies examining the precision of Ground Control Points (GCPs) specifically in

Adama City. There is a gap in analyzing whether land parcel boundaries accurately align with GCP-based geo-referencing systems, which is critical for cadastral integrity. Existing GCPs in Adama may be outdated or derived from less accurate survey methods. However, no recent study has evaluated their current positional reliability.

Local land administration lacks studies that quantify positional errors (e.g., RMSE, standard deviation) between actual parcel positions and mapped data. Variations in datums and projections across datasets are common, yet no systematic study has examined how these inconsistencies affect land parcel location accuracy in Adama City.

## CHAPTER THREE

### 3. MATERIALS AND METHODS

#### 3.1. Description of the study area

The study area, Adama City (Fig. 3.1), is located approximately 80 kilometers southeast of Addis Ababa, Ethiopia. It lies at geographic coordinates  $8^{\circ}30'52.12''\text{N}$  latitude and  $39^{\circ}16'9.33''\text{E}$  longitude, with a maximum elevation of 1,712 meters above mean sea level. Due to its strategic location approximately 777 kilometers from the Port of Djibouti Adama serves as a key hub for trade and industry, making it one of the country's most economically significant urban centers.

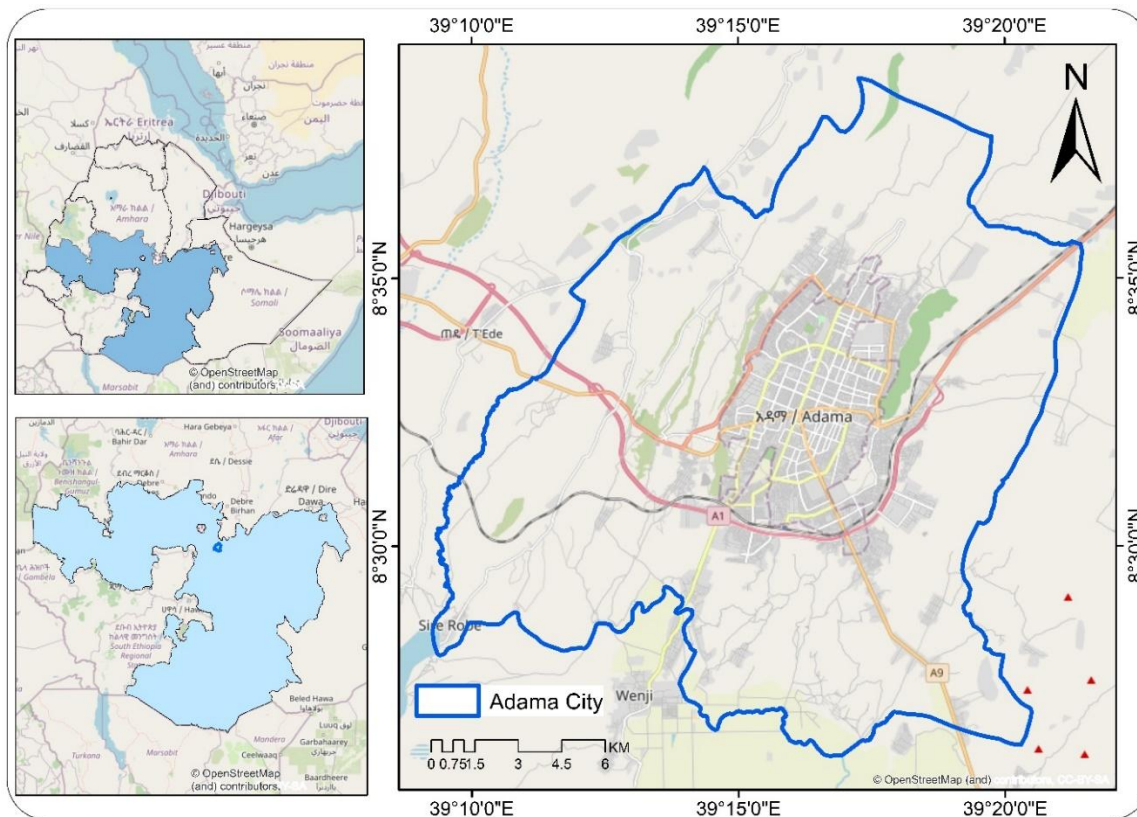


Figure 3-1: Location map of the study area

#### 3.2. Description of designed Methodology

The methodology involved several key steps to improve infrastructure asset management in Adama City. First, a literature review was conducted, focusing on ISO 55000, current studies, and best practices. Data were gathered from the infrastructure geodatabase, maintenance records,

financial reports, and the city's Asset Management Plan. Interviews with stakeholders were also conducted to collect additional insights.

Assessment indicators were developed based on ISO 55000. The collected data were analyzed to identify trends, strengths, and weaknesses. Based on this, recommendations were proposed for improvement.

A requirement analysis was carried out to understand specific infrastructure management needs. A spatial database model was then designed through three stages: conceptual (defining entities and relationships), logical (creating a relational design), and physical (implementing and optimizing the design). Various datasets, including GIS data and maintenance records, were integrated and tested in the database for functionality and performance.

### 3.3.Data source and software used

The study utilized both spatial and non-spatial data collected from primary and secondary sources. Key spatial datasets included a 2013 orthophoto from Adama City, which was used for digitizing land parcels in the land administration process. Operational documents were also obtained from the city’s land administration office to provide comprehensive attribute information for the parcels. Additionally, Differential GPS (DGPS) Ground Control Point (GCP) data were used to verify cadastral GCPs and ensure the accuracy of parcel boundaries. The cadastral land parcel data, sourced from Adama's land administration department, served as a reference layer for checking and validating land information.

*Table 3-1: Data source and type*

Data	Sources	Purpose
Orthophoto 2013	Adama Land administration	Digitizing parcel
Operational Documents	Adama Land administration	For full information attribute
DGPS GCP Data	Adama Land administration	To check cadaster GCP
Cadastral land parcel	Adama Land administration	For checking

Several software tools were employed throughout the study to process, analyze, and validate the data. ArcGIS 10.8 was used for spatial data processing and the preparation of thematic maps. QGIS

plugins facilitated system integration tasks. Google Earth Pro supported data validation by comparing mapped features with satellite imagery. Microsoft Excel was used to perform accuracy computations and data analysis. These tools together enabled comprehensive spatial and non-spatial data handling, ensuring the quality and reliability of the study's outputs.

Table 3-2: Software

Name of software	Purpose
ArcGIS 10.8	Data processing and thematic map preparation
QGIS Plugins	For System Integration
Google Earth Pro	Validation.
Excel	For accuracy computations

### 3.4. Research work flow

The workflow illustrated in (Figure 3-2) outlines a detailed process for assessing and enhancing cadastral information with a focus on Adama city. It begins with the data collection phase, which forms the foundation for all subsequent analyses. In this stage, various datasets such as ground control points (GCPs), land parcel information, and possibly satellite imagery or GIS data are gathered to support the precision analysis and modeling efforts.

Following data collection, the workflow splits into two parallel tracks. The first track involves the conceptual modeling of the cadaster, where theoretical frameworks and data structures for representing land parcel data are developed. This includes designing how spatial data, ownership information, and land-use types are integrated into the cadastral system. After conceptualization, a discussion on the advancement of the cadaster model is conducted, focusing on potential improvements or modernization strategies based on identified needs and technological opportunities. This track culminates in the generation of maps and models that illustrate the positional precision of the cadastral data in Adama city.

The second track concentrates on evaluating the precision of GCPs for Adama city. GCPs are essential for georeferencing spatial data accurately. Once the GCPs are evaluated, attention shifts to assessing the precision of land parcel boundaries in the city. This step ensures that the boundaries captured in the data reflect the actual ground reality with minimal positional error. The outcome

of this evaluation is then subjected to validation, where the created land parcel dataset is tested using established GIS standards—likely involving a comparison against known reference datasets or accuracy benchmarks, possibly within software like ArcGIS.

Ultimately, both tracks feed into the final product: maps and a cadastral model showing the positional precision of Adama city's land parcels. This output provides stakeholders with a clear visualization of the current accuracy of cadastral data and offers a basis for decisions on land administration, urban planning, and legal documentation. The workflow emphasizes both conceptual development and empirical validation to ensure a reliable and modern cadastral system.

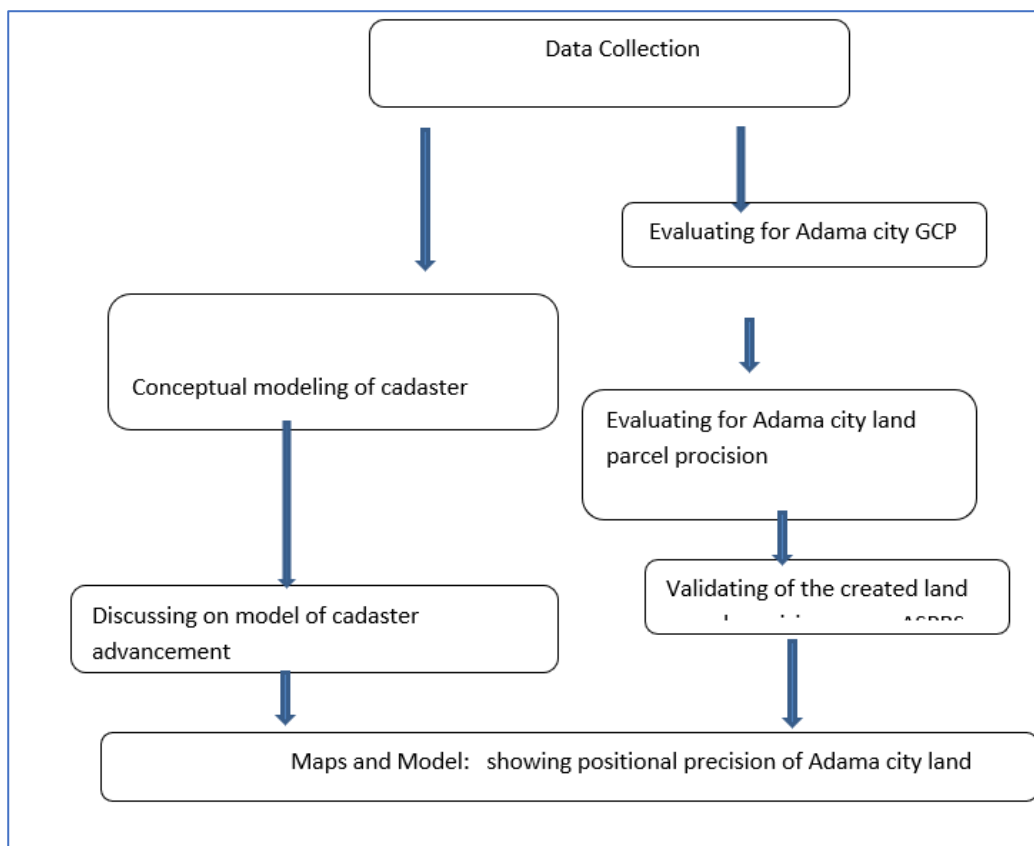


Figure 3-2: Research work flow

### 3.5. Sampling techniques

In this research, purposive sampling was used as the primary sampling technique for selecting Ground Control Points (GCPs). Purposive sampling, also known as judgmental or selective sampling, is a non-probability sampling method in which the researcher deliberately selects participants or data points based on specific characteristics or criteria relevant to the research objectives. Unlike probability sampling, which aims to produce a representative sample through

random selection, purposive sampling focuses on obtaining rich, relevant, and insightful data from carefully chosen sources. Although it may not yield a statistically representative sample, it is particularly effective in studies that require expert input, specific conditions, or high-precision data.

In this study, purposive sampling was applied to the selection of GCPs used for evaluating positional accuracy in Adama city. The technique allowed the researchers to strategically select GCPs that would offer the most meaningful contribution to the assessment of cadastral precision. Selection was based on a range of criteria including visibility, stability, and spatial distribution of the GCPs across the study area. This approach ensured that the selected GCPs were not only suitable for accurate georeferencing but also reflective of both the 2nd and 3rd order control networks present in the city.

Specifically, five GCPs were purposively selected from a total of 159 available 2nd order GCPs, and another five were chosen from a total of 46 available 3rd order GCPs, as detailed in Appendix 4. These ten points were chosen intentionally rather than randomly to enable a focused and practical evaluation of positional precision. The purpose of selecting a small but strategically important subset of GCPs was to represent the broader network in a way that could effectively demonstrate the quality and reliability of the geospatial data used in cadastral mapping.

This targeted selection method is particularly well-suited to geospatial applications such as remote sensing and photogrammetry, where the quality and relevance of the data often take precedence over randomness. By selecting GCPs based on known ground characteristics and location reliability, the study was able to produce more accurate and reliable georeferenced data. In essence, purposive sampling of GCPs enabled the researchers to concentrate on quality over quantity, ensuring that each chosen point significantly contributed to the objective of evaluating and improving positional precision in the cadastral system of Adama city.

## CHAPTER FOUR

### 4. RESULTS AND DISCUSSIONS

#### **4.1. Identifying the determinant indicators for evaluating the precision of GCP and land parcels**

The accuracy of geospatial data, particularly in the context of the cadastral system of Adama city (or any other city), is influenced by several factors. These factors can be technical, environmental, and procedural, and they impact the reliability and quality of cadastral mapping and land management. The following are basic factors:

##### **4.1.1. Surveying Equipment and Technology**

The precision of positioning technologies, such as GPS (Global Positioning System) and GNSS (Global Navigation Satellite Systems), plays a crucial role in determining the accuracy of geospatial data. Lower-cost GPS devices, while widely accessible, tend to offer limited positional accuracy. This limitation becomes more pronounced in urban environments, where tall buildings can obstruct satellite signals and cause interference, leading to errors in location data. In contrast, high-precision GNSS equipment—which includes systems capable of receiving signals from multiple satellite constellations—can provide significantly better positional accuracy. However, these advanced systems come at a higher financial cost, which may limit their use in some projects.

Total Stations, another commonly used tool in land surveying, operate by measuring angles and distances to determine precise point locations on the ground. While they are capable of high accuracy, their performance heavily depends on proper calibration and the skill level of the operator. Inaccuracies can arise from human error, poor equipment maintenance, or environmental factors affecting the measurement process.

In recent years, Unmanned Aerial Vehicles (UAVs), commonly known as drones, have become increasingly popular in cadastral surveying and mapping. When equipped with high-resolution cameras or LiDAR (Light Detection and Ranging) sensors, UAVs can capture detailed spatial data efficiently over large areas. However, the accuracy of UAV-derived data depends on several factors, including flight altitude, camera resolution, GPS signal quality during data capture, and the robustness of post-processing techniques such as photogrammetry or point cloud analysis.

While UAVs offer significant potential for rapid and detailed mapping, their effectiveness is closely tied to both technological parameters and operator expertise.

#### **4.1.2. Data Processing and Correction**

Geo-referencing is the process of aligning geospatial data—such as aerial photographs, satellite imagery, or scanned maps—with a known coordinate system so that each pixel or feature accurately corresponds to a real-world location. This step is fundamental in spatial data analysis, especially in cadastral mapping, where precision is critical for land parcel delineation. However, errors in geo-referencing can lead to spatial distortions, misalignments, and ultimately, inaccuracies in cadastral datasets. Such errors compromise the reliability of the information used for land administration, planning, and legal documentation.

To ensure spatial accuracy, the correction of raw data obtained from field surveys or remote sensing platforms is essential. Raw geospatial data often contain distortions due to factors like terrain variation, sensor orientation, or lens distortion. If these errors are not identified and corrected during the geo-referencing process, the resulting datasets will be misaligned with actual ground features, reducing their utility for precise applications.

Additionally, when working with datasets referenced in different coordinate systems, proper transformation between systems is necessary. Converting data from one coordinate system to another—such as from a local datum to a global one—requires the use of accurate transformation parameters. Inaccurate or poorly executed transformations can introduce spatial discrepancies, compounding the problem of misalignment. Therefore, geo-referencing must be performed with careful attention to both positional accuracy and coordinate system consistency to ensure that cadastral and other geospatial data are both reliable and useful for decision-making.

#### **4.1.3. Human Factors**

The experience, training, and expertise of surveyors and field personnel play a vital role in ensuring the accuracy and reliability of geospatial data collection. Skilled surveyors are more likely to follow standardized procedures, apply appropriate methods, and use equipment effectively to minimize measurement errors. In contrast, inexperienced or inadequately trained personnel may introduce significant errors—such as incorrect measurements, improper equipment handling, or misidentification of features—that can compromise the quality of cadastral data. These inaccuracies can lead to disputes over land boundaries or misrepresentation of property extents.

Moreover, human error can also occur during the data entry or interpretation phase. Mistakes in recording coordinates, inputting attribute information, or digitizing boundaries from field sketches can result in incorrect or inconsistent data. Subjective interpretation of land features—especially in areas where boundaries are unclear or not physically marked—can further contribute to discrepancies. These inconsistencies may affect the integrity of the cadastral records and reduce the effectiveness of land administration systems. Therefore, ensuring that field workers are well-trained and applying rigorous quality control procedures is essential for maintaining high standards in cadastral data accuracy.

#### **4.1.4. Environmental Factors**

In regions characterized by challenging topography, such as steep slopes, rugged terrain, or densely built urban environments, the accurate measurement of land features becomes significantly more complex. Elevation variations, uneven ground surfaces, and physical obstructions like buildings, trees, or walls can interfere with line-of-sight measurements and reduce the effectiveness of both ground-based and aerial survey methods. These limitations can lead to positional errors and incomplete data, thereby affecting the overall accuracy of cadastral mapping.

Additionally, adverse weather conditions such as heavy rainfall, fog, or snow can further impede data collection efforts. Many surveying instruments, including total stations and UAV-mounted sensors, rely heavily on clear visibility and stable environmental conditions to function optimally. Poor weather not only reduces visibility but can also degrade the performance of GPS signals, delay field operations, and compromise the quality of aerial imagery or remote sensing outputs.

Furthermore, dense vegetation cover poses another significant challenge in data acquisition, especially in rural or forested areas. Thick tree canopies can obstruct satellite signals, reducing the accuracy of GPS readings. They also hinder the ability of aerial sensors to capture clear imagery of the ground surface, making it difficult to delineate property boundaries and other cadastral features. These environmental and physical constraints underscore the importance of using appropriate technologies and planning fieldwork carefully to mitigate data accuracy issues in complex terrains.

#### **4.1.5. Cadastral System Design and Methodology**

The accuracy of cadastral data is fundamentally dependent on the clear definition and proper marking of boundary points. When boundary markers are ambiguous, misplaced, or poorly

maintained, the spatial representation of property limits can become inaccurate. Such discrepancies may result in overlapping claims, disputes between landowners, or administrative confusion, particularly in areas undergoing rapid development or land use change.

In the context of Adama, the quality of historical cadastral data also significantly influences the accuracy of the current cadastral system. Older surveys may have been conducted using less precise equipment or outdated methodologies, and if these records were not well maintained, they can introduce inconsistencies into modern datasets. Over time, natural changes, urban expansion, or alterations in land use may have caused boundaries to shift or become misaligned with official records. Relying on such data without proper verification can compromise the integrity of contemporary cadastral maps.

Moreover, the methodology adopted for cadastral mapping plays a critical role in determining data accuracy. The choice of survey techniques, the equipment used, and the level of precision mandated by governing authorities all affect the final outcome. Inconsistent or outdated mapping standards, along with variations in how boundaries are recorded and interpreted, can introduce further errors. Therefore, the establishment and enforcement of clear, modern surveying and data management standards are essential to improving and maintaining the accuracy of cadastral systems.

#### **4.1.6. Satellite and Aerial Imagery**

The quality of satellite or aerial imagery used in cadastral mapping plays a crucial role in determining the accuracy of feature identification, including property boundaries, infrastructure, and land use patterns. High-resolution imagery enables more precise digitization and interpretation of features, supporting the creation of accurate and reliable cadastral maps. However, the availability of such high-quality imagery can be limited by cost constraints or access restrictions, particularly in developing regions. As a result, projects may be forced to rely on lower-resolution or outdated imagery, which can reduce mapping accuracy.

Another important consideration is temporal accuracy—that is, the date when the imagery was captured. Land features and property boundaries are not static; they can change due to construction, land development, natural events, or changes in land ownership. Using outdated imagery risks incorporating obsolete or incorrect information into cadastral records, leading to inconsistencies between the map and the current on-ground reality. Therefore, both spatial and temporal resolution

must be considered when selecting imagery for cadastral mapping to ensure the resulting data is both current and accurate.

#### **4.1.7. Government and Institutional Factors**

The legal and regulatory framework in Adama plays a significant role in shaping the quality and reliability of cadastral data. Laws governing land ownership, land registration, and boundary demarcation can either facilitate or hinder accurate data collection and long-term maintenance. Inconsistent or outdated regulations, along with unclear legal procedures for resolving land disputes, may create challenges in ensuring that cadastral records are both comprehensive and legally valid. A well-defined legal environment is essential for supporting transparent land administration and minimizing ambiguity in property rights.

The technological infrastructure, including the software and databases used to manage cadastral information, also directly affects data accuracy and accessibility. Robust Geographic Information System (GIS) platforms and reliable database systems enable efficient data storage, real-time updates, and streamlined retrieval. In contrast, outdated or poorly managed systems can lead to data redundancy, loss of information, or inconsistencies in records. Ensuring that cadastral data is maintained on modern, secure, and interoperable platforms is key to sustaining high-quality land administration systems.

Disputes between landowners, particularly over boundary locations, are another source of inaccuracy in cadastral data. These disputes can result in conflicting claims or overlapping property boundaries, and often require legal resolution before updates can be made to the cadastral record. This process can be time-consuming and may delay the accurate documentation of land parcels.

Additionally, the presence of incomplete cadastral records further undermines the integrity of the system. This may occur due to unrecorded land transactions, missing historical survey data, or informal land occupation that has never been formally registered. Such gaps in the dataset hinder the creation of a complete and precise cadastral map, emphasizing the need for ongoing data verification, record digitization, and field validation to ensure the accuracy and completeness of the cadastral system.

#### **4.1.8. Evaluating the level of positional precision of the existing GCP networks in Adama city as per the standard of ASPRS**

Positional precision of Ground Control Points (GCPs) plays a fundamental role in geospatial mapping and cadastral surveys. In this study, the aim is to evaluate the accuracy of Differential GPS (DGPS) in determining the geographic coordinates (latitude, longitude, and elevation) of GCPs compared to established reference values. These GCPs serve as the foundation for spatial alignment in mapping processes, making their precision essential for ensuring reliable land parcel delineation. By assessing the alignment of DGPS-derived coordinates with known values, the study provides insights into the baseline accuracy required for high-quality cadastral mapping.

The accuracy of land parcel boundaries is highly dependent on the positional precision of the GCPs used during cadastral surveys. Land parcels are typically delineated with reference to these points; thus, any error in GCP positioning directly affects the boundaries of individual properties. This research evaluates how DGPS technology enhances the positional accuracy of GCPs and minimizes boundary errors, particularly in complex or densely built urban environments like Adama City. The study further investigates horizontal accuracy (X, Y) of both the GCPs and the resulting parcel boundaries, aiming to quantify the extent of improvement achieved through DGPS.

DGPS significantly improves spatial accuracy over conventional GPS by using correction signals from ground-based reference stations to reduce satellite-based errors. These corrections address issues such as orbital drift, signal timing delays due to atmospheric interference, receiver errors, multipath effects, and antenna miscentering. As part of the data processing methodology, redundant observations are conducted and analyzed using least squares adjustment techniques to ensure consistency and minimize errors. This two-stage process includes calculating the baseline components (X, Y, Z) through adjusted carrier phase observations, followed by adjustment of the station network. All GNSS-derived coordinates are transformed into the Earth-centered, Earth-fixed (ECEF) geocentric coordinate system to maintain a standardized spatial reference framework.

An important analytical aspect of GNSS precision involves evaluating loop closure errors. For every closed loop in a GNSS network, the algebraic sum of X, Y, and Z components should ideally be zero. Significant misclosures may indicate systematic errors or blunders, which must be

corrected before using the data for further analysis. This error-checking mechanism is analogous to those used in traditional survey techniques like leveling and traverse adjustment, emphasizing the rigor required in GNSS-based surveys.

From a GIS (Geographic Information System) perspective, "point networking precision and accuracy analysis" refers to evaluating the geometric integrity of a network of points. Precision denotes the consistency of repeated measurements, while accuracy measures how closely those points match their real-world positions. In spatial network analyses—such as shortest path calculations or service area modeling—minor coordinate errors can have a significant impact on the outcomes. Therefore, precise GCP positioning is critical for ensuring reliable cadastral analyses and land management decisions.

In this study, GCPs used were a purposive sample of 2nd and 3rd order points, selected from datasets provided by the Ethiopian Mapping Authority (EMA), now operating as the Space and Geospatial Institute. The selection criteria adhered to standards defined by the American Society for Photogrammetry and Remote Sensing (ASPRS), ensuring optimal point distribution, stability, and visibility. By applying purposive sampling based on technical merit rather than randomness, the research prioritizes data quality and accuracy in representation over statistical generalization. This approach provides a reliable basis for evaluating the effects of GCP precision on cadastral boundary accuracy and overall geospatial data integrity.

Table 4-1 presents the coordinate values for five Ground Control Points (GCPs) classified as 2nd order in Adama City. Each GCP is listed with corresponding Easting and Northing values in meters (projected coordinates) and Latitude and Longitude in decimal degrees (geographic coordinates). The 2nd order GCPs are typically established with higher accuracy and are used as the main reference for geospatial surveys. These points are vital in establishing a primary geodetic control network, serving as benchmarks for all geospatial activities, including cadastral mapping.

These coordinate values provide the foundational dataset for evaluating positional precision. By comparing these observed coordinates against a predefined reference system (e.g., an official national geodetic network), one can calculate the Root Mean Square Error (RMSE) and standard deviation to quantify the spatial accuracy of the 2nd order GCPs. These statistical measures help determine how well the GCPs conform to the expected positional standards set by ASPRS (American Society for Photogrammetry and Remote Sensing), which defines acceptable positional

accuracy thresholds for geospatial data. The availability of both projected and geographic coordinate systems further facilitates transformation accuracy checks and consistency verification across coordinate systems.

Table 4-1: Sample coordinates of 2nd order GCP network in Adama

ID	Easting(m)	Northing(m)	Latitude	Longitude
1	526809.9086	951661.6998	8.60481	39.27253
2	527484.1599	950249.266	8.60292	39.2565
3	529524.1027	951131.4034	8.59549	39.25435
4	529744.6371	950194.1324	8.59668	39.27084
5	527704.6942	949311.9949	8.59497	39.28292

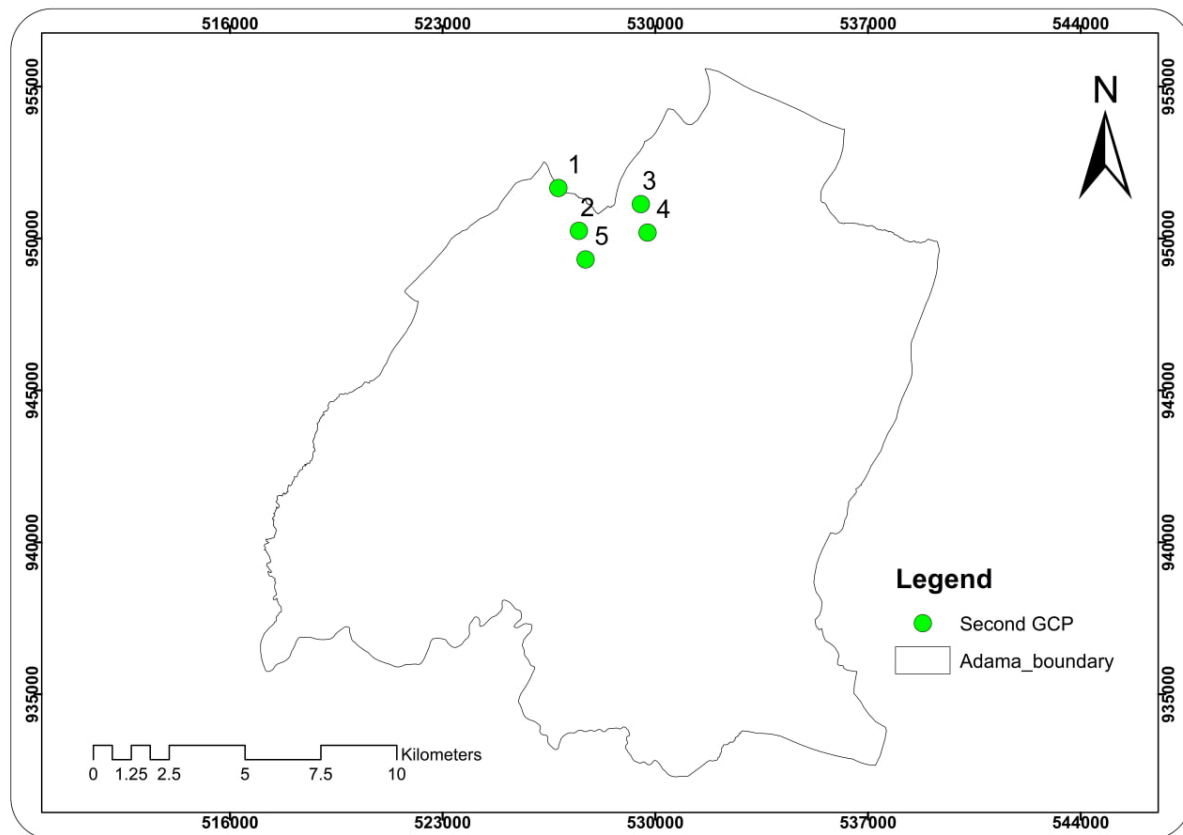


Figure 4-1: Sample Adama city GPS 2nd GCP coordinates

Figure 4-1 illustrates the spatial distribution of these points, allowing for an assessment of their coverage, spacing, and density within the study area. A well-distributed 2nd order GCP network is critical for ensuring uniform positional accuracy across the cadastral database. This figure aids in assessing how effectively these points serve as spatial references for cadastral data layers. It also

enables identification of any clustering or gaps that might affect spatial interpolation or transformation accuracy. The map gives a visual context for the spatial analysis, especially when positional errors and RMSE are calculated between the GCPs and reference coordinates. This allows spatial analysts to not only quantify but also visually inspect the nature and distribution of positional precision.

Table 4-2 lists the 3rd order GCP coordinates, which are derived through densification from the 2nd order network. These points typically have slightly lower accuracy but are essential for supporting local surveying and mapping tasks. The table presents projected coordinates (Easting, Northing) and geographic coordinates (Latitude, Longitude) for five sample GCPs.

The 3rd order GCPs are significant in extending control from the more precise 2nd order network to localized areas. In the context of Objective 2, the precision of these GCPs should also be evaluated using statistical measures such as RMSE and standard deviation. Since they are often used in cadastral mapping and photogrammetric tasks, their accuracy directly impacts the reliability of parcel boundary delineation. Any positional discrepancies at this level may propagate through to cadastral records, making it crucial to assess whether these GCPs meet ASPRS standards. The data in this table can be compared with orthophoto-derived coordinates or surveyed values to measure actual positional deviation.

*Table 4-2: Sample coordinates of 3rd order GCP network in Adama*

ID	Easting (m)	Northing (m)	Latitude	Longitude
1	528042.3	940601.8	8.50998	39.25478
2	530508.2	941156.7	8.51498	39.27719
3	529841.9	942653.5	8.52853	39.27115
4	527452.9	942278.8	8.52515	39.24944
5	530052.2	944100.5	8.54162	39.27307

Figure 4-2 provides a visual representation of the 3rd order GCPs displayed over a basemap of Adama City. This spatial overview enables analysis of how these points are distributed within the urban landscape and in relation to existing cadastral infrastructure. The figure is particularly useful for evaluating whether these GCPs provide adequate spatial support across the city for high-precision mapping. By visually examining the locations of 3rd order GCPs, one can assess their coverage density and identify whether they adequately fill spatial gaps between 2nd order points.

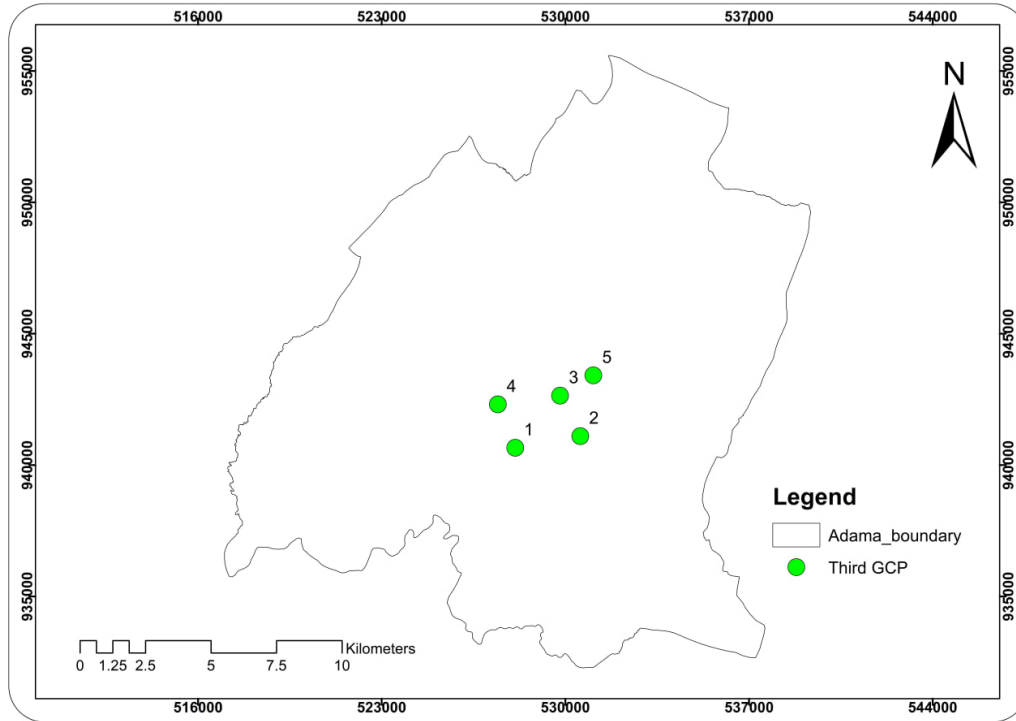


Figure 4-2: Sample Adama city GPS 3rd GCP coordinates

Figure 4-3 displays the cadastral data layer of Adama City, likely composed of land parcel boundaries.

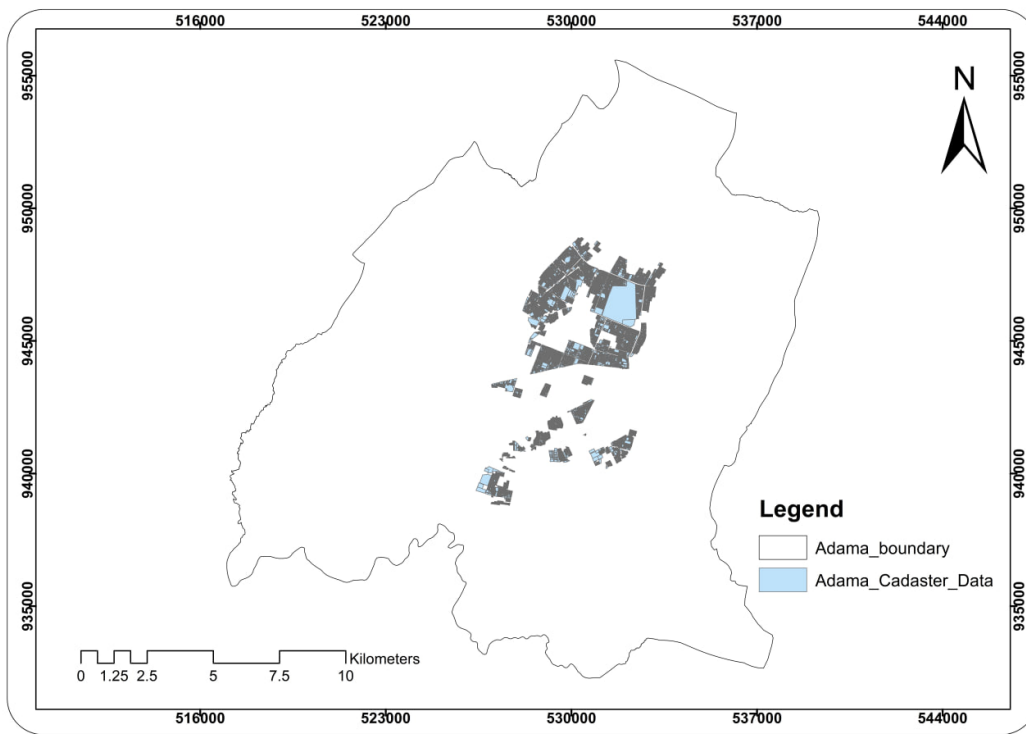


Figure 4-3: Adama city cadastral data

While this figure directly aligns more with Objective 3 (geometric precision of land parcels), it is indirectly useful for Objective 2. The cadastral layer relies heavily on the underlying GCP network, so its accuracy is dependent on the positional precision of those control points. This map helps spatially correlate cadastral data with GCPs. Any observed misalignment or distortion in parcel boundaries may indicate positional inaccuracies in the underlying GCP framework, thus providing visual evidence for spatial error propagation from GCPs to cadastral features.

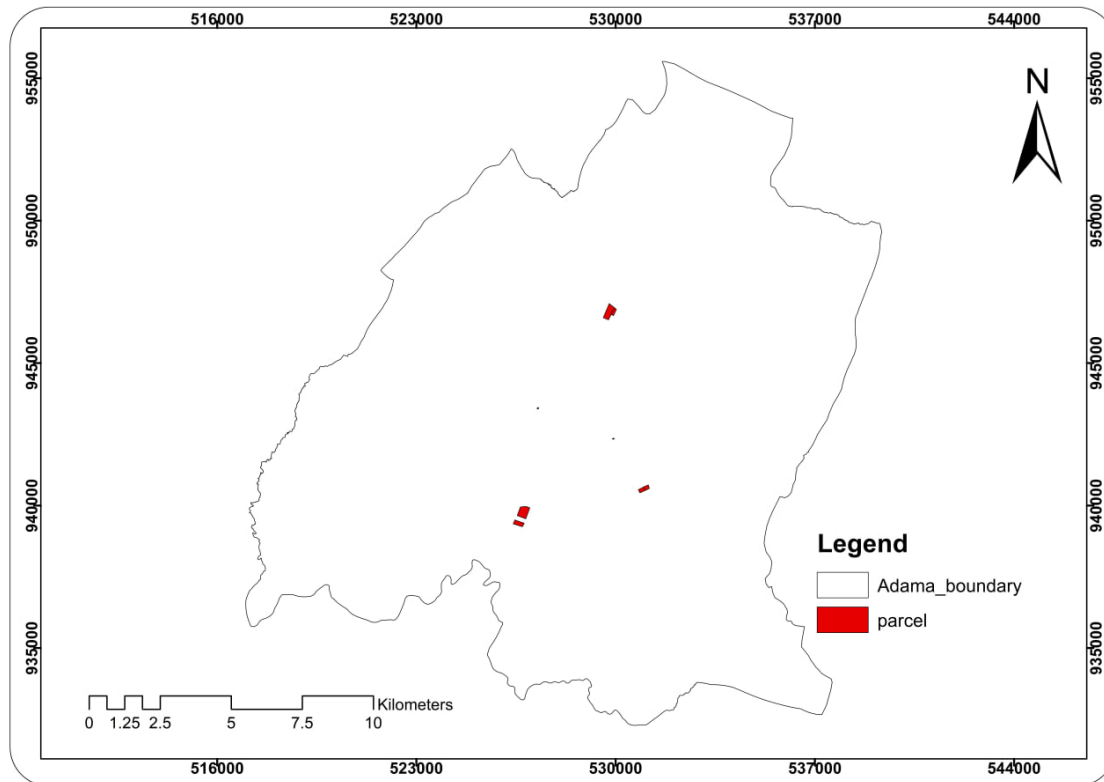


Figure 4-4: Adama city sample land parcels

Figure 4-4 zooms in on sample cadastral land parcels, offering a more detailed view of boundary shapes and configurations. It helps in assessing how cadastral data are aligned with spatial control, particularly the GCP network. This figure helping identify spatial anomalies in areas where 2nd or 3rd order GCPs are present nearby. If positional precision issues exist in GCPs, their impact will be noticeable here. Therefore, using this figure in conjunction with GCP coordinate analysis can reveal the relationship between control network accuracy and parcel boundary integrity.

Figure 4-5 presents attribute data associated with the land parcels, such as parcel ID, area, ownership status, or other cadastral elements. While this figure is primarily attribute-based and

less directly tied to positional accuracy, it provides context for evaluating the practical implications of spatial errors. Misaligned GCPs could result in incorrect parcel dimensions or boundary overlaps, affecting cadastral record validity. Thus, this figure helps reinforce the importance of accurate GCP networks, as errors in spatial referencing can compromise both the spatial and tabular integrity of the cadastral system.

OBJECTID *	SHAPE *	ORIG_FID	POINT_X	POINT_Y
1	Point	1	530853.0588	946082.5206
2	Point	1	530932.131	946284.537
3	Point	1	531202.2195	946184.3748
4	Point	1	531128.545	945967.914
5	Point	1	530853.0588	946082.5206
6	Point	2	532495.5742	947121.2799
7	Point	2	532515.9969	947116.3065
8	Point	2	532512.8939	947092.9675
9	Point	2	532492.3061	947096.6987
10	Point	2	532495.5742	947121.2799
11	Point	3	529772.1171	947090.0183
12	Point	3	529950.4554	946950.1728
13	Point	3	529749.5552	946519.3886
14	Point	3	529561.7993	946593.2026
15	Point	3	529772.1171	947090.0183
16	Point	5	526787.8896	939380.5294
17	Point	5	526721.7058	939258.9673

Figure 4-5: Adama city sample land parcels attribute

#### 4.1.9. Computation of Least Square adjustment of Adama city 2nd and 3rd orders GCP's

Least squares adjustment is a mathematical technique widely used in geodesy and surveying to estimate the most probable values of unknown parameters by minimizing the sum of the squares of the residuals—differences between observed and computed values. In the context of Ground Control Points (GCPs) collected via GPS or GNSS, this method plays a critical role in refining coordinate estimates by accounting for observational errors. Since GPS measurements inherently contain random and systematic errors, applying least squares adjustment improves spatial accuracy by ensuring that all available observations contribute optimally to the final coordinate solution.

In practical applications, not all observations have the same level of precision. Some measurements—due to better satellite geometry, signal strength, or environmental conditions—may be more reliable than others. The weight matrix in a least squares adjustment accounts for this

by assigning greater importance to higher-precision observations. Through this process, more accurate data exert more influence on the final coordinate estimates, thereby enhancing overall positional precision.

The typical workflow for least squares adjustment of GPS control points includes several essential steps. First are the observation equations, which mathematically model the relationships between observed quantities (e.g., distances, angles, or baseline components) and the unknown parameters (coordinates). Second is weighting, where each observation is weighted according to its expected precision. Finally, the adjustment computation solves this system of equations to obtain the coordinate values that best fit the entire set of observations, minimizing the weighted sum of the squared residuals.

In ArcGIS 10.8, the Ordinary Least Squares (OLS) tool, available under the Spatial Statistics and Modeling Spatial Relationships toolbox, facilitates regression-based spatial modeling. This tool is used not only for estimating relationships between variables but also as part of quality assessment and model diagnostics. Upon execution, the tool generates a detailed report in the Results window. Users can access this by right-clicking the “Messages” entry and selecting “View,” which displays an Exploratory Regression Summary Report.

pointid	Longitude	Latitude	Estimated	Residual	StdResid
1	8.60481	39.27253	8.598636	0.006174	1.191364
2	8.60292	39.2565	8.599698	0.003222	0.621728
3	8.59549	39.25435	8.59984	-0.00435	-0.839484
4	8.59668	39.27084	8.598748	-0.002068	-0.399042
5	8.59497	39.28292	8.597948	-0.002978	-0.574576

Figure 4-6: Least square adjustment for GCP network for Northing in Adama city

Table						
c2nd_Output_OrdinaryLeastSqu2						
	pointid	Longitude	Latitude	Estimated	Residual	StdResid
▶	1	39.27253	8.60481	39.264783	0.007747	0.571569
	2	39.2565	8.60292	39.26564	-0.00914	-0.674364
	3	39.25435	8.59549	39.269007	-0.014657	-1.081419
	4	39.27084	8.59668	39.268468	0.002372	0.17505
	5	39.28292	8.59497	39.269242	0.013678	1.009174

Figure 4-7: Least square adjustment for GCP network for easting in Adama city

Table						
Output3rd_OrdinaryLeastSquar						
	pointid	Latitude	Longitude	Estimated	Residual	StdResid
▶	1	8.50998	39.25478	8.520844	-0.010864	-0.800364
	2	8.51498	39.27719	8.527793	-0.012813	-0.944004
	3	8.52853	39.27115	8.52592	0.00261	0.192279
	4	8.52515	39.24944	8.519188	0.005962	0.439278
	5	8.54162	39.27307	8.526516	0.015104	1.112806

Figure 4-8: Least square adjustment for 3rd GCP network for easting in Adama city

Table							
Output3rd_OrdinaryLeastSquar1							
	pointid	East	Longitude	Latitude	Estimated	Residual	StdResid
▶	1	39.25478	8.50998	39.260849	-0.006069	-0.451679	
	2	39.27719	8.51498	39.262369	0.014821	1.103008	
	3	39.27115	8.52853	39.266487	0.004663	0.347029	
	4	39.24944	8.52515	39.26546	-0.01602	-1.192205	
	5	39.27307	8.54162	39.270465	0.002605	0.193847	

Figure 4-9: least square adjustment for 3rd GCP network for northing in Adama city

#### 4.1.10. Standard deviation computation for precision measurement of Adama city 2nd and 3rd orders GCP's

Standard deviation is a key statistical metric used to evaluate the variability or dispersion of a dataset relative to its mean. In geospatial analysis and surveying, it is a critical measure for

assessing the precision of control point measurements. A low standard deviation indicates that the data points are closely grouped around the mean, suggesting high precision and repeatability. Conversely, a high standard deviation suggests greater variability, indicating lower precision.

In the context of GPS measurements and control point networks, standard deviation plays a vital role in evaluating the consistency of coordinate measurements—specifically the X (easting/longitude), Y (northing/latitude), and Z (elevation) values. A straightforward way to assess GPS precision is to compute the standard deviation of repeated measurements for each coordinate of a control point. Smaller standard deviations imply that the control point location is more stable and reliable, which is essential for accurate geodetic and cadastral applications.

To use standard deviation effectively in a control point network, the process typically involves several steps. First, multiple coordinate measurements are collected for each GCP (Ground Control Point). Next, the mean for each coordinate (latitude, longitude, and elevation) is calculated. The residuals—differences between each observed value and the mean—are then determined. These residuals are squared and averaged to obtain the variance, and finally, the square root of the variance gives the standard deviation.

As illustrated in Figure 4-7, which presents standard deviation adjustments for northing values in the Adama City GCP network, 2nd order GCP points 2 and 3 exhibit lower standard deviations. This indicates that these points are more precise in the northing direction, showing greater consistency in their measured values. Similarly, Figure 4-8 demonstrates that points 3 and 5 have the smallest standard deviations for easting values, confirming their higher positional precision in the east-west direction.

In Figure 4-9, focusing on 3rd order GCPs, point 1 and point 2 show smaller standard deviations for easting, while points 1 and 3 are more precise in terms of northing. These observations collectively suggest that certain control points—particularly those measured with high-precision equipment and methodologies—exhibit superior repeatability and can be relied upon as stable geospatial references.

In summary, the standard deviation is a critical measure for evaluating the quality and precision of GCPs in a control network. Points with small standard deviations can be trusted to represent accurate and consistent positions, making them suitable for use in applications like cadastral

mapping, GNSS network design, and spatial modeling. The use of precise GCPs improves the reliability of any geospatial dataset derived from them.

#### **4.1.11. RMSE based precision measurements of Adama city 2nd and 3rd orders GCP's**

As presented in Table 4-3, the primary horizontal accuracy standard for digital geospatial data—including digital orthoimagery, planimetric datasets, scaled planimetric maps, and elevation models—is defined using the Root Mean Square Error in the horizontal plane (RMSEH). RMSEH quantifies the combined linear error in a radial (horizontal) direction and serves as a widely accepted metric for assessing the positional accuracy of Ground Control Points (GCPs) in mapping and surveying applications. In the context of the GCP network in Adama City, RMSE was used to evaluate how accurately the measured GPS coordinates align with known reference values.

The process of calculating RMSE for the GCPs in Adama City involved several steps. First, the measured coordinates (latitude, longitude, and elevation) of each GCP were compared against their corresponding reference or true values. The differences between these pairs, known as errors, were then calculated. These errors were squared to eliminate negative signs and emphasize larger deviations. Next, the average of these squared errors was computed to obtain the Mean Square Error (MSE) for each coordinate axis. Finally, the square root of the MSE provided the RMSE value, offering a clear representation of positional precision for each control point. Horizontal RMSE (RMSEH) was computed by combining the RMSE values of the latitude and longitude components.

According to the American Society for Photogrammetry and Remote Sensing (ASPRS) horizontal accuracy standards, the highest category—Zero-order accuracy—requires an RMSE of 0.002 meters or less. First-order accuracy allows for an RMSE of up to 0.003 meters. More generally, a widely used threshold is the 7.5 cm horizontal accuracy class, meaning the RMSEH of a dataset must not exceed 0.0075 meters. These accuracy classes provide essential benchmarks for evaluating the quality of geospatial datasets and ensuring they meet industry requirements.

Upon evaluating the precision of both 2nd-order and 3rd-order GCPs in Adama City, the results indicated that neither class of control points met the minimum criteria defined by the ASPRS 7.5 cm horizontal accuracy standard. This finding suggests that the positional precision of the current GCP network falls short of optimal levels. Possible contributing factors could include limitations

in GPS equipment, environmental interference, inadequate field procedures, or insufficient post-processing and adjustment techniques.

Table 4-3: 3rd order GCP accuracy checking

points	X Residual	Y Residual	MAE_X	MAE_Y	MSE X	MSE_Y	RMSE_X	RMSE_Y	RMSEX-Y
1	-0.006	-0.01	0.000036	0.0001					
2	0.014	-0.012	0.000196	0.000144					
3	0.004	0.002	0.000016	0.000004					
4	-0.016	0.005	0.000256	0.000025					
5	0.002	0.015	0.000004	0.000225					
			0.000508	0.000498	0.000102	9.96E-05	0.01008	0.00998	0.014184

Table 4-4: 2nd order GCP accuracy checking

points	X Residual	Y Residual	MAE_X	MAE_Y	MSE X	MSE_Y	RMSE_X	RMSE_Y	RMSEX-Y
1	0.007	0.006	0.000049	0.000036					
2	-0.009	0.003	0.000081	0.000009					
3	-0.014	-0.004	0.000196	0.000016					
4	0.002	-0.002	0.000004	0.000004					
5	0.013	-0.002	0.000169	0.000004					
			0.000499	0.000069	9.98E-05	1.38E-05	0.00999	0.003715	0.010658

#### 4.2. Evaluating the Geometric precision of land parcel data digitized from orthophoto compared with the GNSS ground truth

The geometric precision of a digitized land parcel derived from orthoimagery refers to how accurately and consistently land parcel boundaries are captured in the digital environment. This precision encompasses the spatial position, shape, and alignment of features as interpreted from orthophotos. In the context of Geographic Information Systems (GIS) and remote sensing, maintaining high geometric precision is essential for ensuring the spatial integrity of land records, particularly when such data is used for cadastral, planning, or legal purposes.

To assess geometric precision in compliance with ASPRS positional accuracy standards, a regular network of eight check points was established across a relatively flat area, characterized by minimal elevation differences. These control points serve as a basis for comparison between the observed GPS data and the digitized coordinates extracted from the orthoimagery. Accurate and precise ground reference data is essential for evaluating the quality of orthoimages, and the choice

of Global Navigation Satellite System (GNSS) data processing software plays a critical role in this process. Generally, scientific GPS processing software is preferred for high-precision applications, particularly over large baselines. However, as noted by Featherstone (2004), advancements in commercial GPS software have significantly closed the accuracy gap, making them viable alternatives for many applications.

In this study, the horizontal Root Mean Square Error (RMSE) between the in-situ GNSS-derived coordinates and the corresponding coordinates digitized from the orthophoto was calculated in both the X (easting) and Y (northing) directions. The overall horizontal accuracy of the orthoimage was evaluated at a 95% confidence level, in accordance with ASPRS guidelines. The accuracy assessment involved calculating the mean and standard deviation of the differences between the two coordinate sets, providing a statistical basis for understanding the level of agreement.

Positional accuracy, which is a critical element of spatial data quality, refers to the correctness of the geographic location of features within a defined spatial reference system (Drobnjak et al., 2017). As highlighted by López and Gordo (2008), the emergence of GPS technology has heightened the importance of positional accuracy. Specifically, horizontal positional accuracy is measured in terms of latitude and longitude, or local easting and northing, and represents how precisely a spatial entity is located. This aspect of accuracy is fundamental in cartographic production, and is routinely assessed by national mapping agencies using standardized methodologies, including the RMSE statistical approach.

The objective of this study is to evaluate the positional accuracy and quality of the orthophoto by comparing it with high-precision GPS ground observations. The reference data for this evaluation were generated using both online and offline GNSS post-processing services. According to ASPRS (2014), horizontal accuracy is quantified using RMSE in the X and Y directions—RMSE<sub>x</sub> and RMSE<sub>y</sub>—combined into a single horizontal accuracy metric, RMSE<sub>h</sub>. As explained by Tsarovski (2015), RMSE is the square root of the average of the squared differences between the dataset coordinates and the reference coordinates of the same points.

The accuracy of the orthophoto was evaluated by comparing the 2D coordinates of the GNSS-measured check points against those extracted from the orthophoto. The deviations were analyzed using RMSE formulas for eastings, northings, and overall horizontal precision. For this evaluation, coordinates obtained via both online and offline GNSS processing were considered equally

representative of high-accuracy ground truth data. According to ASPRS (2014), recommended horizontal accuracy thresholds for large-scale maps are  $\leq 15$  cm for high-accuracy work, 30 cm for standard mapping and GIS use, and  $\geq 45$  cm for visualization and general-purpose applications.

A set of eight control points was used for this analysis. These points were measured using static GNSS methods and processed using professional GNSS services. The final outcome of this assessment, including RMSE values and the horizontal positional accuracy at a 95% confidence level, indicates how well the orthophoto aligns with the ground truth and whether it meets ASPRS standards for standard mapping applications.

#### **4.2.1. Topological consistency of land parcel data extracted from Ortho-imagery for evaluating the Geometric precision of land parcel data**

Ensuring geometric precision during the digitization of land parcels from orthoimagery involves more than just drawing accurate boundaries—it requires that these boundaries maintain topological consistency. Topological rules such as adjacency, connectivity, and containment must be strictly followed to ensure there are no overlaps or gaps between parcels. In cities like Adama, where irregular land parcel shapes may result from historical land use patterns, maintaining topological consistency becomes a significant challenge.

The resolution and geo-referencing accuracy of the ortho-imagery also influence geometric precision. If the resolution is too low, fine parcel boundaries might not be distinguishable, and if geo-referencing is inaccurate, spatial distortions can compromise topological consistency. Therefore, a combination of high-quality imagery and careful digitization practices is essential for producing precise land parcel data.

Topological consistency ensures that spatial relationships between geographic features—such as land parcels—are logically correct. For example, adjacency consistency means that neighboring parcels share common boundaries without any gaps or overlaps. This is crucial in urban areas like Adama, where land parcels are closely packed and accurate boundary delineation is necessary for legal, planning, and administrative purposes.

Another aspect, connectivity consistency, requires that parcel boundaries form continuous, closed polygons. Any break or disconnection in the boundary line indicates a topological inconsistency. Maintaining such integrity ensures that the data is not only visually correct but also analytically

usable for further GIS operations such as spatial queries, overlay analysis, or cadastral computations.

Maintaining topological consistency leads to numerous benefits. It enhances data quality by ensuring the parcel data is reliable and free of spatial errors. It supports efficient analysis, enabling accurate computations of area, proximity, and spatial relationships. It also facilitates better decision-making, especially in land management, zoning, and urban planning. Moreover, topological consistency contributes to data integrity, allowing for long-term data maintenance, integration with other datasets, and compliance with national and international geospatial standards.

To manage and enforce topological rules, geodatabases in GIS platforms like ArcGIS provide a robust solution. These systems allow users to define rules such as “no gaps,” “no overlaps,” and “must not have duplicate boundaries.” Topology tools, like the Topology Checker in QGIS or ArcGIS’s topology validation tools, can detect and correct errors such as slivers, overlaps, and disconnected lines.

For the land parcel data of Adama City extracted from ortho-imagery, a systematic approach to topological editing should be adopted. The process begins with obtaining accurate GIS data from authoritative sources such as municipal planning departments or land registration offices. The data should be projected into an appropriate coordinate system (e.g., UTM) for consistent spatial analysis.

Once the parcel layers are loaded into the GIS environment, topological rules must be defined. Common rules include: no gaps (ensuring all adjacent parcels connect without empty spaces), no overlaps (ensuring parcels do not intrude into each other), and no duplicate boundaries (ensuring shared borders are represented only once). During editing operations like splitting or merging parcels, the GIS software can maintain these rules automatically when topological editing is enabled.

After editing, a topological validation must be conducted. This step ensures that all spatial rules have been respected and that no new inconsistencies have been introduced. Any detected issues should be corrected before finalizing the dataset. Finally, attribute data such as parcel ID, land use

type, ownership information, and zoning status should be updated to reflect the new spatial structure.

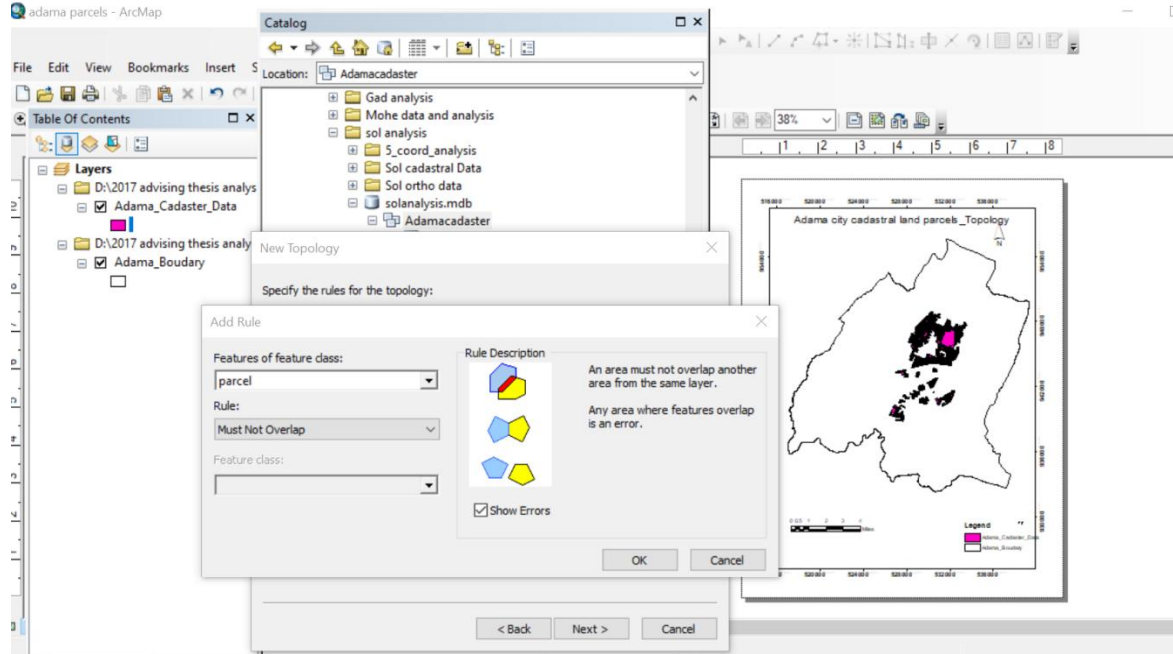


Figure 4-10: Adama land parcels Topological errors

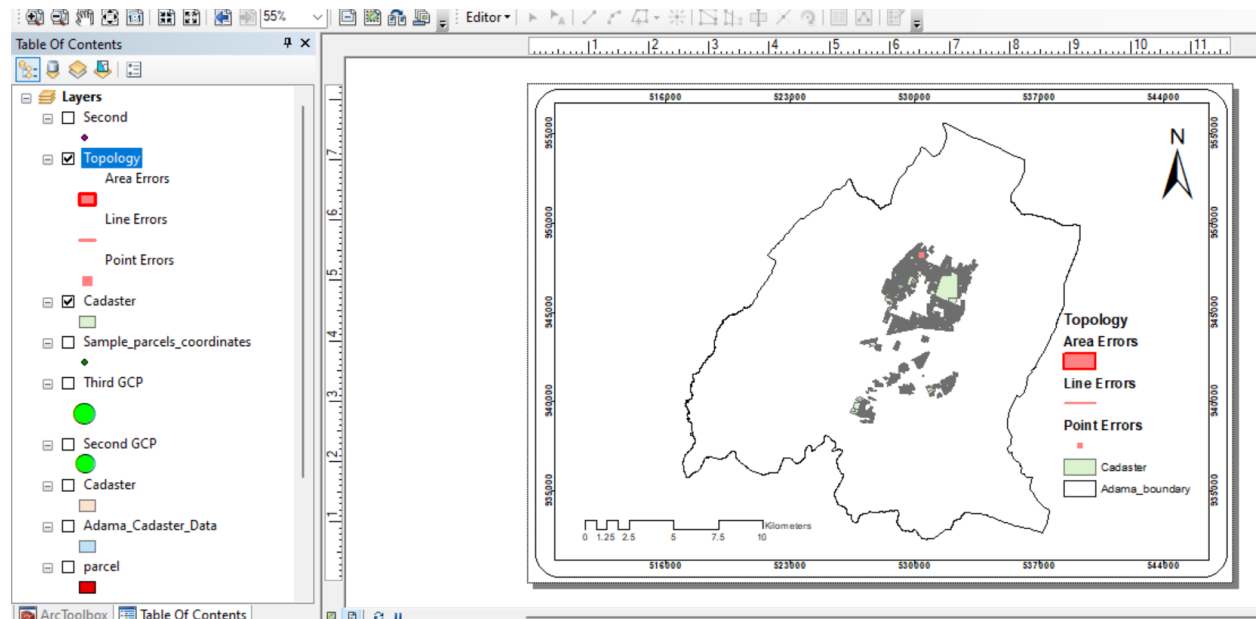


Figure 4-11: Adama land parcels Topological corrections

#### **4.2.2. Evaluating the Geometric precision of land parcel data digitized from orthophoto compared with the GNSS ground truth using RMSE**

Point network analysis in GIS refers to the examination of spatial relationships and connectivity between individual data points within a network framework. These points—such as intersections, land parcel centroids, or utility nodes—are analyzed to understand movement, flow, or interaction across the network. Using principles from graph theory, point network analysis enables the computation of shortest paths, service areas, and connectivity measures based on how points are linked. This is especially useful in urban planning, transportation modeling, and land management scenarios where spatial efficiency and connectivity play critical roles.

In the context of Adama City, point network analysis can be applied to examine spatial relationships between land parcels, infrastructure points, or utility service nodes. When used together with spatial datasets, it can help in identifying access gaps, optimizing land use, or planning public services based on spatial distribution.

To assess the precision of land parcel data extracted from orthoimagery or satellite sources, one of the most widely accepted methods is calculating the Root Mean Square Error (RMSE). RMSE provides a statistical measure of the differences between values predicted or extracted from GIS tools and values from a trusted reference dataset. This is crucial for evaluating the geometric and positional accuracy of mapped features.

The process to calculate RMSE for land parcel data in Adama City involves several steps. First, reference data must be collected. This data serves as the ground truth and typically comes from manual surveys, cadastral maps, or high-precision GPS measurements. It includes reliable information such as parcel boundaries, centroids, and geometric dimensions like area.

Second, the extracted dataset—usually derived from satellite imagery or remote sensing processes—is compiled. This is the dataset that needs to be evaluated for accuracy. Third, the corresponding features in both datasets are matched. This alignment ensures that each land parcel from the extracted data has a corresponding parcel in the reference data.

#### **4.3. Modeling Framework for Continuous Quality of Cadastral precision controlling**

Accuracy standards in cadastral surveying and mapping are essential to ensure that positional uncertainties, angular measurements, distances, and closure requirements adhere to predefined tolerances. These standards require that the positional uncertainty resulting from survey

measurements must not exceed the allowable positional tolerance. To achieve this, surveyors must implement robust measurement techniques and apply stringent quality control measures. This is particularly critical for maintaining the integrity and legal reliability of cadastral records, which form the backbone of property rights and land administration.

Data quality in the cadastral context is multidimensional. It extends beyond accuracy to include completeness, consistency, relevance, and availability. Quality can be assessed from various perspectives—such as the needs of end-users, the efficiency of digitization processes, or the broader objectives of land governance. The cadastre plays a vital role in land management and development, yet in many cases, it lacks the capacity to fulfill its potential in a digital environment. In Adama City, where urbanization is accelerating, there is an urgent need for cadastral systems to evolve and become more responsive to modern demands.

To address these challenges, developing a framework for continuous quality monitoring of cadastral data is essential. Such a framework must be systematic, adaptive, and institutionally integrated, incorporating geospatial technologies, clearly defined accuracy standards, and continuous feedback mechanisms. Cadastral data underpins land administration, urban planning, taxation, and development control; therefore, maintaining up-to-date and reliable records is critical for effective decision-making and sustainable urban development.

A proposed modeling framework for Adama City should support a structured, repeatable process that allows for the detection of inaccuracies, evaluation using measurable metrics, continuous improvement, and informed decision-making based on both real-time and historical data. The framework must draw from a variety of data sources, including high-precision GNSS/GPS survey data, remote sensing data such as satellite or UAV-based imagery, and existing cadastral and registry records. These diverse sources contribute to a comprehensive and reliable geospatial foundation.

Key dimensions of cadastral accuracy should be defined with corresponding metrics and methods:

- Positional Accuracy: Measured using RMSE (Root Mean Square Error) and Circular Error (CE90).

- **Attribute Accuracy:** Evaluated using error rates by auditing cadastral records against official registries.
- **Topological Consistency:** Assessed through gap/overlap ratios and GIS-based topology rules.
- **Completeness:** Measured as the percentage of missing features by comparing actual parcel data to a baseline dataset.

The quality monitoring layer of the framework should employ automated or periodic tools for error detection, statistical analysis (e.g., computing RMSE and standard deviations), and potentially even machine learning models for pattern recognition and anomaly detection. These technologies help streamline and scale the monitoring process.

A critical component of the framework is a feedback and correction mechanism, which includes an error log database, structured correction workflows, and even tools for public participation to crowdsource error reporting. Furthermore, interoperability must be ensured with other systems such as Land Information Systems (LIS), urban planning tools, legal registries, and the broader Spatial Data Infrastructure (SDI). This enhances data sharing, legal coherence, and policy alignment.

The core cadastral domain model serves as a conceptual foundation for building distributed and interoperable systems. It outlines the relationships among land parcels, legal rights, and spatial features. Implementing this model ensures that different agencies and stakeholders can collaborate using a unified data structure and shared standards.

The framework can be broken down into four major phases:

- **Data Acquisition:** Using modern tools such as GNSS, total stations, and UAVs to collect accurate ground and aerial data.
- **Data Integration and Analysis:** Overlaying digitized cadastral data with collected geospatial coordinates, identifying spatial errors using GIS tools such as RMS analysis, buffer methods, and overlay techniques.
- **Error Correction and Adjustment:** Applying georeferencing, coordinate transformations, parcel boundary corrections, and topological cleaning.

- Validation and Quality Control: Conducting accuracy assessments against ground-truth points and verifying records through legal documentation and survey archives.

The final outputs of the framework include an updated, high-precision cadastral database, spatially accurate parcel maps, and a reduction in discrepancies between legal boundaries and real-world conditions. This not only strengthens land governance but also facilitates secure land tenure, efficient urban planning, and equitable land taxation in Adama City.

## CHAPTER FIVE

### 1. CONCLUSION AND RECOMMENDATION

#### 1.1. Conclusion

This study assessed the positional precision of cadastral land parcels in Adama City by comparing existing digitized cadastral data with accurate ground-truth coordinates obtained using modern geospatial technologies. The comparative analysis revealed notable spatial discrepancies between the official parcel boundaries and their true geographic locations. These positional inaccuracies are primarily attributed to outdated base maps, errors introduced during manual digitization, weak geodetic control frameworks, and the limited use of high-precision surveying methods in earlier cadastral mapping initiatives.

The Root Mean Square Error (RMSE) values for horizontal accuracy were found to exceed 0.3 meters in several locations. This level of error surpasses the acceptable tolerance thresholds set by the American Society for Photogrammetry and Remote Sensing (ASPRS). According to ASPRS standards, zero-order and first-order closed GCP traverse surveys should demonstrate horizontal accuracy of  $\leq 25$  mm (0.0025 m), with zero-order meeting the standard at 0.002 m and first-order slightly lower at 0.003 m. Furthermore, ASPRS defines the 7.5 cm horizontal accuracy class as requiring an  $RMSEH \leq 0.0075$  m. Based on these criteria, the study found that second-order and third-order data used in the existing cadastre do not meet this minimum standard, indicating that large portions of the cadastral dataset fall short of the required precision.

A comparison between orthophoto-derived parcel boundaries and ground-truth field survey data (from GPS and total station instruments) provided further insights. The geometric accuracy of parcel boundaries extracted from orthophotos was generally within the acceptable range for Class II or Class III mapping standards under ASPRS. However, this level of accuracy is not sufficient for legal cadastral purposes, which require higher precision for property delineation, legal adjudication, and land registration.

While orthophoto-based data can support urban planning, land use visualization, and preliminary assessments, it lacks the accuracy needed for authoritative cadastral documentation. Validation through ground control points (GCPs) remains essential. When GPS data were compared against digitized parcels derived from orthophotos, none of the GPS data met the ASPRS 7.5 cm accuracy

standard. In contrast, total station data consistently fulfilled this threshold, indicating that positional accuracy from total station surveys closely aligns with the orthophoto-derived parcels—though both still exhibit marginally lower precision than required for strict cadastral standards.

These findings underscore the need to integrate high-precision ground survey techniques and robust geodetic control networks into ongoing cadastral data updates in Adama City. Doing so will ensure that land parcel data meets legal and technical requirements, thereby supporting reliable land administration, dispute resolution, and property rights protection.

## **1.2.Recommendations**

- **Adopt Advanced Surveying Technologies**

Integrate high-precision GNSS technologies (such as RTK GPS), Total Stations, UAVs (drones), and high-resolution satellite imagery into cadastral surveying workflows. These technologies will significantly enhance the positional accuracy and reliability of land parcel data.

- **Establish a Robust Geodetic Control Network**

Develop a well-distributed and permanently marked geodetic control network by deploying Continuously Operating Reference Stations (CORS) or installing high-accuracy benchmarks. This network is essential to maintain consistent and accurate spatial referencing across all cadastral operations.

- **Implement Scheduled Map Updates and Revisions**

Conduct regular updates and revisions of cadastral maps to reflect real-world changes, especially in rapidly developing urban areas. This includes periodic re-surveying of land parcels to prevent spatial discrepancies and ensure the cadastral database remains current and reliable.

- **Enforce Rigorous Data Validation Procedures**

Adopt standardized protocols for geospatial data quality assurance, including topological consistency checks, Root Mean Square (RMS) error analysis, and comprehensive accuracy assessments. These procedures will ensure the integrity and reliability of cadastral data during digitization and integration processes.

- **Enhance Capacity Building and Training**

Provide continuous professional development opportunities for cadastral surveyors, GIS technicians, and land administration personnel. Training should focus on the use of modern surveying instruments, GIS software applications, and adherence to international data management standards.

- **Develop and Enforce National Cadastral and Geospatial Standards**

Promote the formulation and implementation of national standards and guidelines for cadastral surveying, mapping, and geospatial data sharing. This will facilitate interoperability, consistency, and data quality across various institutions involved in land administration.

## REFERENCES

- Abanmy, F., H. Khamees et al., 1995. An evaluation of DEM and orthophoto generation on Orthomax. In: ACSM/ASPRS Annual Convention & Exhibition, Technical papers, Vol 2, pp. 479-486.
- Accuracy of digital orthophotos. MSC thesis, The University of New Brunswick. Trinder, J.C., 1987. Measurements on digitized hardcopy images. *Photogrammetric Engineering and Remote Sensing*, 53(3), pp.315-321.
- Ackermann, F., 1994. Digital elevation models – techniques and application, quality standards, development. In: Symposium on Mapping and Geographic Information Systems, ISPRS, Arctur, D.; Zeiler, M. Parcels and the Cadastre. In *Designing Geodatabases: Case Studies in GIS Data Modeling*; ESRI Press: Redlands, CA, USA, 2004; pp. 166–219. [Google Scholar]
- Arctur, D.; Zeiler, M. Parcels and the Cadastre. In *Designing Geodatabases: Case Studies in GIS Data Modeling*; ESRI Press: Redlands, CA, USA, 2004; pp. 166–219.
- Athens, Ga., Vol.30 (4), pp. 421-432. Joachim Hole, 1996. Experience with the production of digital orthophotos. *Photogrammetric Engineering and Remote Sensing*, 62(10), pp. 1189-1194.
- Babalola, S. O. and Kardam, M. S. (2011). Developing a cadastral information system for part of Fadaman-mada area of Bauchi metropolis for sustainable development. *ATBU Journal of Environmental Technology*, 4(1): 105 – 118.
- Bennett, R.; Unger, E.-M.; Lemmen, C.; Dijkstra, P. Land administration maintenance: A review of the persistent problem and emerging fit-for-purpose solutions. *Land* 2021, 10, 509.
- Berber, M.; Dare, P.; Vaníček, P. Robustness Analysis of Two-Dimensional Networks. *J. Surv. Eng.* 2006, 132, 168–175. [Google Scholar] [CrossRef][Green Version]
- Čeh, M.; Gielsdorf, F.; Trobec, B.; Krivic, M.; Lisec, A. Improving the positional accuracy of traditional cadastral index maps with membrane adjustment in Slovenia. *ISPRS Int. J. Geo-Inf.* 2019, 8, 338.

- Cete, M., and Yomralioglu, T. (2004). Cadastre: the key component in urban-based information systems, FIG working week, Athens, Greece, 22 – 27.
- Daniel, T. (2014). Urban cadaster in Ethiopia. The municipal development partnership, Africa local government action forum presentation, 1 –15.
- Danko, D. Geospatial Metadata. In Handbook of Geographic Information; Springer: Berlin, Germany, 2012; pp. 359–392.
- ESRI. ArcGIS Parcel Fabric. Available online: <https://pro.arcgis.com/en/pro-app/2.8/help/data/parcel-editing/whatisparcelfabric.htm> (accessed on 20 December 2021).
- ESRI ArcGIS Parcel Fabric. Available online: <https://pro.arcgis.com/en/pro-app/2.8/help/data/parcel-editing/whatisparcelfabric.htm> (accessed on 20 December 2021).
- European Union Agency for the Space Programme. What Is SBAS? Available online: <https://www.euspa.europa.eu/european-space/eu-space-programme/what-sbas> (accessed on 20 December 2021).
- Femenia-Ribera, C.; Mora-Navarro, G.; Martinez-Llario, J. Advances in the coordination between the cadastre and land registry. *Land* 2021, 10, 81.
- FIG Policy Statement. Publication No. 11. FIG Statement on the Cadastre. International Federation of Surveyors. 1995. Available
- Foster, L.; Blanford, J. Improving cadastre: Development of a workflow prototype utilizing ESRI's Parcel Fabric. *URISA J.* 2013, 25, 63–74
- Grant, D.; McCamley, G.; Mitchell, D.; Enemark, S.; Zevenbergen, J. Upgrading Spatial Cadastres in Australia and New Zealand: Functions, Benefits & Optimal Spatial Uncertainty. 2018.
- Grant, D.; McCamley, G.; Mitchell, D.; Enemark, S.; Zevenbergen, J. Upgrading Spatial Cadastres in Australia and New Zealand: Functions, Benefits & Optimal Spatial Uncertainty. 2018. Available
- Hesse, W.; Benwell, G.; Williamson, I. Optimising, maintaining and updating the spatial accuracy of digital cadastral data bases. *Aust. Surv.* 1990, 35, 109–11

- Heuvelink, G.; Burrough, P.; Stein, A. Propagation of errors in spatial modelling with GIS. *Int. J. GIS* 1989, 3, 303–322.
- Lemmens, M. Land Administration. In *Geo-Information*; Springer: Dordrecht, the Netherlands, 2011; pp. 297–338.
- Liseč, A.; Navrátil, G. The Austrian land cadastre: From the earliest beginnings to the modern land information system. *Geod. Vestn.* 2014, 58, 482–516.
- Logan, D.A. *First Course in the Finite Element Method*, 6th ed.; Cengage Learning: Boston, MA, USA, 2016.
- Manzer, G., 1995. Practical consideration for avoiding problems in the production of digital orthophotos. *GEOMATIC*, 49(4), pp. 455-462.
- Mikhail, E, 1993. Quality of photogrammetric products from digital frame photography. In: *International Archives of photogrammetry and remote sensing Vol.29 (B2)*, pp.390-396. Pierre G.Simard, 1997.
- Ogundare, J.O. *Understanding Least Squares Estimation and Geomatics Data Analysis*; John Wiley & Sons: New Jersey, NJ, USA, 2019. [Google Scholar]
- Srinivasa Rao, S. (2004). Application of high-resolution satellite data for development of Land Information System (LIS).Ph.D. thesis, Andhra University, Visakhapatnam, 15 – 25.
- Todd, P.; Higgins, M.; Williams, G. *Levels of Maturity for Survey Infrastructure*; Queensland Government: Brisbane, Australia, 1999.
- Tong, X.; Shi, W.; Liu, D. Introducing scale parameters for adjusting area objects in GIS based on least squares and variance component estimation. *Int. J. Geo. Info. Sci.* 2009, 23, 1413–1432.
- Vaniček, P.; Craymer, M.; Krakiwsky, E. Robustness analysis of geodetic horizontal networks. *J. Geod.* 2001, 75, 199–209.
- Williamson, I Land administration “best practice” providing the infrastructure for land policy implementation. *Land Use Policy* 2001, 18, 297–307

Williamson, I. (1996). UN-FIG, Bogor declaration on cadastral reform. Report from United Nations interregional meeting of experts on the cadastre, Symposium on Cadastre and Land Management, 64th FIG Permanent Committee Meeting and Symposia, Singapore, Singapore Institute of Surveyors and Values, 64: 1- 5

Wolf, P.; Ghilani, C. Adjustment Computations: Statistics and Least Squares in Surveying and GIS, 3rd ed.; John Wiley & Sons: New York, NY, USA, 199

Solomon, and Berhanu, A. (2018). "Geodetic Datum Transformations in Ethiopia: Issues and Solutions." Journal of Geospatial Science, 4(1), 23-34.

#### Appendix I: Adama city 2nd order GCP's

##### ADAMA GROUND CONTROL POINTS IN ADINDAN UTM ZONE 37

NAME EASTING(ADINDAN) NORTHING(ADINDAN)

A001 529988.113 951086.665

A002 528224.374 950875.748

A003 527988.259 950053.99

A004 528614.985 950132.092

A005 529802.074 950187.56

A006 531132.436 949999.451

A007 532265.764 949862.459

A008 532757.95 949852.507

A009	534073.021	949839.662
A010	534965.72	950201.534
A011	534992.941	948833.745
A012	534099.213	949086.831
A013	532781.227	948643.001
A014	531842.969	949065.183
A015	531015.217	949091.507
A016	530090.638	948880.918
A017	529078.535	949014.629
A018	527680.761	949016.845
A019	526999.814	949006.656
A020	526640.995	948262.389
A021	528136.731	947625.197
A022	529057.405	947887.455
A023	530112.571	947944.912
A024	530934.841	947914.524
A025	532036.926	948067.827
A026	533255.319	947870.16
A027	533980.705	948070.546
A028	534640.264	947757.905
A029	526174.988	946896.693
A030	526979.704	946950.432
A031	528109.546	947129.073
A032	528991.189	946998.637
A033	530142.281	947044.304
A034	530997.033	946976.003

A035	531979.044	947084.867
A036	533098.091	946936.298
A037	534239.881	947156.986
A038	535189.299	947169.448
A039	536129.161	946865.765
A040	535951.284	945973.713
A041	535051.013	946059.816
A042	533998.883	945922.063
A043	532905.441	945988.294
A044	531907.311	945641.809
A045	531119.564	945967.332
A046	530315.635	946277.747
A047	529090.799	945657.41
A048	528109.868	946112.111
A049	526796.898	946108.695
A050	525947.373	945995.659
A051	525105.021	945921.044
A052	524734.205	945195.783
A053	525785.412	945153.817
A054	526874.274	944945.071
A055	527747.44	945373.526
A056	528877.061	944884.998
A057	530034.376	945300.045
A058	530996.824	945048.94
A059	532274.229	944948.428
A060	532805.816	944957.09

A061	534431.108	944814.183
A062	535009.136	945081.924
A063	533807.23	943833.099
A064	532968.878	944166.574
A065	533919.475	942388.875
A066	533021.651	941998.448
A067	532066.12	941912.971
A068	529970.64	942333.067
A069	530809.353	942227.792
A070	528602.278	941967.076
A071	528052.493	942045.138
A072	527046.238	942038.786
A073	526142.774	941745.524
A074	524483.184	941871.046
A075	524883.312	941851.332
A076	525913.623	941027.252
A077	527005.486	940890.487
A078	528042.249	940601.805
A079	528848.185	940890.966
A080	529952.866	940904.337
A081	531098.715	940958.836
A082	531971.245	941084.619
A083	533024.352	941033.145
A084	533969.966	940937.465
A085	531814.779	943974.552
A086	530840.811	944080.594

A087	530275.246	944145.91
A088	528949.931	943814.931
A089	528135.427	944064.572
A090	526893.772	944067.658
A091	525913.531	944001.088
A092	525205.621	943988.92
A093	524952.254	942993.087
A094	525795.409	943043.734
A095	526731.169	942952.273
A096	527758.586	942848.925
A097	528719.415	943106.873
A098	529839.278	942652.694
A099	530979.33	942969.25
A100	532004.849	942973.533
A101	532976.99	943018.229
A102	534004.391	942992.962
A103	523975.127	940000.958
A104	524678.467	939968.954
A105	525907.329	940039.604
A106	527162.233	939815.685
A107	528047.413	940026.58
A108	528935.933	940165.551
A109	528809.171	939724.953
A110	531018.971	940025.236
A111	531925.529	940053.683
A112	533002.489	940017.42

A113	534009.612	940003.41
A114	533015.71	938888.87
A115	532168.147	938943.347
A116	530688.171	939170.756
A117	529892.278	939017.724
A118	528817.44	938981.282
A119	527757.978	938916.856
A120	526969.816	939130.248
A121	525984.704	938996.714
A122	524652.93	939085.612
A123	525048.27	938316.419
A124	526411.359	937901.367
A125	527097.687	937977.109
A126	527990.381	937935.033
A127	529007.024	937898.531
A128	529936.356	938106.794
A129	530964.031	937993.216
A130	531874.963	938056.319
A131	531039.987	937045.565
A132	529825.352	936870.18
A133	528732.489	937309.409
A134	528124.201	937191.545
A135	526907.113	936931.601
A136	525990.955	936910.962
A137	523069.537	937065.992
A138	526959.895	936042.776

A139	527852.279	935803.665
A140	528659.794	936264.284
A141	530041.124	936301.464
A142	528741.876	934838.963
A143	528037.129	934911.474
A144	527008.309	934969.415
A145	525900.444	935049.787
A146	523989.012	939186.426
A147	523910.124	937852.226
A148	532311.081	947932.037
A149	531437.817	946803.677
A150	528446.038	945057.926
A151	531327.3	945843.559
A153	527405.618	942020.678
A154	527452.929	942278.767
A155	530508.451	941156.936
A156	530682.935	940732.68
A157	528890.576	939470.472
A158	532490.014	939473.577
A159	526549.589	936149.334

Appendix II: 3rd Order Adama city GCP's

Point Id	Easting (m)	Northing (m)
AD01	528042.2641	940601.8184
AD02	531018.9793	940025.2177

AD03 530508.2301 941156.7204  
AD04 529970.6621 942333.0818  
AD05 529841.9194 942653.5359  
AD06 527405.254 942020.6117  
AD07 527452.9299 942278.7707  
AD08 527752.1574 942845.5583  
AD09 528930.5634 943823.8179  
AD10 530052.1901 944100.4965  
AD11 530840.4487 944080.6076  
AD12 530016.8043 945320.5723  
AD13 530996.4389 945047.9315  
AD14 532274.2553 944948.4504  
AD15 531906.6907 945645.1748  
AD16 531330.1366 945845.7515  
AD17 531126.5044 945961.2271  
AD18 532905.4814 945988.3164  
AD19 531437.8629 946803.6999  
AD20 531979.0753 947084.8988  
AD21 533098.1077 946936.2456  
AD22 534518.7664 944801.1081  
AD23 533255.3534 947870.1144  
AD24 532781.2961 948642.9675  
AD25 530979.3646 942969.2475  
AD26 532066.0276 941912.9531  
AD27 528848.1746 940890.9686  
AD28 525606.5533 942862.8775

AD29	526740.1705	942950.5897
AD30	531597.419	947983.9455
AD31	531455.0105	948016.8994
AD32	531358.6506	948064.3474
AD33	531289.6143	948150.2942
AD34	531391.8576	948156.0301
AD35	531600.8119	948364.875
AD36	531628.7024	948444.4238
AD37	532104.4442	949179.0017
AD38	532182.8144	949253.4876
AD39	531922.3039	949408.8446
AD40	531820.0398	949303.9121
AD41	531645.7625	948877.1649
AD42	531736.8976	948849.9991
AD43	532279.6024	948120.6127
AD44	532257.5959	948106.4638
A055	528446.0529	945057.9465
BOKU	530351.3925	941764.6835

Appendix III Comparing precision of GPS points with digitized orthphoto land parcels

ID	X_Ortho X_RMSE	Y_Ortho Y_RMSE	X_GPS	Y_GPS	X_diff	y_diff	X_MAE	Y_MAE	X_MSE	Y_MSE
----	-------------------	-------------------	-------	-------	--------	--------	-------	-------	-------	-------

3	529772.117 0.00974	947090.0183	529772.017	947090.117	0.1	-0.0987	0.01
	529950.455 9.2E-05	9476950.173	529950.452	9476950.182	0.003	-0.0096	9E-06
	529749.555 9.8E-05	946519.3886	529749.561	946519.3787	-0.006	0.0099	3.6E-05
05	529561.18 1E-08	946593.2026	529561.17	946593.2027	0.0099	-0.0001	9.8E-
				0.010143	0.00993	0.002536	
	0.002483	0.050356	0.049829				
5	526787.89 1E-08	939380.5294	526787.881	939380.5295	0.009	-1E-04	8.1E-05
05	526721.706	939258.9673	526721.716	939258.9575	-0.01	0.0098	0.0001 9.6E-
	526401.543 0.0001	939358.4846	526401.534	939358.4744	0.009	0.0102	8.1E-05
	526457.531 3.6E-05	939495.299	526457.524	939495.293	0.007	0.006	4.9E-05
	5.9E-05	0.008818	0.007683	0.000311	0.00024	7.77E-05	
6	531144.904 0.00012	940726.4859	531144.805	940726.475	0.099	0.0109	0.009801
	531182.052 0.00012	940601.814	531182.153	940601.825	-0.101	-0.011	0.010201
	531028.593	940527.5611	531028.693	940527.5601	-0.1	0.001	0.01 1E-06
	530989.024 0.00885	940658.327	530989.122	940658.2329	-0.098	0.0941	0.009604
	0.002274	0.099506	0.047685	0.039606	0.0091	0.009901	

10	529886.694 0.0098	942348.425	529886.683	942348.326	0.011	0.099	0.000121	
	529937.487 0.00993	942369.0554	529937.488	942369.155	-0.001	-0.0996	1E-06	
	529949.658	942341.5386	529949.668	942341.6376	-0.01	-0.099	1E-04	0.0098
	529898.601	942320.788	529898.501	942320.888	0.1	-0.1	0.01	0.01
				0.010222	0.03953		0.002555	
	0.009882	0.050552	0.099408					
11	526865.412 9.8E-05	939965.0696	526865.4511	939965.0597	-0.039	0.0099	0.001529	
	526982.168 0.000324	939920.0709 9.8E-05	526982.186	939920.0808	-0.018	-0.0099		
	526840.647 0.00168	939534.38	526840.658	939534.339	-0.011	0.041	0.000121	
	526542.514 9.8E-05	939651.2202	526542.535	939651.2103	-0.021	0.0099	0.000441	
	526650.734 0.0001	939946.6546	526650.835	939946.6445	-0.101	0.0101	0.010201	
	526778.734 0.009801	939966.3396 9.8E-05	526778.635	939966.3495	0.099	-0.0099		
				0.022417	0.00218		0.003736	
	0.000363	0.061124	0.01904					
12	530989.024 0.00865	940658.327	530989.033	940658.42	-0.009	-0.093	8.1E-05	
	531028.593 0.0102	940527.5611	531028.574	940527.4601	0.019	0.101	0.000361	
	530851.796 0.01	940450.0703	530851.777	940450.1703	0.019	-0.1	0.000361	

	530794.254	940658.327	530794.265	940658.426	-0.011	-0.099	0.000121	
	0.0098							
				0.000924	0.03865		0.000231	
	0.009663	0.015199	0.098299					
13	529950.455	946950.1728	529950.444	946950.2726	0.011	-0.0998		
	0.000121	0.00996						
	530025.877	946884.9072	530025.866	946884.9173	0.0105	-0.0101		
	0.00011	0.0001						
	529925.452	946669.9915	529925.442	946669.9814	0.01	0.0101	0.0001	0.0001
07	529836.226	946707.845	529836.236	946707.8441	-0.01	0.0009	0.0001	8.1E-
				0.000431	0.01016		0.000108	
	0.002541	0.010383	0.05041					
14	527243.709	943440.861	527243.609	943440.762	0.1	0.099	0.01	0.0098
	527294.531	943444.861	527294.511	943444.761	0.02	0.1	0.0004	0.01
	527281.512	943391.2552	527281.511	943391.355	0.001	-0.0998		1E-06
	0.00996							
	527236.514	943403.0372	527236.523	943403.1373	-0.009	-0.1001		8.1E-
05	0.01002							
				0.010482	0.03978		0.00262	
	0.009945	0.051191	0.099726					

#### Appendix 4 Comparing precision of Total station points with digitized orthphoto land parcels

ID	X_Ortho X_MSE	Y_Ortho Y_MSE	X_Total sta X_RMSE	Total sta stastaX	stastaY	X_diff	y_diff	X_MAE	Y_MAE
----	------------------	------------------	-----------------------	----------------------	---------	--------	--------	-------	-------

3	529772.117 7.6E-05	947090.0183	529772.107	947090.027	0.01	-0.0087	0.0001
07	529950.455	9476950.173	529950.453	9476950.172	0.002	0.0008	4E-06 6.4E-
	529749.555 3.6E-07	946519.3886	529749.562	946519.388	-0.007	0.0006	4.9E-05
05	529561.18 1E-08	946593.2026	529561.187	946593.2027	-0.007	-0.0001	5.04E-
				0.000203	7.7E-05	5.09E-05	
	1.92E-05	0.007131	0.004379				
5	526787.89 1E-08	939380.5294	526787.881	939380.5295	0.009	-1E-04	8.1E-05
05	526721.706	939258.9673	526721.716	939258.9575	-0.01	0.0098	0.0001 9.6E-
	526401.543 0.0001	939358.4846	526401.534	939358.4744	0.009	0.0102	8.1E-05
	526457.531 3.6E-05	939495.299	526457.524	939495.293	0.007	0.006	4.9E-05
				0.000311	0.00024	7.77E-05	
	5.9E-05	0.006818	0.007683				
6	531144.904 0.00012	940726.4859	531144.905	940726.475	-0.001	0.0109	1E-06
	531182.052	940601.814	531182.053	940601.815	-1E-03	-0.001	1E-06 1E-06
	531028.593	940527.5611	531028.583	940527.5601	0.01	0.001	0.0001 1E-06
	530989.024 3.5E-05	940658.327	530989.022	940658.3329	0.002	-0.0059	4E-06
				0.000106	0.00016	2.65E-05	
	3.89E-05	0.005148	0.006237				

10	529886.694	942348.425	529886.683	942348.436	0.011	-0.011	0.000121	
	0.00012							
	529937.487	942369.0554	529937.488	942369.055	-0.001	0.0004	1E-06	1.4E-
07								
	529949.658	942341.5386	529949.668	942341.5376	-0.01	0.001	1E-04	1E-06
	529898.601	942320.788	529898.603	942320.799	-0.002	-0.011	4E-06	
	0.00012							
				0.000226	0.00024		5.65E-05	
	6.08E-05	0.007517	0.007796					
11	526865.412	939965.0696	526865.4211	939965.0597	-0.009	0.0099	8.28E-05	
	9.8E-05							
	526982.168	939920.0709	526982.166	939920.0708	0.002	0.0001	4E-06	1E-08
	526840.647	939534.38	526840.658	939534.389	-0.011	-0.009	0.000121	
	8.1E-05							
	526542.514	939651.2202	526542.515	939651.2103	-0.001	0.0099	1E-06	9.8E-
05								
	526650.734	939946.6546	526650.735	939946.6545	-1E-03	0.0001	1E-06	1E-08
	526778.734	939966.3396	526778.735	939966.3385	-1E-03	0.0011	1E-06	1.2E-
06								
				0.000211	0.00028		3.51E-05	
	4.64E-05	0.005927	0.00681					
12	530989.024	940658.327	530989.023	940658.333	0.001	-0.006	1E-06	3.6E-
05								
	531028.593	940527.5611	531028.584	940527.5601	0.009	0.001	8.1E-05	
	1E-06							
	530851.796	940450.0703	530851.787	940450.0603	0.009	0.01	8.1E-05	
	0.0001							

	530794.254 1E-06	940658.327	530794.265	940658.326	-0.011	0.001	0.000121	
				0.000284	0.00014	7.1E-05		
	3.45E-05	0.007426	0.005874					
13	529950.455 0.000121	946950.1728 9.6E-05	529950.444	946950.1826	0.011	-0.0098		
	530025.877 1E-08	946884.9072	530025.876	946884.9073	0.0005	-1E-04	2.5E-07	
	529925.452	946669.9915	529925.454	946669.9814	-0.002	0.0101	4E-06	0.0001
07	529836.226	946707.845	529836.236	946707.8441	-0.01	0.0009	0.0001	8.1E-
				0.000225	0.0002	5.63E-05	4.97E-	
05	0.007504	0.007051						
14	527243.709 0.00012	943440.861	527243.719	943440.872	-0.01	-0.011	0.0001	
	527294.531	943444.861	527294.532	943444.863	-0.001	-0.002	1E-06	4E-06
	527281.512 1.7E-06	943391.2552	527281.511	943391.2565	0.001	-0.0013	1E-06	
	527236.514	943403.0372	527236.513	943403.0373	0.001	-1E-04	1E-06	1E-08
				0.000103	0.00013	2.58E-05		
	3.17E-05	0.005074	0.005628					