Comparison between Conventional and Fit-for-Purpose Cadastral Mapping Practices in Ekiti State, Nigeria

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Key words: Access to land; Cadastre; Digital Cadastre; GNSS/GPS; Land Management; Low-Cost Technology; Photogrammetry; Professional Practice; Security of Tenure; Land Demarcation; Cadastral Mapping; Land Administration; Land Governance

SUMMARY

Cadastral mapping plays a crucial role in managing and governing land resources, ensuring secure tenure, and supporting sustainable development. In Ekiti State, Nigeria, where land-related conflicts and challenges persist among communities and individuals, and the extent of registered and unregistered land remains uncertain, the adoption of effective cadastral mapping practices is essential for facilitating land governance. This research examines the differences and consequences of employing conventional techniques vis-à-vis the "fit-for-purpose" (FFP) approach. Specifically, this study contrasts the conventional use of theodolite traverse and Real-Time Kinematic Global Navigation Satellite System (RTK GNSS) surveys with the application of high-resolution aerial imagery for cadastral mapping as an FFP alternative in Ekiti State Nigeria. The comparison of cadastral mapping methods was carried out by evaluating the processes and outcomes based on time, cost, and accuracy. Additionally, an analysis of relevant documents guiding cadastral mapping in Nigeria was conducted to understand the possible adoption of earth-observation data for fit-for-purpose cadastral mapping approaches and their potential to accelerate land registration in Ekiti State. The study found that using high-resolution aerial imagery produces results that are consistent with conventional surveying instruments used for cadastral mapping in Nigeria. In terms of efficiency, the RTK GNSS method was the quickest for data collection, while the theodolite method was the slowest. The very high-resolution imagery obtained gives the notable advantage of its abundant topographic data, which supports the creation of a detailed 3D cadastral dataset. This dataset can be used to build a more accurate digital representation, benefiting land administration, management, and sustainable development efforts. However, the research identified a challenge related to obtaining high-resolution imagery. This underscores the need for regulatory adjustments concerning the use of Unmanned Aerial Vehicles (UAVs) in cadastral mapping processes and the importance of having tools to aid faster UAV imagery processing. In conclusion, this research contributes valuable insights into cadastral mapping, administration and governance, particularly in Ekiti State, Nigeria. It advocates for a progressive shift towards technology-driven cadastral mapping approaches, capable of accelerating land registration processes and enhancing the responsible management of land resources. It recommends regulatory reform and innovative solutions to promote sustainable development through effective land governance and emphasizes the need for improvements to the legal and institutional frameworks of land administration in the state.

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1.0 INTRODUCTION

1.1 Research Context

1.1.1 Land Governance and Cadastral Mapping Practices

Effective land governance is contingent on sound land demarcation and cadastral mapping practices (Hull & Whittal, 2021; Taiwo et al., 2022). Land governance encompasses the policies, laws, institutions, and processes that regulate land rights, land use, and land tenure (Williamson, 2010). Cadastral mapping is a critical aspect of managing and governing land resources. Cadastral mapping encompasses the identification of boundary points and the determination of the location of such points. It involves the establishment of clear and legally recognized boundaries for land parcels. Cadastral mapping is pivotal to establishing and enforcing property rights, ensuring land tenure security, reducing land-related disputes, facilitating land market transactions for the population it serves and overall land management (UN-HABITAT, 2012). Effective cadastral mapping practices promote transparency, ensure secure tenure, and support sustainable development. Across the globe, various countries employ diverse methodologies for cadastral mapping, each influenced by historical, cultural, and technological factors (Enemark et al., 2014).

1.1.2 Overview of Cadastral Mapping Practices in Ekiti State

Conventional cadastral mapping methods typically rely on traditional surveying techniques and physical markers for cadastral mapping. Matsimbe et al., 2022 argue that while traditional methods have been employed for centuries, they often suffer from limitations, including lengthy processing times, high costs, and susceptibility to human errors. These drawbacks have led to the exploration of alternative approaches that can streamline cadastral mapping processes. In Ekiti State, as in many parts of Nigeria, cadastral mapping has taken a gradual development with technology, from the use of tapes and chains to manual and digital theodolites and then GNSS receivers. Surveyors use these tools to demarcate parcels for the preparation of survey plans, which a majority consider sufficient to show the extent of their land. A few then proceed to pursue the acquisition of certificates of occupancy with the received survey plans, which is the government-recognised document to confer title or ownership to interested parties. The Land Use Act of 1978 recognises both the statutory and customary rights of occupancy. However, what exists in practice is that persons within the customary context acquire a survey plan and proceed to pursue statutory rights of occupancy. The conventional approach to cadastral mapping in Ekiti state employs the use of beacons and physical markers to demarcate land boundaries. These markers serve as reference points but are susceptible to displacement or disputes over their precise location. In practice, people adopt fences to demarcate their properties. The creation of a land survey plan in the state is digital but without the use of databases. Submitted record copies are charted on CAD platforms where consistency with existing surveys is checked before the survey is regarded as complete. In many developed nations, cadastral mapping has evolved to incorporate advanced technologies such as Geographic Information Systems (GIS), Global Navigation Satellite Systems (GNSS), and photogrammetry (Koeva et al., 2020; Matsimbe et al., 2022). These technologies have enhanced the accuracy and efficiency of cadastral mapping processes, enabling precise mapping and documentation of land boundaries.

1.1.2 The Fit-for-Purpose Land Administration Approach

In the 21st century with increased knowledge and quest for land rights, it is important to ensure that cadastral mapping and of course administration is flexible, inclusive, participatory, affordable, reliable, attainable, and upgradeable to meet the needs of the society, which underscores the Fit-for-Purpose (FFP) approach. The Fit-for-Purpose Land Administration approach represents a paradigm shift in land administration (Enemark et al., 2014). It aims to expedite land registration and enhance tenure security, particularly in regions with limited resources and complex land tenure systems (Barry, 2018; Enemark et al., 2014). FFPLA leverages innovative low-cost technologies such as GNSS devices, aerial imageries, and participatory methodologies; to empower communities and individuals in the cadastral mapping process (Enemark et al., 2014). The FFP approach emphasizes participatory cadastral mapping, involving communities, landowners, and other stakeholders in the demarcation process (Asiama et al., 2017; Land & Network, 2010). This collaborative approach promotes local knowledge and buy-in, contributing to more reliable boundary determination (Enemark et al., 2014; Taiwo et al., 2022). It supports low-cost and accessible technology to enable field surveyors and community members to capture geographic coordinates efficiently. Geospatial data collected through FFP methods are processed digitally, reducing the time required for data analysis and map creation. Geographic Information Systems (GIS) and cloud-based platforms facilitate the rapid generation of land records.

The FFPLA approach has gained international recognition as a viable solution for addressing land-related challenges in various contexts because of its potential to expedite land registration, enhance tenure security, and improve land administration (Balas et al., 2021; R. M. Bennett et al., 2021; Taiwo & Mabakeng, 2023). Its application in various countries has shown promising results in terms of efficiency and fast-tracking of land registration. Its success stories span from Latin America to Africa, where it has enabled rapid land registration and increased land tenure security for millions of people.

1.2 Problem Statement

In Ekiti State, as in many parts of Nigeria and other countries of the world with untrackable or incomplete coverage of land registration, the complexities of land governance and the persistence of land-related conflicts underscore the need for alternative approaches. Despite the proven success of the FFPLA approach in several countries, the implementation of its principle is still lacking in Ekiti state and several other states of Nigeria as land administration remains inefficient and unsustainable. The Fit-for-Purpose (FFP) approach promotes the use of aerial imagery and other innovative techniques for land administration (Bennett et al., 2020; Enemark et al., 2014; Koeva et al., 2020; Tan et al., 2021). The increasing prevalence of Unmanned

Aerial Vehicles (UAVs) and their capacity to capture high-resolution orthophotos can achieve accuracy levels that are consistent with the requirements of cadastral surveying using traditional methods like theodolites, total stations, and some Global Navigation Satellite Systems (GNSS) (Matsimbe et al., 2022; Stöcker et al., 2022). Despite the presence of these advantages, aerial imageries are not being used for cadastral mapping in Ekiti state, thereby leaving the question of how fit the technology is for providing scalable tenure security to the citizens unanswered. Although surveys in Ekiti state are one of the cheapest compared to other states of Nigeria, this non-adoption of innovative aerial technologies in land administration in the state and similar local contexts poses challenges to the efficiency and cost-effectiveness of cadastral mapping practices in such contexts. This issue underscores the need to investigate the integration of aerial imagery and UAV technology within cadastral mapping processes, particularly in the context of the Fit-for-Purpose (FFP) cadastral mapping approach.

1.3 Research Objective

This research aims to assess and compare the obstacles and possibilities associated with the adoption of aerial imagery and UAV technology versus conventional cadastral mapping practices in Ekiti State, with a particular focus on the Fit-for-Purpose approach. The investigation centred on cost, time, and efficiency as key factors of analysis. To accomplish this, the following research objectives were addressed:

1. Examine the current cadastral mapping practices in Ekiti State, Nigeria
2. Examine how conventional cadastral mapping practices in the state compare with the FFP approach
3. Identify the required regulatory adaptations and technological advancements necessary to enable the efficient utilization of aerial imagery and UAVs in cadastral mapping processes within Ekiti State and comparable regions.

This paper delves into the significance of the FFP approach and its utilization of aerial imagery as a means to enhance cadastral mapping practices. In the Nigerian context, the intricacies of cadastral mapping are influenced by a set of regulations and guidelines. These regulations not only define the processes involved but also shape the tools and technologies that can be employed for effective cadastral mapping.

Subsequent aspects of the paper explain the methods used in the study, including the study area, data collection, and data analysis approaches. The paper presents the results of the study, including the findings on the obstacles and possibilities associated with the adoption of aerial imagery and UAV technology in cadastral mapping. The paper concludes with a discussion of the implications of the findings for cadastral mapping in Ekiti State, Nigeria and other places with similar situations.

1.4 Limitation

This work did not consider the use of single GNSS receivers with Continuously Operating Reference stations because CORS networks are seldom used in Ekiti state.

2.0 MATERIALS AND METHODS

2.1 Study Area

In Nigeria, land is principally administered with the provisions of the Land Use Act (LUA) Chapter 202 Laws of the Federation of Nigeria, 1990. Likewise, surveying activities are regulated generally across Nigerian states by the Surveyors Council of Nigeria, which produces the same documents for regulating the practice of surveying across the entire country. This underscores the similarity of land administration practices across the nation. However, some states have some subsidiary rules guiding land administration. Emphasis was placed on Ekiti State in this research because Ekiti State belongs to the majority class that operates the generally acceptable documents.

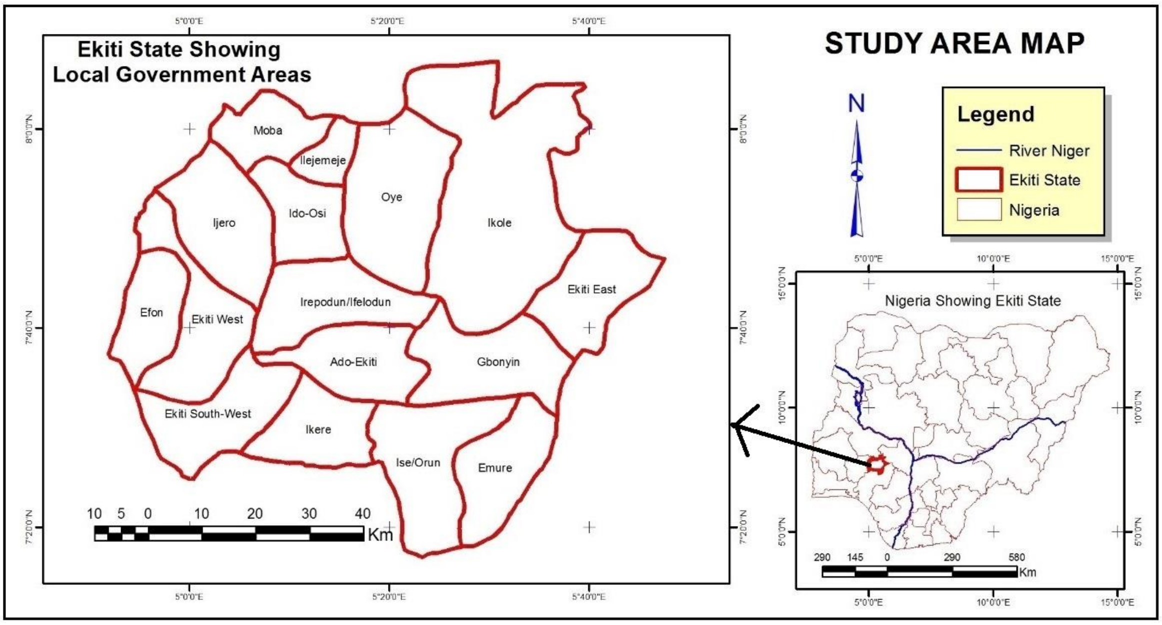

Figure 1: Study Area Map (Taiwo 2018)

Ekiti State, located between latitudes 7º 16'N and 8º 7'N and longitudes 4º 51'E and 5º 48'E, is situated in southwestern Nigeria. It shares its boundaries with Kwara State to the north, Ondo State to the south and part of the southeast, Kogi State to the east, and Osun State to the west. Spanning approximately 5,873 square kilometres, Ekiti State covers a relatively small landmass in comparison to other Nigerian states, covering only 0.57% of the country's total land area. The name "Ekiti" originates from the Yoruba word for hills, signifying its hilly terrain. The landscape is characterized by undulating terrain, with elevations ranging from approximately 291 meters above sea level in the northeastern region, near Iye–Ekiti, to the highest point at around 765 meters above sea level in Ogotun–Ekiti, located in the southwestern part of the state (Taiwo, 2018).

The old school of Engineering of the Federal Polytechnic Ado-Ekiti and Toluwani Bakery part of Olanrewaju Community, Erifun, Ado-Ekiti were chosen as the study area based on their diverse terrain complexity, and land cover characteristics, which are representative of the challenges often encountered in cadastral surveying in the tropics. The locations were also selected based on permission to conduct UAV flights and data availability.

2.2 Data Acquisition and Processing Methods

The theodolite traverse has long been a staple in cadastral mapping in Nigeria. It involves precise measurements using theodolites, angular measurements, and chaining. The total station is a more accurate form of theodolite that uses digital means for angular measurements and employs electromagnetic waves for distance measurement instead of tapes. Boundaries are marked on the ground with physical markers, and their measurements are then recorded in cadastral maps. RTK GNSS surveys have gained popularity due to their efficiency. They rely on satellite-based positioning systems to provide real-time, centimetre-to-millimetre-level accuracy. These surveys are comparatively faster than the theodolite traverse but require specialized equipment. The FFP approach canvasses for the use of aerial imagery or other easily accessible and widely available tools for cadastral mapping. This approach leverages the capabilities of Unmanned Aerial Vehicles (UAVs) equipped with cameras to capture detailed aerial images. These images are processed to orthophoto where precise land boundaries can be extracted.

The direct observation methodology adopted for this research provides an understanding of the current landscape of cadastral mapping and its potential for improvement through the adoption of FFP methods. The study employed CHCNAV i50 Global Navigation Satellite System (GNSS) receivers, Mavic Pro Platinum UAV (Unmanned Aerial Vehicle), and South T160s Digital Theodolite for measuring the delineated points. CHCNAV i50 GNSS receivers were used based on their wide availability in Ekiti State Nigeria. Mavic Pro Platinum UAV was used to show the possibility of using low-cost advanced surveying equipment. Having gathered contextual insights into cadastral survey practices in the state, South T160s Digital Theodolite was used because of its availability and to ensure the research captures the perspective of those who observe with tapes in the states. South NTS 352R total station was also used. Table 1 below shows the list of equipment and other materials used in this work:

Table 1: List of Equipment

S/No.	Equipment	Purpose
1.	CHCNAV i50 GNSS receivers	GNSS coordination,
2.	Mavic Pro Platinum UAV, Samsung S8 for UAV screen data and accessories.	UAV flight
3.	South T160s Digital Theodolite and accessories	Theodolite Traverse
4.	South NTS 352R total station	Traversing

5.	HP ENVY Laptop 13 - ba1xxx	Image processing, data processing, comparison and report writing
6.	Agisoft Metashape Professional Version 1.5.5 Build 9097 (64-bit)	UAV Image Processing Software
7.	WebODM Lightning	UAV Image Processing Software
8.	LibreOffice Calc	Data Comparison
9.	Pix4DCapture	Flight Planning
10	QGIS 2.14.17	Spatial analysis
11.	20 x 20 and 30 x 30 mm Ground Markers	For Ground Control Point and Point of Interest Identification

The survey of the Old School of Engineering was done such that Five boundary pillars of approximately 18cm x 18cm dimension were established around the area and an existing control point within the area was adopted as one of the boundary beacons. GNSS, electronic theodolite and UAV were used in the Old School of Engineering. The survey of the Toluwani Bakery area was done by observing the pillars and half fences in the area at various times. GNSS, total station and UAVs were used in the area. Below are the procedures employed in using the equipment.

1. CHCNAV i50 GNSS receivers: to acquire GNSS observations for the Old School of Engineering Area, CHCNAV i50 GNSS receivers were employed to acquire precise geographic coordinates for ground markers and checkpoints within the study areas in RTK mode. This device utilizes signals from global navigation satellites to determine accurate positions on the Earth's surface. Adopting the differential mode, a receiver with radio broadcast accessories was set up at the base station FPA 164s - second order control - having its coordinates as 840006.157mN, 753778.975mE and 377.001mH (UTM Zone 31 Minna Datum). The second receiver and its PDA were used as a rover to capture the coordinates of features and ground markers around the area to be mapped. The collected GNSS data was exported into CSV format for further processing. The acquired data served as the reference for the comparison. For the Toluwani Bakery Area, the base was set on FGPEK036 841810.329mN, 749248.739mE, 384.438mH, a second-order control in the area. And observations were made.
2. South T160s Digital Theodolite: The South T160s digital theodolite was utilized to measure angles, and distances were measured by ground taping. Angular measurements were done on both faces. The field book was reduced, computations were manually done with computation sheets (See Appendix) and the final coordinates of points were typed into CSV format using LibreCalc software.

3. South NTS 352R total station: Control points were foremost established with south S82 receivers before the South NTS 352R total station was used in observing the points necessary for demarcation in the area.

Mavic Pro Platinum UAV: The Mavic Pro Platinum drone was used for aerial data acquisition. For the UAV Old School of Engineering area, the UAV was programmed to follow a predetermined flight path at 100m above the home point to ensure comprehensive coverage of the study area. Equipped with a 10mp resolution camera, the double grid mode of Pix4Dcapture was adopted to acquire images with a frontal overlap of 80% and side lap of 72% using a 70^{o} camera angle at 100m flying height above the home point. 287 m x 269 m was covered. A total of 5631m path was traversed within 16 mins 37s flight time during which 298 images of the study area were acquired. This process enabled the collection of aerial imagery for both photogrammetric analyses. Agisoft Metashape Professional was used in processing aerial imagery and generating 3D point clouds, orthophotos, and digital surface models (DSMs). The DEM created was imported into QGIS and the “Sample Raster Values" tool of QGIS that creates a new vector layer with the same attributes of the input layer and the raster values corresponding to the point location was used in extracting elevation values from the DEM.

For the Toluwani Bakery Area, a ground sampling distance of 3.2cm/pix was targeted. The same observation methods as described above were followed except that GCPs were not used during the photogrammetric image processing. After the orthophoto generation, the orthophoto was georeferenced with coordinates of known points on QGIS 2.14.17 before the coordinates of comparison points were extracted from the georeferenced image.

2.3. GNSS Data Validation Method

GNSS is majorly used in establishing controls in Ekiti State Nigeria. FPA 164s was established using the static observation method of GNSS surveying techniques by the Federal Polytechnic Ado-Ekiti with FGP EKY 036 as the base. FGP EKY 036 was established as second-order GNSS control points in Ekiti State. Controls of the FGP series are used as a base for control point densification in the state.

During the GNSS survey carried out in this work, the Real Time Kinematic mode of GNSS observation method was adopted by ensuring a base–rover configuration. The observations were calibrated using existing control points of known coordinates. In case 1, FPA 164s was used for calibration. A difference of -0.0145mN, -0.0012mE and -0.0004mH was observed between the given and obtained GNSS coordinates after calibration.

2.4 Data Analysis Methods

2.41. Comparative Analysis

Personal observations were made during the GNSS observations, electronic theodolite traverse exercise, Total Station traverse and UAV flight data acquisition, processing, and information extraction. The three methods were compared based on accuracy, time efficiency, and cost-effectiveness. The positional accuracy was evaluated by comparing the coordinates obtained from UAV, electronic theodolite methods and total station traverse with the GNSS coordinates. Root Mean Square Errors (RMSE) were computed and compared to identify the most positionally accurate technique. The time required for data acquisition, processing, and final results computation were also compared. The expenses associated with each method, including approximate equipment cost, personnel cost, and data processing requirements, were analysed. This approach allowed for a thorough assessment of the advantages and limitations of each data acquisition method.

2.5 Document analysis

The Land Use Act (LUA) Chapter 202 Laws of the Federation of Nigeria, 1990; the Survey Coordination Act and the Surveyors Council of Nigeria (SURCON) specification for cadastral survey was studied to identify the required regulatory adaptations necessary to enable the efficient utilization of aerial imagery and UAVs in cadastral mapping processes within Ekiti State and comparable states.

3.0 RESULTS AND DISCUSSIONS

3.1 Results of Cadastral mapping Practices: Case 1

1. RTK GNSS Observation: A total of 70 RTK GNSS observations were made within 114 minutes. 10 minutes was earlier used in setting up the base station receiver, which amounts to a total of 124 minutes. The complete data is shown in Appendix Section
2. Theodolite Traversing: 6 pillar points and 29 detail points comprising roads, buildings and electric poles were observed for the theodolite traverse. Angular measurements were carried out with the Theodolite and distances were measured by a steel band tape. 33 spot heights were observed along the perimeter of the area using Wild Automatic Level, and 11 spot heights were observed within the perimeter covered by the area using tachometer methods.

3. Aerial Photo: 298 images were acquired to cover an area of 21.8 ha. While the flying altitude was preset at 100m, an average flying height of 114m was computed based on the geography of the terrain. The ground resolution of the orthophoto produced was 3.52 cm/pix. The UAV mapping carried out produced a 14.1 cm/pix resolution (50.5 points/m² Point density) Digital Elevation Model. Below is a screenshot from the orthophoto produced:

Figure 2.0 Sample Orthophoto showing comparison points for the Old School of Engineering Area

3.2 Results of Land Demarcation Practices: Case 2

1. RTK GNSS Observation: A total of 8 points were observed using the RTK GNSS within 4 minutes 15 seconds after the base was setup. The complete data is contained in the Appendix.
2. Total Station Traversing: 4 pillar points were observed using the South NTS 352R total station.
3. Aerial Photo: 262 images were acquired to cover an area of 0.6462 ha. While the flying altitude was preset at 50m, 112 of the 262 images produced acquired were processed using WebODM to leverage the cloud processing option and aid in fast-tracking the image processing. The Average Ground Sampling Distance of the orthophoto produced was 3.2 cm/pix. Below is a screenshot from the ortho imagery produced:

Figure 3.0: Sample Orthophoto Showing comparison points for Toluwani Bakery

3.3 Comparative Analysis of Cadastral Mapping Methods

3.3.1 Positional Accuracy - RTK GNSS Survey, Theodolite Traverse and UAV Mapping

In the first case, the RMSE of the 4 points identifiable in the 3 methods used were computed. While adopting the GNSS method data as a reference, an RMSE of 2.405 was obtained for the theodolite traverse exercise and an RMSE of 1.013 was obtained for the UAV flight Northings and Eastings coordinates. The higher RMSE obtained in the theodolite traverse exercise when compared with the UAV mapping technique adopted shows that the UAV mapping technique could produce better accuracy than the conventional electronic theodolite traverse method.

Table 2: RMSE for RTK GNSS Survey, Theodolite Traverse and UAV Mapping

	GNSS Survey		ET Theodolite					
Point ID	Northings (m)	Eastings(m)	Northings (m)	Eastings(m)	N_{ET} - N_{GNSS}	E_{ET} – E_{GNSS}	$(N_{ET} – N_{GNSS})^2$	$(E_{ET} – E_{GNSS})^2$
PL1	839438.661	753623.234	839436.986	753622.652	-1.675	-0.582	2.805	0.339
PL2	839459.995	753528.595	839458.325	753528.003	-1.670	-0.592	2.788	0.351
PL4	839499.468	753363.965	839498.426	753360.806	-1.042	-3.159	1.085	9.979
PL5	839628.509	753426.457	839629.257	753424.171	0.748	-2.286	0.560	5.226
							1.345	1.993
				Electronic Theodolite Traverse RMSE:			2.405	
	GNSS Survey		UAV					
Point ID	Northings (m)	Eastings(m)	Northings (m)	Eastings(m)	N_{UAV} - N_{GNSS}	E_{UAV} - E_{GNSS}	$(N_{UAV} – N_{GNSS})$	$(E_{UAV} – E_{GNSS})^2$
PL1	839438.661	753623.234	839439.08	753622.048	0.419	-1.186	0.176	1.407
PL2	839459.995	753528.595	839460.298	753527.587	0.303	-1.008	0.092	1.016
PL4	839499.468	753363.965	839499.282	753363.309	-0.185	-0.656	0.034	0.430
PL5	839628.509	753426.457	839628.338	753425.499	-0.171	-0.958	0.029	0.918
							0.288	0.971
					UAV Mapping RMSE:		1.013	

3.3.2 Positional Accuracy - RTK GNSS Survey, Total Station Traverse and UAV Mapping

Likewise, the positional accuracy of the GNSS, Total Station and UAV mapping in case 2 was examined. The result of the process is tabulated in Table 3. The RMSE of the 4 points identifiable in the 3 methods used were computed, 1.320 and 1.321 were observed as the RMS of the Total station and UAV-based techniques when they were compared to the GNSS method. The similarity of RMSE between the Total station and UAV-based techniques indicates similar accuracy levels between the procedures.

Table 3: RMSE for RTK GNSS Survey, Total Station Traverse and UAV Mapping

	GNSS Survey		Total Station					
Point ID	Northings (m)	Eastings(m)	Northings (m	Eastings(m)	N_{ET} - N_{GNSS}	E_{ET} – E_{GNSS}	$(N_{ET} – N_{GNSS})^2$	$(E_{ET} – E_{GNSS})^2$
TIO1	840233.221	751795.695	840234.467	751796.359	1.246	0.665	1.553	0.442
TIO2	840225.935	751831.864	840227.099	751832.621	1.164	0.757	1.355	0.573
TIO3	840206.669	751822.243	840207.816	751822.434	1.147	0.191	1.316	0.036
TIO4	840210.044	751783.250	840211.269	751783.685	1.225	0.435	1.501	0.189
							1.196	0.557
				Total StationTraverse RMSE:			1.320	
	GNSS Survey		UAV					
Point ID	Northings (m)	Eastings(m)	Northings (m	Eastings(m)	N_{UAV} - N_{GNS}	E_{UAV} - E_{GNSS}	$(N_{UAV} – N_{GNSS})$	$(E_{UAV} – E_{GNSS})^2$
TIO1	840233.221	751795.695	840234.401	751796.281	1.180	0.586	1.392	0.344
TIO2	840225.935	751831.864	840227.217	751832.650	1.282	0.785	1.645	0.617
TIO3	840206.669	751822.243	840207.825	751822.395	1.156	0.151	1.337	0.023
TIO4	840210.044	751783.250	840211.221	751783.738	1.178	0.487	1.387	0.237
							1.200	0.553
					UAV Mapping RMSE:		1.321	

To further confirm the accuracy of the procedure, the area of the plot used for comparison was computed from the 3 sets of data obtained from the 3 different methods The result of the process is tabulated in Table 3. The areas computed in square meters were 856.347, 858.480 and 858.794 for GNSS, Total Station and UAV. A discrepancy of 2.134 Sq. Meters and 2.447 Sq. Meters were observed between the areas of Total Station and UAV compared to that of the GNSS.

3.4 Presentation of findings

Table 4 shows how fit for cadastral mapping are the methods tested. The table underlines the inability of UAV mapping techniques or aerial images to stand alone without GNSS technologies. Aerial imageries will become the rule of thumb for land administration when UAVs can carry receivers with precise point positioning facilities.

Table 4: Fitness of RTK GNSS, Theodolite Traversing, Total Station Traverse and UAV

	RTK GNSS	**Theodolite Traverse**	**Total Station Traverse**	**UAV Mapping**
Efficiency (Time)	Most Efficient	Least Efficient	Less Efficient	Efficient
Cost-Effectiveness	Most Cost-Effective	Not Cost-Effective	Least Cost-Effective	Cost-Effective
Accuracy	Most Accurate	Least Accurate	Accurate	Accurate
Coverage	Good Coverage	Least coverage	Low Coverage	Widest Coverage

3.4.1 Time Efficiency

In all cases, aside from the 10 minutes used for setting up the base station, the RTK GNSS surveys were identified as the quickest method for data collection. The 115 minutes used to gather 70 data over the 287 m x 269 m area was largely used to walk around the large expanse of land. Only 7 minutes was required to coordinate the 8 points measured during phase 2 of the area observed in the Toluwani Bakery Area of Olanrewaju Community, Erifun, Ado-Ekiti.

Considering the time required in setting up the theodolite at all the instrument stations and moving targets to and from all observation points, the use of theodolite traverse was observed to be the least efficient of the methods tested. Next was the use of total station because a combination of GNSS and total station is required except in cases where the area to be surveyed is coterminous with existing survey beacons or where control points are proximal to the area.

The UAV flight process was considered to be efficient. Only 16 minutes 37 seconds was required to acquire the 298 images that covered a 5631m flight path, while only 4 minutes 15 seconds was required to cover the 6462 Sq Meters area around Toluwani Bakery area. While the time required during the field exercise of the UAV flights was quite little compared to other surveying activities, the time required for processing locally and using the cloud considerably differed. Processing the 298 images locally took a total of 1 day 19 hours, 10 minutes and 58 seconds aside from the time used in designing the workflow. Whereas, 112 images were selected for cloud processing out of the 112 images of the Toluwani Bakery area took only 15 minutes 55 seconds.

3.4.2 Cost Analysis

Estimated at USD 2600, the CHC GNSS receivers were deemed the most cost-effective in terms of cost because it was necessary for every other method and it is readily available for use in Ekiti state Nigeria. The South T160s Digital Theodolite and accessories used are no longer available for sale in the market. However, it is still readily used by students and practitioners in the state. The South NTS 352R total station was regarded as the least effective. New ones are no longer available for sale but the fairly used ones that can be bought were estimated as 1,600USD. New total stations now cost around 400 USD. Likewise, the South T160s Digital Theodolite is no longer available for sale. However, the fairly used ones are estimated at 600 USD. The Mavic Pro platinum UAV is estimated at 1000 USD. Newer versions of UAVs are estimated at 2500 USD, hence it was regarded as the most cost-effective, especially because of the large volume of data it can gather and the large area it can cover easily.

CHC GNSS receivers are mostly used in Ekiti state. To rent a CHC GNSS receiver in the state currently costs between 10-20 USD, which is relatively available for use. However, the challenge of setting the base on a known station which could be sometimes as far as kilometers away from the site poses a constraint in the use of GNSS receivers.

3.4.3 Accuracy

High-resolution aerial imagery was found to produce results compliant with the accepted 1:3000 cm specification for cadastral mapping in Nigeria. This adherence to mapping standards shows how much innovative technologies have advanced the use of aerial imagery for cadastral mapping. The GNSS method is a more accurate but field-intensive method of observation. The RMSE of 2.006 observed when comparing the GNSS method with theodolite traverse indicates a lower level of accuracy when compared with the available methods. Whereas, the RMSE of 1.101 between the GNSS and UAV mapping methods indicates a comparatively higher accuracy than that of the electronic theodolite traverse method.

3.4.4 Coverage

Amidst all methods, the use of UAVs or aerial photos was notably the approach that covered a large expanse with great detail. Using GNSS ranked second, Total station ranked third and electronic theodolite ranked lowest. The very high-resolution imagery obtained has the notable advantage of its abundant topographic data. This topographic data can be used to create a detailed 3D cadastral dataset, which is a digital representation of land that includes its boundaries, ownership, and other relevant information. This dataset can be used to build a more accurate digital representation of land, which can benefit land administration, management, and sustainable development efforts. For example, it can be used to identify and track changes in land use, assess the impact of development projects on the environment, build a digital twin of the environment and plan for future development.

3.5 Result of Document Analysis

The review conducted on the Land Use Act (LUA) Chapter 202 Laws of the Federation of Nigeria, 1990; the Survey Coordination Act and the SURCON specification for cadastral and topographical survey reveals the lack of domesticated standards and guidelines for cadastral mapping with aerial imageries or UAVs in Ekiti state and Nigeria as a whole.

The LUA serves as an act that vests land in the territory of each state, except land vested in the Federal Government or its agencies, solely in the governor of the state, who holds such land in trust for the people. The act encompasses laws governing the general principles of land tenure, the powers of Governor and Local Governments, rights of occupiers, rents, alienation and surrender of rights of occupancy, revocation of rights of occupancy and compensation, transitional provisions, jurisdiction of Courts on land matters and other supplemental provisions. The act states nothing about specific cadastral mapping methods.

The Survey Co-ordination Act dated 13th September 1962 stipulates the need to notify the Director of Federal Surveys before survey works are implemented in an area. The major regulation in the Act around the theme of aerial imagery use is found under subsection (3)(ii) which states that it is required to provide the original or copy of all aerial photographs produced in connection with survey works to the Director of Federal Surveys. In addition, the SURCON specification for cadastral surveys that gives regulations concerning cadastral surveying methods only provides information about angular and linear measurement for cadastral survey mapping. It does not give regulations about aerial surveys or UAV mapping techniques. Hence, the need for regulations for aerial survey and UAV mapping in Nigeria.

4.0 CONCLUSION

4.1 Merits of UAV Mapping Methods and Other Sources of Aerial Imagery for FFP Cadastral Mapping

The following are the merits of UAV mapping methods for cadastral mapping

1. Faster data collection for Mapping: One notable advantage of UAV mapping techniques or the use of Aerial imagery is the abundance of topographic data it provides within a short period of time. This data supports the creation of detailed 3D cadastral datasets, enhancing land administration, management, and sustainable development efforts. Capturing topographic data with a drone is up to five times faster than with land-based methods and requires less manpower (Putra et al., 2023; Skondras et al., 2022). With PPK geo-tagging, placing numerous GCPs is no longer necessary, saving time and ultimately delivering survey results faster and at a lower cost.
2. Access to difficult areas: An aerial surveying drone can take off and fly almost anywhere, capturing data during operation without organizational overhead (Török et al., 2020). Unreachable areas, unsafe steep slopes, or harsh terrain unsuitable for conventional measuring tools no longer limits surveyors.
3. High accuracy: Advancements in UAV technologies have made it possible to take highly accurate measurements and photographs while collecting data to map geographic locations (Bablet et al., 2020; Stöcker et al., 2020). UAV technologies have made it

possible to acquire huge volume of spatial data at accuracies comparable to ground survey techniques. Incorporating GNSS, and an Inertial Navigation System (INS), UAVs can navigate and capture important information.

4. Cost-effective: UAV surveys have low overheads and reduced costs. UAVs make more things possible for surveying professionals for a fraction of the cost (Casiano Flores et al., 2020; Xia et al., 2019).
5. Detailed and complete data: UAVs generate high-resolution orthomosaics and detailed 3D models of areas where low-quality, outdated, or even no data are available. They thus enable high-accuracy cadastral maps to be produced quickly and easily, even in complex or difficult-to-access environments. More information that is detailed can be collected in less time and at a lesser cost (Hamylton et al., 2020).

As the spatial resolutions of aerial imagery obtainable from UAV mapping increase and affordability increases, the use of aerial imagery for cadastral mapping will increase.

4.2 Limitations of GNSS and UAV Methods

While GNSS and UAV methods are the most efficient and effective methods of land administration, it is important to acknowledge that the methods do not exist as a one-size-fits-all. A critical concept in choosing fit-for-purpose methods is to ensure the suitability and applicability of the approach in the local context. The importance of designing land administration systems to suit local circumstances and needs remains pivotal to the fitness of such approaches (Barry, 2018).

Among other factors, GNSS are dependent on clear horizons and the accuracy of positions determined are often reliant on this and other factors such as the type of receivers, the number and type of satellites in view, atmospheric conditions, and the presence of any obstacles or obstructions. The quality of the GNSS data processing algorithm also affects the accuracy of the position determination. One of the limitations of UAV technology for land administration is the limited flight time, which can restrict the amount of data that is collectable in a single flight (Stöcker et al., 2022). Weather conditions can also affect the performance of UAVs, making it difficult to collect data in harsh weather conditions(Mohsan et al., 2023). Additionally, data accuracy issues can arise due to the limitations of the sensors and cameras used in UAVs (Leslie, 2023). Therefore, it is important to assess the project characteristics against the capabilities of UAVs before using them for land administration projects(Bennett & Koeva, 2020).

4.3 Summary of Key Findings

The research has undertaken a comparison between conventional cadastral mapping practices in Ekiti state and the aerial imagery approach of the FFPLA concept. The use of GNSS receivers, theodolite traverse and total station were compared with UAV-derived high-resolution aerial imagery for cadastral mapping. The key findings of the study shed light on critical aspects of cadastral mapping:

1. The use of GNSS is most fit for cadastral mapping in terms of efficiency (time), cost-effectiveness and accuracy.

2. The accuracy obtained in the use of high-resolution aerial imagery for FFP cadastral mapping meets with conventional cadastral mapping standards in Ekiti State, offering a valuable tool for wide-coverage, expedited and accurate land registration.
3. High-resolution imagery has become more available and affordable with advancements in technology.
4. High-resolution imagery offers the advantage of abundant topographic data, supporting the creation of a comprehensive 3D cadastral dataset beneficial for land administration, management, and sustainable development.
5. The development of tools and approaches to facilitate UAV imagery processing is important to leveraging high-resolution UAV-based imageries for cadastral mapping.

4.4 Implications for Land Governance in Ekiti State

The implications of these findings for land administration and governance in Ekiti State are profound. The research highlights the need for a shift in cadastral mapping practices from total station and theodolite traverse to improved use of GNSS and its synergetic use with UAVs to fast-track demarcation processes. Embracing modern technology, particularly the integration of high-resolution aerial imagery and UAVs, would revolutionize land governance in the following ways:

1. Enhanced Efficiency: The adoption of aerial imageries for FFP cadastral mapping practices can lead to more efficient land registration processes, reduced disputes, and increased transparency, contributing to improved land governance.
2. Improved Accuracy: The prevalence of High-resolution imagery ensures scalable precise boundary delineation, enhancing tenure security and reducing land disputes than conventional land administration techniques.
3. Cost Savings: While initial investments are required for the acquisition of UAV data capture and processing gadgets, long-term cost savings would be realized through streamlined processes, improved turnover and reduced administrative overhead.
4. Data-Driven Governance: Abundant topographic data from high-resolution imagery and improved coverage of land rights would enable data-driven decision-making, supporting sustainable land management.
5. Transparency and Inclusivity: The use of aerial imageries would support participatory mapping and community engagement, thereby promoting transparency and inclusivity in cadastral mapping processes, which would result in improved land tenure security.

5.0 RECOMMENDATIONS

Leveraging aerial Imageries to fast-track land registration using the FFPLA approach is imperative to achieving sustainable development goals. Based on the findings and implications from the comparative and document analysis implemented in this research, some recommendations are proposed to enhance cadastral mapping practices in Ekiti State and similar contexts towards promoting efficient land governance and sustainable development.

5.1 Regulatory Framework Enhancement for Legal and Institutional Reforms

It was found that the existing regulations, such as the LUA and the SURCON specifications, do not provide enough guidance on how to use aerial imagery in cadastral surveying. Therefore, policy reforms are needed at the local level to establish a clear framework for FFP implementations. Stakeholders need to collaborate and domesticize available guidelines of FFP implementations in their local context. Regulatory bodies must also establish standardized procedures for acquiring, processing and integrating high-resolution aerial imagery into cadastral mapping systems. In addition, the procedure for land registration and acquisition of Certificates of Occupancy needs to be reformed to align with modern practices that would allow for the use of aerial imagery and expedite the land registration process. Local governments, where land is held in trust for the people, should enhance the institutional capacity of land administration by providing the political will for land administration reform implementations within the territories where they hold land in trust for the people.

Concerning data privacy and security concerns, given that high-resolution imagery captures detailed images of private properties; it is important to strengthen regulatory frameworks to safeguard data privacy and security. This should not restrict non-governmental agencies from using UAVs but should promote responsible UAV use for efficient land administration and management.

5.2 Leveraging Innovative Technologies

To take advantage of UAVs as a technological tool for land administration, it is recommended that the following steps be taken. Firstly, the development and deployment of advanced imagery processing tools should be prioritized to facilitate faster UAV imagery processing and analysis. This will enable efficient cadastral mapping procedures and the use of aerial imageries. Additionally, the deployment of faster internet broadband can be considered to better aid the benefits of cloud processing for speeding up UAV image processing. Continuously Operating Reference stations could also be encouraged to aid faster ground marker coordination, while single GNSS receivers with access to globally available correction services can be deployed to improve accuracy.

Furthermore, there is a need for training programs for surveyors, land administrators, and regulatory personnel to ensure the proficient and responsible use of UAVs and other modern cadastral mapping technologies. This will ensure that these technologies are utilized to their full potential. Lastly, effective data management systems and integration strategies should be developed to handle and utilize the vast amount of data generated by high-resolution imagery and cadastral mapping records for the broader functions of land administration and management.

5.3 Recommendations for Further Research

While this research has provided valuable insights into cadastral mapping practices in Ekiti State, by comparing cadastral mapping practices in the state and analysing available documents to identify entry points for leveraging high-resolution aerial imageries from UAVs for FFPLA, further avenues exist for further research:

1. Long-Term Impact: Investigating the long-term impact of FFP cadastral mapping, including its effects on dispute resolution, land tenure security, and sustainable development is of importance.

2. Community Empowerment: Exploring strategies to further empower local communities in the demarcation process and assessing the socio-economic benefits of community involvement is necessary.

3. Guideline for Implementation. Developing a guideline for the use of UAVs and high-resolution aerial imageries in Nigeria is vital.

4. Fitness of Aerial Imageries in Different Contexts: The Fitness of aerial imageries for mapping in rural, urban and peri-urban transition zones differs owing to the differing characteristics of these areas. The presence of tree canopies can sometimes aid or hinder cadastral mapping with UAVs depending on the context. Examining these differences would contribute to better guidelines towards adopting FFP approaches.

5.4 Final Remarks

This work investigates the differences between the use of total stations, electronic theodolite and GNSS for cadastral mapping in Ekiti State. It compares the above approaches with the use of UAV-derived orthomosaics as a FFPLA concept that seeks to aid cost-effectiveness and scalability in cadastral mapping. Conclusively, the adoption of fit approaches will represent a pivotal step toward efficient, transparent, and inclusive land governance. Addressing the identified barriers and implementing the recommendations outlined in this paper can pave the way for a fundamental shift in cadastral mapping practices. Such a shift has the potential to improve the land administration system in the State.

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Link to Appendix:

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