SUITABILITY OF UNMANNED AERIAL VEHICLE TO SUPPORT COMMUNAL LAND REGISTRATION IN ZIMBABWE TITLE THESIS

BLESSING MUNAKAMWE
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BLESSING MUNAKAMWE
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Specialization: Land Administration

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ABSTRACT

The poor land registration in some parts of the world has been attributed to the continuous reliance on conventional cadastral surveying tools. These traditional tools, such as Total Stations and GNSS, are regarded as expensive, time-consuming, complex, and rigorous. Communal lands are the most affected, and the increasing demand for land from the growing population has resulted in several communal lands facing land disputes, forced evictions, and large-scale land acquisitions without compensation. It has become necessary to document and recognise communal land rights ensuring tenure security and alleviating unnecessary and forced evictions. Unmanned Aerial Vehicles (UAV) considered cost-effective and flexible, have emerged as an alternative tool for cadastral surveying and mapping for land recordation. This research determined the suitability of UAVs for communal land surveying in Zimbabwe. A comparison was made against GNSS in terms of legal recognition, accuracy, survey cost, and time required for a participatory boundary beaconing. Fieldwork, interviews, questionnaires, observations, and secondary data were used for the comparison.

The UAV extracted coordinates from 20 Ground Control Points (GCP), and 6 GCPs generated orthophoto compared satisfactorily to GNSS coordinates of the same points. Furthermore, the geometrical accuracy obtained using 20 and 6 GCPs is approximately the same. The distance differences calculated between found beacons from UAV coordinates and previous survey record (DSG filed) coordinates conformed to Class C survey error limits of the Land Survey Regulations of Zimbabwe. In addition, it is less time-consuming and costly to acquire the same cadastral data using UAV than GNSS. Based on the findings of this research, the UAVs orthophotos accuracies are satisfactory for surveying and subsequent registration of communal lands. The survey costs are further reduced by using fewer GCPS which maintain acceptable accuracies. However, the LSR requires amendments to incorporate UAVs as a tool and its datasets. Further research is suggested on improving the automatic extraction of coordinates from the orthophoto for fast and consistent extraction of beacon coordinates.

Keywords:
UAVs, GNSS, Surveying, Land Registration, Communal Land

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Blessing Munakamwe
June 2022

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DEDICATION

I dedicate this thesis to my late mother Winnie Chamanwa Munakamwe. You are forever missed.

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LIST OF ABBREVIATIONS

Department of the Surveyor General	DSG
Land Survey (General) Regulations	LSR
Unmanned Aerial vehicle	UAV
Global Navigation Satellite Systems	GNSS
Her Majesty's Land Registry	HMLR
Ministry of Lands Agricultural Fisheries Water and Rural Resettlement	MLAFWRR
Ground Control Point	GCP
Real Time kinematic	RTK
High resolution image	HRSI
Civial Aviation Authority of Zimbabwe	CAAZ
Fit for Purpose	FFP
Root mean square error	RMSE
Village registration certificate	VRC
Check Points	CP
Rural District Council	RDC
Real time kinematic	RTK

1. INTRODUCTION

1.1. Background Statement

The formal land registrations and cadastral systems with national coverage are found only in a few parts of the world (Frank & Madaleine, 2018). It has left 70% of the world population in developing countries with unregistered security of tenure and rights to land (Stöcker, Koeva, Bennett, & Zevenbergen , 2019). Most affected are the rural people, the marginalized, particularly women who usually constitute the poorest, vulnerable, and their rights are seldomly treated as secondary (Mbiba, 2001). Lengoiboni et al. (2017) noted that most governments fail to recognize and record all citizens' secondary and overlapping rights. Mbiba (2001) pointed out that land registrations prevent unnecessary evictions and large-scale land acquisitions. Countries such as Nicaragua and Vietnam (World Bank, 2017), Tanzania (Kabigi et al., 2021), Namibia (Kasita, 2011), Tanzania, and Rwanda (Koeva et al., 2020) have made significant progress in communal land registration. Zimbabwe is no exception to the above problem as all communal land under the customary tenure system is not registered. The low level of tenure security is attributed to the high registration costs emanating from the high cost of surveying (Kurwakumire & Chaminama, 2012).

Land registration requires cadastral maps (diagrams) that consist of geometrical representations of surveyed land units (Williamson, 1997). These cadastral maps are regularly produced using conventional well-recognized surveying equipment, such as Global Navigation Satellite Systems (GNSS) and Total Stations (Mantey & Tagoe, 2019). These traditional surveying tools are expensive to employ (Koeva et al., 2020). However, cost-effective new surveying technology such as Unmanned Aerial Vehicles (UAVs) have emerged (Pérez et al., 2013). They are used to acquire high-resolution orthophotos used for boundary identification to support land registration. The boundary mapping can be done in a participatory manner where the local members, and stakeholders participate in interactive boundary mapping (FAO, 2020). Most Northern American countries, Kenya, and South Africa, to mention a few have UAVs surveying legal frameworks (Stöcker, Bennett, Nex, Gerke and Zevenbergen, 2017). Zimbabwe's formal survey systems have not yet embraced UAVs into the surveys regulations for communal land surveying and mapping.

As in Laos (Kenney-Lazar, 2017) and Namibia (Kasita, 2011), land occupiers initiate and fund the registration process for use and occupation rights. Similarly, in Zimbabwe, the dwellers who are entitled to reside in Communal Land where land rights are recognized as families, land sales prohibited, and land is vested in the state through the President (Mafa et al.,2019) fund the surveying and registration process. In other instances, as in Laos (Kenney-Lazar, 2017) and Tanzania (Kabigi et al., 2021), the Government and donors fund(ed) the adjudication of communal land registration. Therefore, there is a reliance on donor funding or government funding to map and register communal lands.

In pursuit of recording and registering the land rights of the underrepresented citizens (Nara et al., 2021), land policies are utilizing new technological applications, appropriate concepts, and tools to address land recordation challenges (Zevenbergen et al., 2013). UAVs, also termed Remotely Piloted Aerial Systems (RPAS), have evolved as remote sensing tools for alternative mapping (Stöcker, Nkerabigwi, Schmidt, Koeva, Bennett, Zevenbergen, 2019). In the past years, UAVs have been identified as a cadastral mapping tool (Stöcker et al., 2019). In addition, UAVs can speed up communal land registration (Stöcker et al., 2020). Furthermore, Lauterbach (2021) and Stocker and Koeva (2019) found UAV -based technology to capture land rights in Namibia and Kenya, respectively, potentially competing well with other field surveying methods. UAVs technology was successfully used in participatory mapping and land use in Myanmar (FAO, 2020). Further investigations into the use of UAVs for cadastral boundaries have also been done (Yurtseven, 2019; Mantey, 2019; Benassi et al.,2017; Pérez et al.,2013). Ali (2017) investigated the use of UAVs in fit-for-purpose boundary mapping and valuation of agricultural land in Zimbabwe and recommended further research for registration purposes.

Stocker et al. (2019) observed that UAVs have not only been tested but have hardly been affected in the context of land tenure mapping for formal registration. Stocker's conclusion applies to Zimbabwe, where UAVs have not been used in cadastral mapping for communal land registration. The UAV-generated data has not been compared to existing conventional surveying tools and methods to determine their suitability for cadastral mapping of communal lands and other land surveys in Zimbabwe. Each country has its specific methods for surveying and mapping based on its culture, economy, laws, and historical background (Chipofya et al., 2021). The basic procedures to generate a UAV orthophoto for spatial analysis are similar. However, a customized approach is recommended to derive maximum benefit for cadastral mapping. Therefore, this research seeks to compare UAVs generated datasets to GNSS in terms of legal recognition, accuracy, survey cost, and time as derived from fieldwork and secondary data. Efficiency and complexity comparison measures will be derived from previous research and interview with survey stakeholders. The outcome will determine whether UAVs derived orthophotos are suitable for capturing cadastral data for communal land registration in Zimbabwe.

1.2. Problem Statement

Zimbabwe communal lands were established by the Tribal Trust Lands Act of 1965 and currently constitute 40% of the land (Chambati & Mazwi, 2020). The surveying, mapping, and registration of Communal lands are requirements of the Traditional Leaders Act of 1998 and Communal Land Act of 1980 (Nyoni, 2016). The Communal Land Act protects the inhabitant's rights to reside on the land, erection of any building, cultivation, pasturing of animals, and other rights. Traditional Leaders Act further mandates the issuance of village registration certificates (VRC) and settlement permits to inhabitants. Agonizingly, the two mentioned acts have not been enforced since their enactment. Consequently, 70% of the population living in communal lands (Kurwakumire & Chaminama, 2012) have no proof of physical ownership or possession of occupied land. It, therefore, makes them prone to arbitrary evictions by government agencies and Real Estate companies without compensation (FAO, 2009).

The communal lands have suffered several evictions and large-scale land acquisitions dating back to the 1890s without any form of compensation (HRW, 2021). The Land Apportion Act of 1930, the Land Husbandry Act of 1951, and the Tribal Trust Lands Act of 1965 further increased the evictions of citizens from their ancestral lands until independence in 1980 (Mbiba, 2001). Relocations were to marginal ecological areas known as *(mazuzevha)* such as Gokwe, Sanyati, Hurungwe, Lupane (Nyoni, 2016). After 1980, notable evictions included Mwenezi people paving the way for the construction of Tokwe–Mukosi Dam in 2014, Marange-Chiadzwa people paving for diamond mining in 2010, displacement of 1754 households for Chisumbanje Ethanol Project in 2012 (Mandihlare, 2013), and Munyokowewre people in Chipinge for commercialization of Middle Sabi (Dhliwayo & Refiloe, 2020). Recently, the Chilonga people are fighting evictions to pave the way for commercial lucerne grass farming (HRW, 2021). The Kaseke people of Uzumba (mining operations) were also advised that they do not own the land occupied as they have no title deeds (NewsDay, 2021). Therefore registration of land rights will protect communal land against the troubles mentioned above.

In light of the mentioned evictions, it is necessary to map and register communal land rights and incorporate them into the national cadastre (Kurwakumire & Chaminama, 2012). However, the reliance on conventional methods has slowed down the land registration process. Koeva et al. (2017) noted that though accurate, the conventional methods are rigorous, tedious, and costly. Therefore, it is imperative to consider other cost-effective cadastral mapping techniques to adjudicate communal lands like UAVs in Zimbabwe. The capabilities of UAVs in land mapping have been observed in other countries by (Cao, 2016) and (Cunningham et al., 2012), but the mapping and registration process differs per country (Subedi, 2016). Moreover, the technical aspects, social, legal, and historical elements are different between countries. Consequently, it poses a challenge to develop a UAV approach that is fit for all hence it has to be customized per society (Chipofya et al., 2021).

The main challenge for the application of the UAV technique for communal land cadastral mapping is that it is not clear whether the UAV method is appropriate for the task and be incorporated into Zimbabwe's Land Survey (General) Regulations (LSR) SI 727 of 1979). In particular, it is unknown how UAV as a tool, and its datasets, compare to GNSS in terms of legal recognition, accuracy, survey cost, efficiency, complexity, and time to be used for participatory Communal land cadastral surveying and mapping. It is anticipated that the use of the UAVs will expand the documentary proof of land rights with known boundaries and exact land sizes, thereby reducing boundary disputes and double allocations.

1.3. Research Objectives and Questions

The main objective of this study is to :
Assess the suitability of the UAV as a cadastral mapping tool for Communal land by comparing it with traditional tools recognized by the existing legislation in Zimbabwe.

The sub-objectives and the research questions are framed as illustrated below:

Objective 1: To review existing cadastral mapping methods for Communal Land in Zimbabwe

- *Q 1.1. What laws, policies, technologies, and institutions are involved regarding Communal land and mapping?*
- *Q 1.2. What is the legal framework regarding UAVs and GNNS for cadastral mapping?.*

Objective 2: To compare UAV and GNNS observations in a participatory survey and mapping in Zimbabwe

- *Q 2.1. What is the total surveying cost per land parcel using GNNS and UAV?*
- *Q 2.2. What is the total time taken to produce a surveyed diagram using GNNS and UAV?*
- *Q 2.3. What measurement accuracy is obtained, and does the UAV error fall within the accuracy tolerances in the Second Schedule of the LSR?*
- *Q 2.4. How do results compare to previous investigations?*

Objective 3: To recommend if and how UAVs can be amalgamated in participatory Communal land recordation in Zimbabwe

- *Q 3.1 Who will benefit from the use of UAV high resolution generated orthophotos in boundary mapping*
- *Q 3.2 How do surveying and mapping stakeholders (including Land Surveyors, mapping experts, academic institutions, and DSG) evaluate UAVs and GNNS usage in cadastral mapping.*
- *Q 3.2 What are the recommended opinions for future UAVs approach to communal surveying in Zimbabwe?*

1.4. Conceptual Framework

The conceptual framework in Figure 1 is composed of three main concepts and their relationship. The framework for this study consists of customary land, cadastral surveying, registration, and emerging mapping technologies. UAVs high-resolution orthophotos have emerged as an efficient technology for participatory boundary mapping for customary lands (FAO, 2020). The UAVs need to be compared to traditional land surveying tools to be recognized as cadastral mapping tools good enough for registration in line with the legal framework. The UAVs are then utilized in participatory mapping of Communal land in Zimbabwe. The communal lands have lacked recordation since their establishment in 1965, although registration is a requirement by law. Therefore, this study focuses on how UAVs derived orthophotos can be used in participatory boundary mapping in Zimbabwe. The primary intention is to secure land rights for the communal land users.

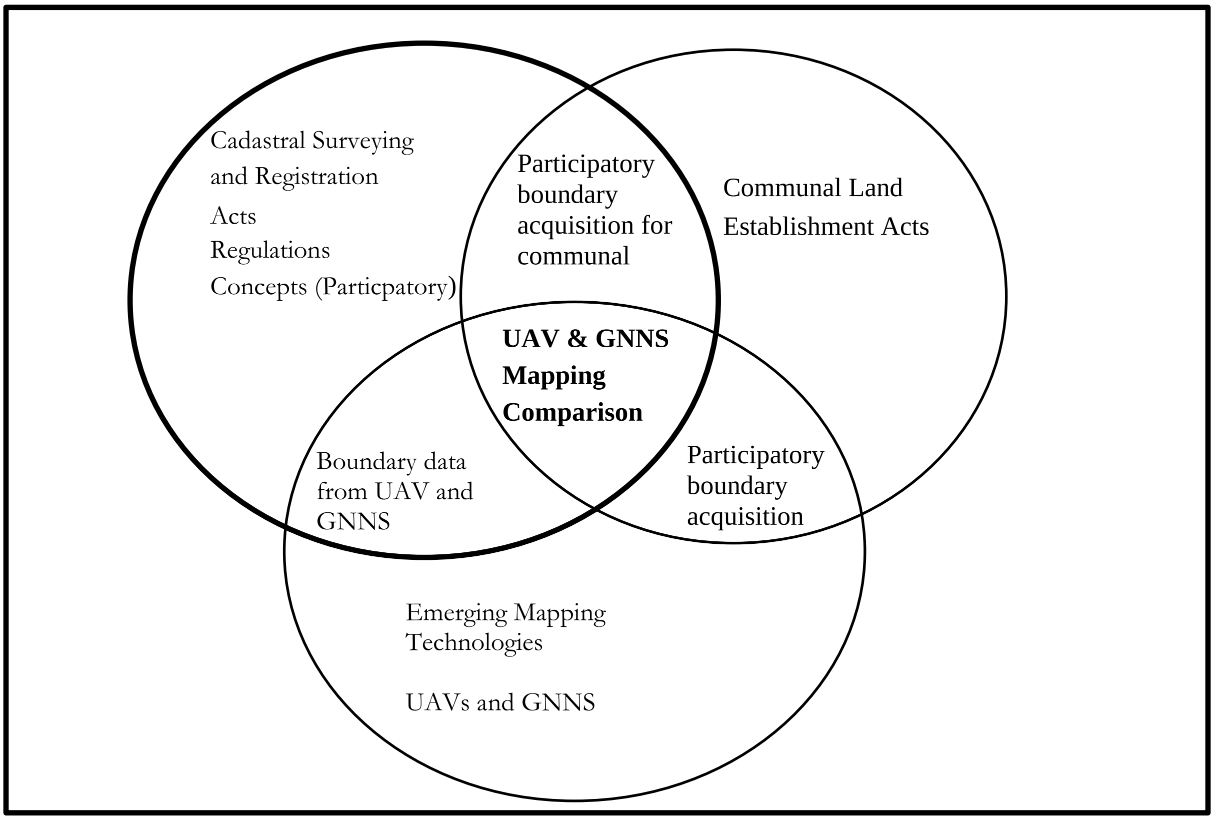


Figure 1: Conceptual Framework.

1.5. Thesis structure

The thesis comprises of five chapters briefly explained below:

Chapter 1: Introduction
This chapter presents the background statement, problem statement, the main objective, minor objectives, research questions, and the conceptual framework.

Chapter 2: Literature Review
This chapter reviews the concepts of customary land tenure, land tenure systems in Zimbabwe, cadastral boundaries, cadastral surveying, boundary mapping techniques, land registration, cadastre, comparison methods, data acquisition method, and other relevant scientific literature.

Chapter 3: Research methodology
The chapter discusses the research methods and techniques used to achieve the study's objectives. The research design workflow and the case study area description are discussed.

Chapter 4: Results
This chapter presents the findings gathered from primary and secondary data to answer questions under sub-objectives 1, 2, and 3.

Chapter 5: Analysis and Discussion
The chapter analyses and discuss the findings of this research.

Chapter 6: Conclusion and Recommendations
This chapter concludes the study by discussing what was achieved from the objectives and research questions. Recommendations for further research were made.

2. LITERATURE REVIEW

This chapter reviewed the concepts of customary land tenure, land tenure systems in Zimbabwe, cadastral boundaries, cadastral surveying, boundary mapping techniques, land registration, cadastre, FFP concept, comparison methods, and UAVs as a tool. The types of boundaries and participatory mapping in the adjudication of communal land are also discussed.

2.1. Customary Land Tenure

Customary tenure exists where community members enjoy the right to independently use the community's holdings (Wily, 2011). According to Mends (2006), the United Nations defines customary land tenure as the right to use and dispose of the rights over land belonging to the community. These rights are recognized as legitimate by the community. Land ownership is vested in family, tribe, group, or lineage, but individuals enjoy use rights. Traditional leaders administer the land on behalf of the community. Common property resources include pasture land, forests, and sources of water. This type of land tenure is prevalent in African communities (Wily, 2011). Despite the lack of land recordation, customary land tenure has remained strong and active in many countries (Wily, 2011). Boundaries under customary tenure are largely made of physical features to demarcate individual land parcels (Nara et al., 2021). The growing population and outside threats to land invasions have rapidly increased the pressure on customary land leading to conflicts. Lack of formal land rights recordation has left the communities vulnerable to losing their ancestorial land. Consequently, the demand for rapid and cost-effective methods of mapping customary land rights has been growing.

In Zimbabwe, customary tenure is administered by traditional leaders and Rural District Councils (RDC). The traditional leaders enjoy the right to dispense and allocate land to qualified persons. They also preside over the transfer of usufructs rights among their people or new land occupies. Communal lands fall under the customary tenure system. They were established by the Tribal Trust Lands Act of 1965 and the Communal Land Act of 1980. Occupiers have usufruct rights over the land. They enjoy the erection of any building, cultivation, pasturing of animals, and other rights. However, the state can repossess the land without recourse to the courts (Chambati and Mazwi, 2020). Under the Traditional Leaders Act of 1998, the communal villages should be surveyed, registered, and issued village registration certificates. In addition, the government instituted a Commission of Inquiry Into Appropriate Agricultural Land Tenure System in 1994 tenure securities in Zimbabwe. The commission report further recommended the issuance of village registration titles (Mafa et al., 2019). However, to date, no communal land has been registered in Zimbabwe.

2.2. Land Tenure Systems in Zimbabwe

The land tenure system in Zimbabwe consists of five categories: freehold, leasehold, permit, communal, and unalienated state land.

Freehold
The freehold owner has exclusive property rights and full responsibility for the land and everything attached to the land. The land can be disposed of, leased, or used as a mortgage. However, the ownership is subject to various planning regulations and restrictive laws that the state may impose regarding using that land (Moyo & Chambati, 2013). Proof of ownership is possession of deed of transfer, deed of grant registered at Deeds Registry Office.

Leasehold
Under leasehold, the freeholder surrenders rights to the land for a period of 5, 25, or 99 years. During the years, the leaseholder has the right to use the property according to the lease agreement. When the lease

period lapse, the freehold owner returns the title of the land. The A2 model farms, which are medium to large scale farms created under the Fast track land reform program (FTLRP) of 2000, dominate this tenure type. The A2 model lease is surveyed and registered at the Deeds Office. The lease specifies the succession plans, subletting conditions, lease termination, allowable developments, and size (Maguranyanga & Moyo, 2006).

The tenurial permit regime (A1 permit)

A large portion of large commercial farms is subdivided into smaller portions of about 5 to 10 hectares. The state, through MLAFWRR, issues land users with use and occupational permits in perpetuity. The land cannot be traded but can be inherited. It can be defined as organised communal land. Land holders live in a self-contained manner or villagized (Maguranyanga & Moyo, 2006). The portions of land are supposed to be surveyed and registered, but the surveying and registration process is costly to the landholders.

***Customary Tenure*.**

This tenure type has been extensively discussed in Section 2.1.

Unalienated State land

Unalienated state land includes protected forests, national parks, and national heritage sites. It also includes state land that the government registers in its name.

2.3. Cadastral boundaries

Cadastral boundaries are the extents of parcels or interest in parcels enjoyed by the landowner at any given time. They can also be defined as a dividing line between physical or abstract spheres (Kaufmann & Steudler, 1998). Cadastral surveying demarcates property boundaries (Bannister et al., 1998). The process requires a licensed land surveyor to produce the cadastral map and monument the boundary markings (Williamson & Enemark, 1996). Boundaries are surveyed to high accuracy according to the legal framework of the different countries. However, countries such as Ethiopia and Rwanda have adopted fit-for-purpose boundary surveys (Van Oosterom et al., 2009), in which high accuracy is not considered necessary. However, the approach allows upgrading of accuracy.

Boundaries are classified into fixed and general boundaries. Fixed boundaries are accurately surveyed and marked with physical monuments (Enemark et al., 2016). Boundaries can be relocated because boundary corners are accurately coordinated. Conventional surveying methods and tools are used to survey fixed boundaries adhering to the legal framework of that society. General boundaries are not accurately surveyed, and physical features are used to demarcate the boundaries (Dale, 1977). Physical features such as fences, walls, canals, and hedges mark the boundaries. General boundaries are surveyed at a lower cost as compared to fixed surveys. These boundaries can be established in rural areas through aerial photogrammetry means (Lemmen et al., 2009). The method is cost-effective and fast to implement to generate boundary maps for land registration. The method has been adopted in Rwanda, Thailand, Indonesia, and Myanmar to map rural areas.

2.4. Cadastral surveying and mapping techniques

Surveying is the art, profession, and science of making measurements of positions of natural and man-made features on earth surfaces (Bannister et al., 1998). The obtained measurements can be presented in the form of graphical or numerically. The surveying techniques of acquiring data are categorized into direct and indirect techniques. The direct techniques are ground-based surveying methods such as taping, traversing, and chaining. These techniques measure land boundaries directly on the ground (Stöcker et al., 2019).

Modern tools include total stations and GNSS. Points are coordinated by a combination of distance and angle measurements in relation to each other or fixed control points. The use of Real Time Kinematic GNSS (a network of referenced satellites) has lessened field observation time while returning sub-centimeter accuracy (Moser et al., 2016). Geometrical positions by GNSS are determined by using the measurement of ranges from ground positions to the satellites.

Figure 2: (a) Total Station (Topcon Positioning Systems, 2022), (b) GNSS set (Leica geosystems, 2022).

Indirect techniques involve the acquisition of boundary data remotely without physical contact with the object. Satellite imagery, manned aerial surveys, and UAV surveys are classified under indirect techniques. UAVs are further discussed in section 2.9. The three provide high-resolution images that are processed into orthophotos for different purposes, including boundary mapping. Manual vectorizations or automatic feature extraction algorithms are used to extract boundaries (Kohli et al., 2018). However, it is important to equally note that satellite and aerial images may suffer from clouds and occlusions, which may affect cadastral boundary delineations. (Stöcker et al., 2019).

2.5. Land registration

Land is fast becoming a scarce, valuable commodity and can potentially affect the economic and social aspects of both developed and developing countries (Todorovski et al., 2020). There is a growing need to document land ownership in the form of land registration. Land registration is described as the process of the official recording of land rights or interests (Zevenbergen, 2002). The rights are recorded through deeds or as a title on the properties. (Kaufmann & Steudler, 1998). The land parcels have to be adjudicated or surveyed if it is a further subdivision to complete registration. The produced maps or diagrams describing the boundary extents and area of the land parcel are used for registrations. Therefore land registration reveals the dynamic man-to-land relationship. Benefits of land recordation include improving tenure security and knowledge of people or entities that own which land. Registration further reduce chances of being evicted (Todorovski & Zevenbergen, 2020).

The continuum of land rights concept adopted by UN-Habitat shown in Figure 3 could also be used for communal land surveying and registration. A continuum of land rights exists when a country's land information management system incorporates various formal, informal, and customary land rights (Lemmen et al., 2015). The recorded land rights could be upgraded gradually from customary up to freehold depending on available resources and technology. The desire is to allow the possibility of the tenure documents issued to be upgradable.

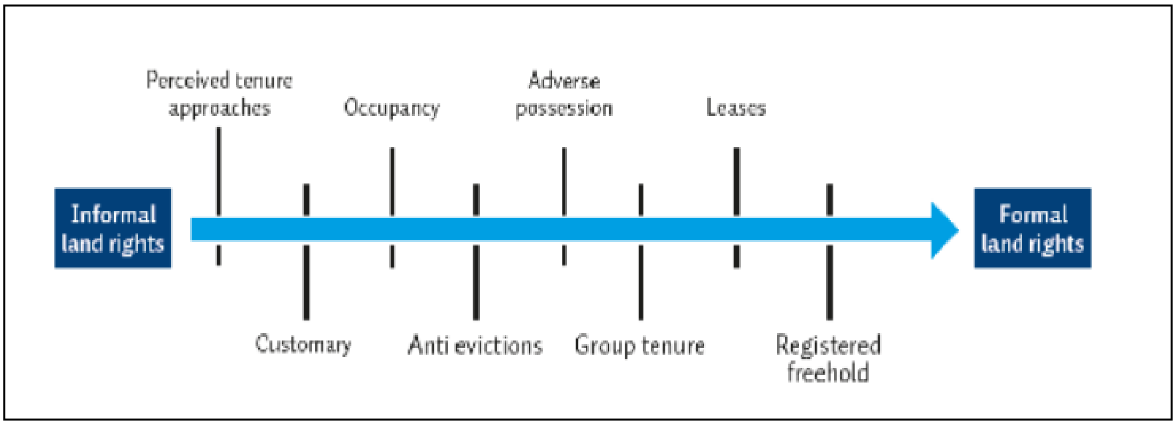


Figure 3: Continuum of Land Rights: Source (UN-Habitat, 2008)

2.6. Cadastre

Zevenbergen (2002) described a cadastre as an official record of data attached to a land parcel. The information includes details of the boundaries, use, tenure, and value of the land parcel. The cadastre is also further defined as a systematically arranged public register of land parcels within a country or district (Williamson, 1997). Surveyed land parcels with unique identifications are generally plotted on large-scale maps showing each parcel's size, value, and legal rights. Cadastres place emphasis on unambiguously tracing property boundaries and ownership to reduce or prevent disputes.

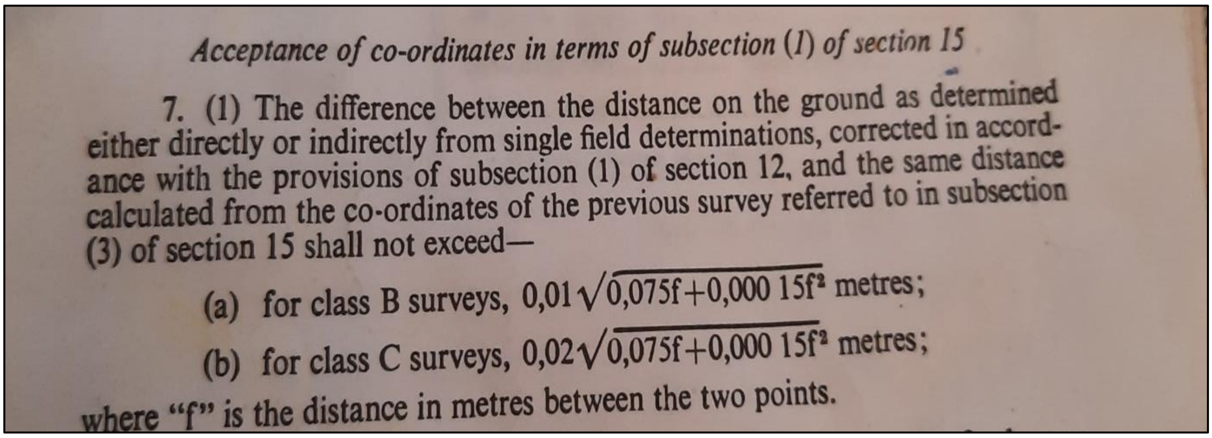
The England and Wales Her Majesty's Land Registry (HMLR) is one example of an agency with a comprehensive cadastre with over 18 million separate titles (Steudler & Kaufmann, 2002). Zimbabwe does not have a cadastre. However, the current manual system adopted enables the tracing of land parcels to state land. The DSG uses a manual recording of land parcels on compilations sheets within the department. The compilation sheets are updated once a survey has been lodged with the office. The approved survey diagrams are passed to the Deeds office to effect registration. The Deeds office keeps separately recording systems of ownership of land parcels. It is important to study this system of manual cadastre as this study aims to register communal land formally.

2.7. Comparisons of UAVs and GNSS

The Cambridge dictionary (2022) describes comparison as examining two more things and finding similarities or differences. Surveying and mapping tools should be implementable and scalable and meet the needs of the targeted user groups (Chipofya et al., 2021). Therefore, examining how a new tool compares well to the currently existing tools used by surveying and mapping professionals is recommended. For this study, the comparison was made in terms of legal recognition, datasets accuracy, cost to produce the datasets, and time taken to produce datasets. Although related investigations have been conducted in other countries, Enemark et al. (2016) noted countries differ in their ways of boundary data acquisition. Therefore, this study is justified to be carried out in the Zimbabwe context.

The cost of carrying out a survey or mapping exercise should not be prohibitive (Mantey & Tagoe, 2019). Therefore cost comparisons between survey tools are important. In addition, the total time taken to carry out a survey is vital. Complex methods are inclined to require more fieldwork time, although sub-centimeter accuracies are achieved. They delay the whole chain of the land registration process and are related to high survey costs. Time activities include preparation, acquisition, processing, and data output (Lukitasari, 2017).

The quality of survey observations, measurements, and calculations is termed accuracy (Chekole, 2014). The accuracy and precision of survey data are vital for field data acquisition and processing (Moser et al., 2016). This study evaluated the conformity to accuracy standards expressed in the LSR Second Schedule for each tool using the formulas shown in Figure 4. The error limits are calculated and compared to distances residuals.



Acceptance of co-ordinates in terms of subsection (1) of section 15

7. (1) The difference between the distance on the ground as determined either directly or indirectly from single field determinations, corrected in accordance with the provisions of subsection (1) of section 12, and the same distance calculated from the co-ordinates of the previous survey referred to in subsection (3) of section 15 shall not exceed—

(a) for class B surveys, $0{,}01\sqrt{0{,}075f+0{,}000\,15f^2}$ metres;

(b) for class C surveys, $0{,}02\sqrt{0{,}075f+0{,}000\,15f^2}$ metres;

where "f" is the distance in metres between the two points.

Figure 4: Error Limits from the Land Survey Regulations: Second Schedule.

Class A surveys refer to surveys to determine control point positions, and class B refers to township surveys. Class C refers to surveys excluded in classes A and B, and thus communal lands belong to class C surveys.

2.8. Participatory Mapping

The involvement of the citizens or land occupied in boundary mapping of their land parcels is called participatory mapping (Kohli, 2015). It has been used widely in Indonesia in mapping agricultural land (Radjawali and Pye, 2015). It has been tested in urban and rural areas of Ethiopia (Bennett & Alemie, 2016). As the use of UAVs orthophotos in mapping emerges, the active involvement of village communities and all local stakeholders is required. The approach can map community infrastructure, forests, agricultural land, ritual sites and delineate boundaries (FAO, 2020). Participatory mapping is mainly conducted after a fit-for-purpose approach (FFP) has been developed at the country or local level. An FFP approach aims to encourage participation by all stakeholders and use innovative surveying and mapping tools and methods that can be scaled in the registration of land (Koeva et al., 2021). Focus is placed on using technology that meets society's needs, leaving room for improvement or upgrades over time (Todorovski et al., 2021). It means reducing reliance on the expensive high, accuracy survey tools or cadastral surveys while focusing on mapping of land to be improved over time based on the needs of the community. The FFT concept takes into account the seven principles stated briefly below.

1. Flexible in capturing spatial data and all users and uses information of the land, covering all land tenure.
2. Inclusive in allowing coverage of all land and tenure types and incremental improvement.
3. Participatory in how the land data is captured and used with the community's support.
4. Affordable to be used by the government and society.
5 Reliable pertaining to information acquired and its updatedness and authoritative
6. Attainable in creating a running system in a given short time frame with the available resources.
7. Upgradable responding to legal, social and economic opportunities and needs of the society (Chipofya et al., 2021).

Land administration systems in Rwanda, Namibia, Indonesia, and Ethiopia have implemented the FFP concept (Koeva et al., 2021). This study seeks to find the use of UAV's high-resolution images in participatory mapping to be acceptable within the formal land administration in Zimbabwe. It is anticipated after the conclusions of this thesis, an FFP approach can be developed to spearhead the registration of communal land in Zimbabwe.

2.9. Unmanned Aerial Vehicle

Unmanned aerial vehicle (UAV) platforms are currently contributing valuable data for different purposes such as surveillance, mapping, and inspection (Nex & Remondino, 2014). UAVs can be defined as motorized aircraft systems piloted remotely, either manually using a remote control device or autonomously using onboard navigation and control systems (Bailey, 2012). They are now considered as a low-cost alternative to other methods of aerial photogrammetry (Nex & Remondino, 2014). UAVs have emerged as a cost-effective cadastral mapping tool, closing the gap between labor-intensive and consuming data acquisition methods (Koeva et al., 2017) in land administration. The generated high-resolution orthomosaics are currently being used in boundary delineations in countries such as Rwanda and Ethiopia.

Various categories of UAV platforms are currently used for different purposes. The platforms can either be fixed-wing, multirotor, or hybrid (Amissah et al., 2021). Multirotor uses multiple fixed pitches propellers to fly. They are easy to deploy, have stable flights, and can capture data from a fixed location. Their major drawback is that they have less endurance and need more batteries. In that case, multirotor UAVs can be deployed to capture data for small areas. Fixed-wing UAVs use wings, ailerons, and a propulsion source to fly. They can cover larger areas as they can fly fast and have more endurance compared to multirotor. They can be used to to map large areas of more than 150 hectares. The boundaries can be digitized manually from the orthophotos or automatically extracted

A high-resolution camera mounted is used to take overlapping images over the study area. These images are downloaded and processed into sparse point density, point cloud, DSM, and finally orthomosaics. Although most have onboard GNNS for georeferencing, it is insufficient to generate orthophotos for cadastral land mapping. In order to improve the positioning accuracy, GCPS are placed and coordinated using the conventional methods on the study area and then used for absolute orientations of the images (Wassie et al., 2018). Furthermore, the accuracies of generated orthophotos depend also on flying height, number of GCPs used overlaps, and flight pattern (Stöcker et al., 2020). In addition, UAVs' accuracy has improved as they are now equipped with a GNSS RTK system that can give spatial accuracy of 2- 5 cm (Paneque-Gálvez et al., 2017).

Figure 5: Different platforms of Unmanned Aerial Vehicles

This study emulates previous investigations that have researched UAVs to collect geospatial data for cadastral surveys and mapping. Pérez et al. (2013) concluded that UAVs orthophotos are feasible, and the accuracy obtained is sufficient for low-cost surveying. A study carried out in Ghana by Mantey & Tagoe (2019) on the suitability of UAVs for cadastral surveys found that the accuracy of digitized boundaries from the orthophoto was within the tolerances limits required by the Survey and Mapping Division of Ghana Lands Commission. In Rwanda and Ethiopia, various investigations were done by Stöcker (2021) and Koeva et al. (2017), developing low-cost boundary data acquisition workflows and adjudication of rural land. The conclusions demonstrated that UAVs orthophotos are an alternative method sufficient for cadastral surveying and boundary mapping. Lastly, UAVs have also been investigated for participatory mapping in Myanmar (FAO, 2020), Ethiopia (Lemmen et al., 2009), and Indonesia (Radjawali & Pye, 2015). The investigations emphasized on flexibility, participation, affordability, and reliability, which are the basic principles for FFP.

In summary, the literature presented discussed some key concepts of this research. Chapter 3 will present the methodology used for this research.

3. RESEARCH METHODS

The chapter discusses the research methods and techniques used to achieve the objectives of the study. The research design workflow shows details of how the research will be conducted and details of the methods and techniques to be used to collect data and process it. Moreover, the description of the case study area is presented.

3.1. Case Study

The research study took place in Stockholm, situated in Goromonzi District, Mashonaland East Province, Zimbabwe. It is home to 15 households that were settled under the A1 model of the Fast Land Reform Program (FLRP). The occupied land covers an area of 305.83 hectares, with 80.34 hectares dedicated for cultivation, 216.66 hectares for grazing land, and 8.83 hectares reserved for a village site. Most households practice subsistence farming. The area was chosen because the landholders were issued occupational permits for unsurveyed land. The area is bounded by existing beacons since the whole area was once a registered property. The relocated beacons coordinates will be used for accurate comparison of UAV and GNSS coordinates. The geodetic control network is also dense for the calibration of GNSS equipment. Stockholm also has linear boundaries, which are easy to map considering the limited time available for this research. Furthermore, Stockholm has an existing site plan (see Annex 1) that was used to settle the landholders. The beneficiaries also have few boundary disputes; hence, the surveying exercise will proceed smoothly. The case study area is shown in Figure 6 below;

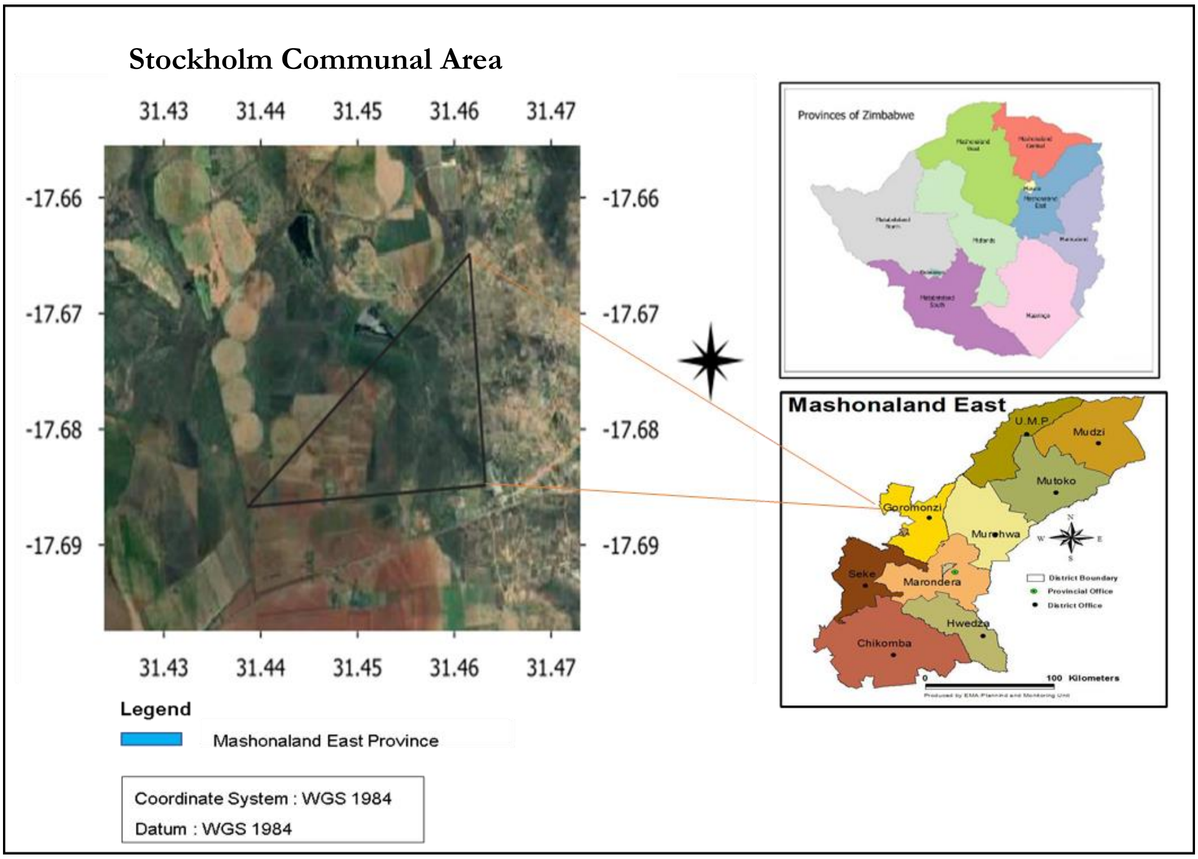


Figure 6: Case study area called Stockholm village in Goromonzi, Zimbabwe.

3.2. Research Design

The study research was carried out according to the research design workflow shown in Figure 2. A case study approach was selected to compare the conventional method (GNSS) and UAVs datasets in surveying and mapping of communal areas in Zimbabwe. A research design is considered as the steps, structure, investigations, and strategies used to carry out the research adopted from Akhtar (2016). In this study, primary data and secondary data were gathered, as explained in detail below. The research study followed three stages; pre-fieldwork, fieldwork, and post fieldwork. Figure 7 describes the stages followed for the study.

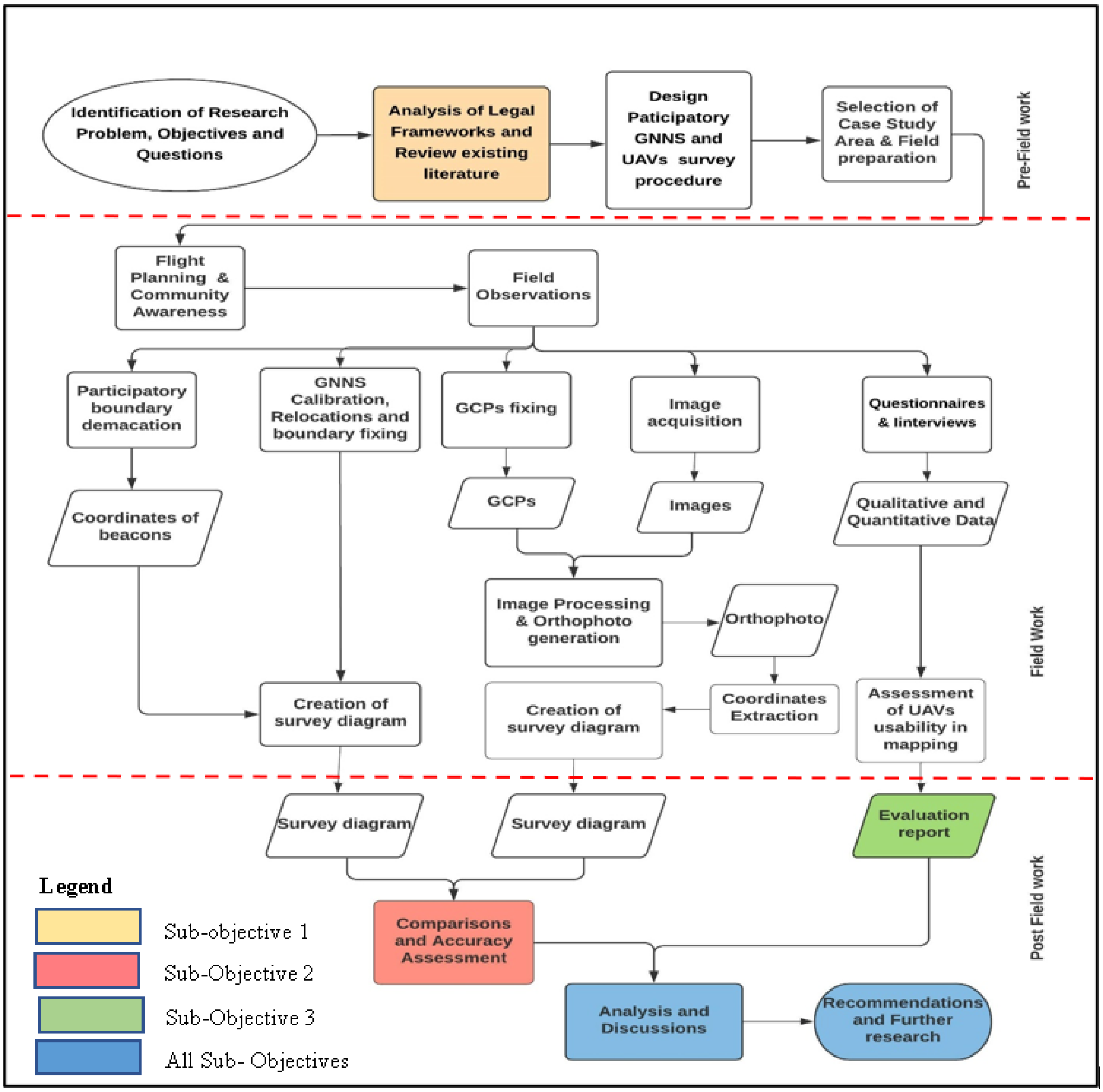


Figure 7: Research design workflow.

3.2.1. Data collection methods

The research data was gathered using a mixed design of both qualitative and quantitative methods. This study collected both qualitative and quantitative data from primary and secondary sources, as depicted in Figure 8 below;

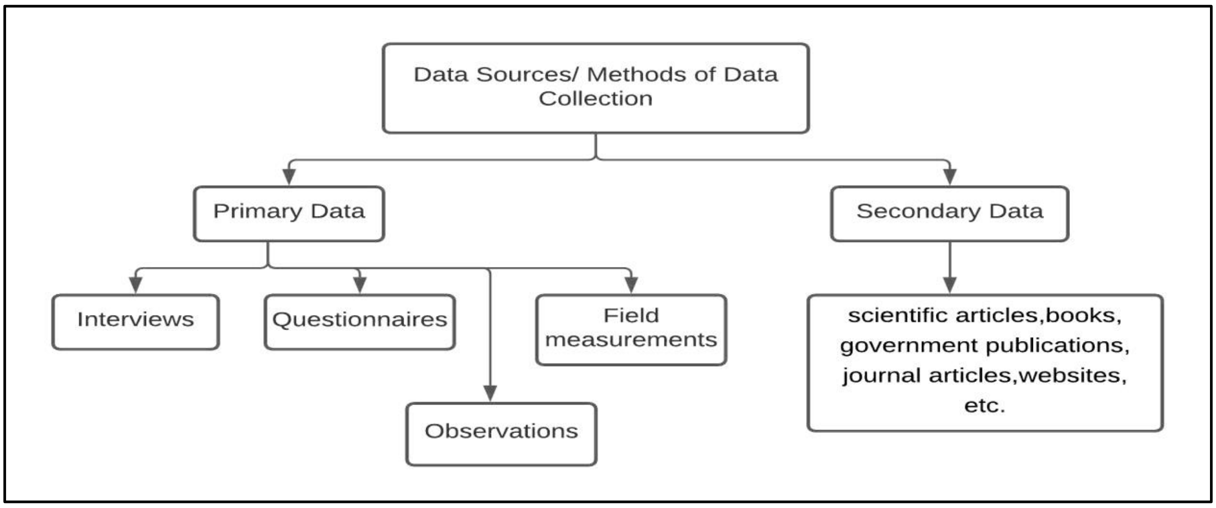


Figure 8: Data sources.

Primary data was obtained from questionnaires, semi-structured interviews, observations, and field measurements. The interviews and questionnaires conducted were both open-ended questions and closed-ended. Furthermore, quotations of the estimated cost of conducting surveying and UAV mapping of Stockholm were obtained from DSG, service providers, and the researcher's experience (see Annex 10 and 11). The cost per hectare presented in Tables 1 and 2 was derived by dividing the total survey cost by the total hectares (306 Ha) of land to be surveyed. The data was used to answer questions under Sub-objective 2. Secondary data described by Hox and Boeije (2004) as data that has been collected in the past by other researchers was also examined. This study collected secondary data through desktop research from scientific articles, scholarly articles, government publications, books, journals, research scholars' reports, and any archived documents. The data was used to answer Sub-objectives 1,2 and 3.

3.2.2. Pre-fieldwork

During the pre-fieldwork stage, conceptual literature was reviewed consisting of concepts and theories related to the research. The concepts such as land surveying, land tenure, the participatory mapping were reviewed. Previous investigations of UAVs applicabilities, comparisons, and usability in participatory cadastral surveying and mapping were examined. The laws, policies, manuals, government official documents and institutions involved pertaining to surveying, mapping, and registration of Communal land were examined. Furthermore, the legal and technical framework pertaining to use of UAVs and GNSS for cadastral surveys were examined. The outcome is presented in Chapter 4 of the results. The documents were reviewed to answer Sub-objectives 1 and 2.

Permission to conduct the study at Stockholm farm was obtained from MLFWRR (see Annex 1). A flying license for the study was obtained from CAAZ (see Annex 1). The researcher informed landholders and all relevant authorities of the pending fieldwork exercise. Furthermore, interview scripts and questionnaires were designed, and the technology of use was chosen. The researcher team obtained coordinates of the Stockholm old survey record SR31058, the geodetic control network coordinates, and topographical maps filed at DSG.

3.2.3. Fieldwork

During the fieldwork stage, primary data from interviews and questionnaires was gathered. The main tasks under this stage were to demarcate the Stockhome individual plots in a participatory manner. GNSS measurements fixed the boundary beacons. A UAV acquired aerial images to generate an orthomosaic.

The orthomosaic extracted coordinates of boundary beacons were compared to GNSS measurements. The fieldwork was carried out to answer Ssub- objective 2 and 3 questions.

After obtaining permission to conduct the study from MLFWRR and CAAZ, fieldwork preparations commenced. Sensitization of the Stockholm landholders about the research was done with the help of the District Lands Officer (DLO). The DLO introduced the researcher and his team to the landholders through the village head. The village head played a pivotal role in the mobilization of the villagers. The land holders were requested to clear boundary corners of their field boundaries to be visible from aerial images. Temporary UAV signals (20cm by 20cm) were prepared, which had different contrast colors for ground control points (GCP) and boundary beacons, as shown in Figure 9. The signals' size was made sure to be greater than obtained GSD to be visible on the generated orthomosaic. Pix4D Capture was used for flight planning and preliminary distribution of GCPS.

Calibration

Four national trigonometrical stations encompassing the study were used to calibrate the site. A Trimble R4 GNSS in RTK mode was used to localize the site. The GNSS set has manufactures accuracy specifications of +/- 1cm + 1ppm RMS horizontal. The purpose of the calibration was to transform the World Geodetic Systems 1984 (WGS84) coordinate system by the GNSS to a local Gauss Coordinate System based on the Clarke 1880 Ellipsoid.

(a) (b) (c)

Figure 9: (a) UAV temporal signals, (b) National Geodetic Trig Station for calibration, (c) Relocation of parent property beacons.

It is worthy to note that this study will use the local Gauss Coordinate System, which is currently being used for all cadastral surveys in Zimbabwe.

Relocation of parent beacons

The case study area Stockholm was once a registered property with well-established surveyed boundaries consisting of 3 beacons. Further subdivision on the property added three more beacons to be relocated under SR31058. Eventually, six previous beacons were relocated. After digging or exposing the beacon, as shown in Figure 9 (c), the researcher measured them using GNSS. After the GNSS measurements, a temporary UAV signal was placed on top of the centre mark and secured to the ground by nails. The signal will be visible on the orthophoto, and then coordinates will be extracted for geometrical positional comparisons.

Georeferencing

Twenty well-distributed GCPs were placed in the case study area. It is recommended that GCPs be well distributed as distribution impacts spatial accuracy (Stöcker et al., 2020). Suitable areas were selected to place the GCPS. The GCPs were used to georeference the images improving the geometrical accuracy of the orthophoto. A 12mm iron peg (40mm in length) was used to mark the position of the temporary GCPs and CPs. The centre mark was then fixed by GNSS, and a temporal signal was placed on top as shown in Figure 10 (b). In addition, permanent GCPs as shown in Figure 10 (a) were also fixed by GNSS. The GNSS measurements obtained geometrical accuracies of 2cm for all measurements. The idea behind placing 20 GCPS was to assess the accuracy of comparison to GNSS coordinates when the number is reduced during the processing of the orthomosaic.

(a)

(b)

Figure 10: GCPS used for georeferencing.

Participatory boundary beaconing

The landholders, led by the village head and her leadership, took part in the beaconing of the boundaries. The DLO and researcher observed the process. At each corner point, a 12mm iron peg was placed, fixed by GNSS, and a signal was placed on top to be visible for the UAV flight. In case of disputed positions, the village head and other senior villages assisted in solving the boundary dispute. All the 15 individual plots were beaconed, and the positions were cleared of any obstructions that may obscure their visibility from drone images. After the first drone flight, the landholders were requested to put a cairn (hip of large stones) on top of the center mark. This was done before the second drone flight. Since this study aims to find the usability of UAVs for communal mapping combined with appropriate monumentation, it was perfect to further examine accuracies obtained if a cairn was used. The second flight covered only a quarter of the study area. Figure 11 below shows the landholders taking part in the beaconing of the boundaries and monumentation.

Figure 11: Participatory mapping.

UAV image acquisition

An ebeex UAV shown in Figure 12 was used to acquire aerial images of the study area following the flight path mission prepared using Pix4D capture software. The ebeex UAV has the following specifications: Camera model name – S.O.D.A_10.6_5472x3648 (RGB), camera resolution – 12MP, focal length – 10.633mm and image size (width*height) – 5472*3648.

Figure 12: eBeex UAV used for the study and signal visible on the aerial image.

The mission flying height was 144 meters with a forward image overlap of 80%, and the side lap was 70%. Higher overlaps were used to prevent gaps from occurring due to tilt and drifts, crab, and flying height variations. Furthermore, high overlaps increase the redundancy during the bundle adjustment process. The image acquisition covered an area of 360 hectares. The first flight covered the whole case study with all found and placed beacons and GCPs covered by temporary UAV signals of different colors. The second flight covered only a quarter of the total area. On all flights, the sky was clear, free of smog and dust and wind speed was less than 10m/s.

Questionnaires and Interviews

Two different questionnaires were distributed to land surveying and mapping professionals and another to landholders. The questionnaires consisted of direct and indirect questions, open and closed-end questions, ratings, and multiple-choice. The researcher wanted to ascertain how the landholders perceived land surveying and registration issues. Fourteen landholders responded to the questionnaire. Land surveying and mapping professionals were asked questions relating to the suitability of UAVs in cadastral mapping, legislations, comparison of UAVs and GNSS as surveying tools on different technical aspects, and changes that they think are necessary to allow UAVs usage. The questions were responded to by 18 private land surveyors, 5 public land surveyors and 3 academic lectures.

Semi-structured interviews were conducted with the Ministry of Lands Director, one Provincial Land Officer, the chairman of the Department of Geoinformatics and Surveying at the University of Zimbabwe, and the Surveyor-General of Zimbabwe. All interviews were conducted online. A deductive approach was used in which the researcher has themes and ideas about the study already (Hox & Boeije, 2004). The interviews were aimed at ascertaining the perception of respondents in the use of UAVs compared to traditional land tools in the cadastral mapping of communal lands.

Observations

The landholder's behavior was observed during the field participatory surveying and mapping phase. The dispute resolution mechanism was observed. The general farming activities, as well as available infrastructure, were documented. This was done to determine how the landholders had confidence in permanently occupying the land.

3.2.4. Post fieldwork

The post fieldwork stage focused on data processing, analysis, and the final presentation of the thesis. This stage was done to answer sub-objectives 2 and 3 and all subsequent research questions. After completing the fieldwork, the first task was to process the aerial images and extract coordinates of the marked points visible on the orthomosaic and from GNSS. Pix4DMapper, a professional software, was used to process the images acquired.

Orthomosaic generation

Interior orientation was done to determine the camera geometry (focal length, position of principal point, and lens distortions). Relative orientation was done to determine the geometric relationships of all overlapping images. Absolute orientation was done by bundle block adjustment to determine the position of the images in the space. The selected 20 GCPS were used to determine the 3D positions of images on the local ground coordinate system. Pix4Dmapper was further used to generate a dense point cloud from the bundle block adjusted images using Image Matching algorithms already embedded in Pix4D mapper. Half of the image resolution was used because of limited CPU processing power. The point clouds were then triangulated into a surface mesh, forming a Digital Terrain Model (DSM). The mosaic generated before was then orthorectified using DSM to produce an orthomosaic. The orthomosaic is free of relief and tilt distortions. Scale and metric measurements can be performed on the orthomosaic. The coordinates (Y and X) of boundary points were extracted from the georeferenced orthomosaic using QGIS. Three orthomosaics were generated (see Annex 7) :

1. *Orthophoto from 20 GCPS*
2. *Orthophoto from 6 GCPs*
3. *Orthophoto of beacons with a cairn*

Quality Assessment
The researcher assessed the quality of the orthomosaics before extracting coordinates. The quality assessment used the ground control points and checkpoints, and reports were generated (see Annex 2, 3, and 4). This procedure was done for all the three generated orthophotos. The RMSE in Y and X were satisfactory and sufficient for this case study. The GSD, which is the size of a pixel projected to the ground, was obtained and was enough to identify placed signals from the orthomosaic. In addition, the orthomosaics were checked for gaps and occlusions, making sure the whole area was covered.

Extraction of Coordinates
Coordinates of relocated beacons and the new individual boundary beacons were first extracted from the orthophoto. The coordinates were then compared to determine whether the difference is within the conformity of error limits as stated in the second schedule of LSR. However, the researcher had challenges with maintaining the same zooming factor to extract coordinates from the orthophoto in QGIS. For all the points, zooming was done to the point where the target's visibility started to blur. Furthermore, other targeted points had poor contrast and deficient brightness due to radiometric challenges. The radiometric challenges were a result of different image acquisition times. The exact center position was difficult to extract.

Draughting
Further comparison of boundaries from GNSS measured and orthophoto derived coordinates were plotted using commercial software Surpac and Autocad. The draughting was mainly done to visualize the property encroachments as a result of participatory beaconing.

Interview data
The data was transcribed using open-source software. The content analysis method was applied to analyze the data. The interviewee's frequently used words and phrases were coded, and patterns were derived and evaluated as Creswell suggested. The coded data were grouped and categorized into meaningful themes according to (Archer, 2018). The relationship between the themes was then examined. The examination revealed how stakeholders compare the UAVS and conventional tools in surveying and mapping. Their opinions, knowledge, experiences, and expectations of various factors affecting communal land registration were examined. The information was used to answer Sub-objective 3.

Questionnaires
The data was captured using open-source software called EpiCollect. The data was converted to Excel and transferred to SPSS for analysis. In other instances, the mean, median, mode, frequency, and range values of values were calculated for analysis. The data was examined and was used to answer Sub- objectives 2 and 3.

3.3. Limitations to the research

The issue of land is a sensitive topic in Zimbabwe hence getting data from authorities as well as individuals is difficult. Some of the topical issues were not fully expressed by the interview respondents. Although sensitized about the research, the landholders and local traditional leaders remained skeptical about the research motive, resulting in the researcher losing a field book. The researcher failed to conduct physical interviews because he was forced to return to the Netherlands due to an outbreak of corona virus in Zimbabwe during field data collection. They had to be organized online. In addition, the researcher had to seek voluntary workmates for data collection using questionnaires as he could not have time to do that by himself on the ground.

3.4. Ethical considerations

The primary data and secondary data collection involved government serving members. They are not allowed to conduct interviews without authority. In this regard, the researcher informed them on time. The researcher's motive was made clear to relevant authorities such as DSG and MLAFWRR to receive their support. The Surveyor General was engaged and provided assistance by liaising with the Minister of Lands. The landholders and local traditional leaders were sensitized and made aware of the purpose of the research and that a UAV will be used to acquire aerial images. Their consent to be involved in participatory mapping was sought. They were also informed of their rights to withdraw their consent. Professional respondents were also informed of their rights. The collected information from interviews and questionnaires will be treated with confidentiality and only used for academic purposes. Personal information obtained will be kept confidential as well.

3.5. Research matrix

The research matrix is a system of rows and columns in which the research objectives, questions, variables, and analysis method are fitted (Choguill, 2005). This study research matrix is presented in Annex 6. It shows data sources used for this study and expected outcomes for each sub-objective.

3.6. Research datasets, instruments, and software

The table contains a summary of the research datasets and instruments that were used to collect data. The softwares used to capture, and process data are presented. The source of the resources and data used for this case study is also presented in the table (see Annex 7).

3.7. Conclusion

The chapter introduced the case study area and the study's research design or methodology. The research design included all data collection methods used, pre-fieldwork, fieldwork, and post-fieldwork. In addition, the limitations of the study were stated. The next chapter will present the results from the data collected.

4. RESULTS

This chapter presents the findings gathered from both primary and secondary data for the purpose of answering questions under sub-objectives 1,2 and 3. Results are presented following the sequence of the sub-objectives stated in Chapter 1.

4.1 Laws, policies, technologies, and institutions regarding Communal land, surveying/mapping, and registration.

4.1.1. Legislative Acts, Policies, and government documents

The section presents the results of reviews found from legislative acts, policy, and official government documents reviewed regarding Communal land establishment, surveying, and registration in Zimbabwe.

The Constitution of Zimbabwe 2013

The Constitution of Zimbabwe (Government of Zimbabwe [GoZ], n.d.-b) is Zimbabwe's supreme law and defines land as finite, sharable natural resources that form part of Zimbabweans heritage. It states that every Zimbabwean inhabitant has a right to acquire, hold, occupy, use, transfer, lease, or dispose of agricultural land regardless of his color or race. It also provides rights to the property, be it movable or immovable.

The 2019 National and Gender-Sensitive Land policy (draft)

The drafted land policy meets international standards and guidelines stated by the FAO Voluntary Guidelines for Responsible Governance of Tenure (Chambati & Mazwi, 2020). It is also aligned with the African Union Framework Agenda 2063 and the UN 2030 SDGs. Security of tenure for Communal land through registration is specifically mentioned and considered a priority.

Communal Land Act (Chapter 20:04) of 1982 (as amended 2002)

The Communal Land Act (GoZ, n.d.-a) established and defined communal land, who may occupy, use, and dispose of it. It states that the land is vested in the President but in the custodians of RDCs and Traditional leaders. It has several references to the Traditional Leader's Act, which specifies communal land surveying and registration. Furthermore, the act is specific that occupational and use permits should be issued to landholders. However, the President, Minister, and RDC authorities have the right to withdraw the permits and set aside any part of communal land.

Traditional Leaders Act (Chapter 29:17) of 25/1998, 22/2001,17/2007.

The Traditional Leaders Act (GoZ, 2020f) complements the Communal Land Act. Section 23 of the Act mandates the establishment of communal / village boundaries by surveying and generating a map. The generated surveyed diagrams should be filed at the Ministry of Local Government. It further mandates the issuance of village registration certificates (VRC) and settlement permits to landholders. Furthermore, the District Administrator (DA) is mandated to keep an accurate update of the maps and permits of the village.

Land Acquisition Act (Chapter 20:10) of 1992 (amended 2001, 2002, 2004, 2006)

The Land acquisition act (GoZ, 2020b) allows for the compulsory acquisition of commercial farms for public resettlement purposes. It supports section 72 of the Constitution which mandates the government to compulsory acquire any agricultural land for land resettlement. The A1 model, which is organized communal land, falls under this category, and MLAFWRR issues permit to landholders. The permits are attached to a map generated by the Ministry's technical department.

The Land Commission Act Chapter 20:29 of 2017.
The act complements the Land Acquisition act. It states that the Minister of MLAFWRR may issue leases, offer letters, deeds of grant, and permits for state land (GoZ, 2017). Any of the mentioned above ownership documents could be given to communal land after cadastral surveys. The ministry should keep a register of all alienated state land.

Land Survey Act (Chapter 20:12) of 1932 (as amended 2002)
This Land Survey Act (GoZ, 2020c) provides rules relative to the survey of land in Zimbabwe to effect registration at the Deeds Registry. It establishes the DSG as the custodian of all land in Zimbabwe. It provides how the land shall be charted, the expertise required, the methods, land diagrams and plans, protection of survey monumentation, and the records to be produced for storage by the DSG.

Land Survey (General) Regulations of 1979
The regulations (Government of Zimbabwe, 2019) guide all cadastral surveys intended for registration purposes. The aim of this study was to find whether UAV measurements will attain the same results as specified in these regulations. The communal lands are not specifically mentioned but fall under the blanket of surveys classified as rural surveys or class C surveys.

a) Orthophoto and Beacons
Section 14(2) mentions the use of orthophoto to extract curvilinear boundaries only. Furthermore, the regulations provide comprehensive specifications of boundary beacons for the different surveys and land classes under sections 21 and 22. The act requires the beaconing of every boundary corner.

b)Accuracy
The Land Survey (General) Regulations specify accuracy standards for each survey class under the Second Schedule- limits of error section.

Deeds Registry Act (Chapter 20:05) of 1959 (as amended 2001)
The Deeds Registry Act (GoZ, 2020a) principally makes provision for the making and registration of deeds regarding land and other real rights, for rights in lands such as lease and servitude, and the transfer of land. The act is so specific on the requirement of a DSG-approved geometrically framed diagram representing the land to effect registration.

Regional Town and Country Planning Act (Chapter 29:12) of 1976 (as amended 1998)
Defines the boundaries or areas that fall under the provincial, district, or municipal offices. It provides the guiding principles required to develop and administrate the urban and regional areas (GoZ, 2020e).

Manual for Systematic Land Registration 2019 (unpublished draft)
This manual was drafted by the DSG, Zimbabwe Land Commission, MLAFWRR, and WorldBank (Burns, 2019). The manual developed an automated process to collect data in the field, field dispute resolution mechanisms, and participatory beaconing of A1 model plots (Communal land). Field data was to be collected using existing open-source systems called Mobile Applications for Secure Tenure (MAST), High-resolution satellite images, and GNSS.

4.1.2. Institutions

Ministry of Lands, Agricultural, Fisheries, Water and Rural Resettlement (MLAFWRR)
The Ministry of Lands (MLAFWRR, 2017) is responsible for the A1 model classified as organized communal land. The Ministry issues occupation and use permits. The permits are silent on surveying the individual plots but use settlement layout maps generated by the technical department.

Department of Surveyor General (DSG) and Deeds Registry Office
The DSG (DSG, 2019) is mandated to undertake administrative, regulatory, advisory, and technical functions pertaining to land, aerial, space surveys, mapping, storage, and geoinformation obtained in Zimbabwe. It is responsible for cadastral surveys for rural and urban state land to effect registration, the maintenance of Zimbabwe's international boundaries, and the calibration of all survey equipment. Title surveys are approved first by DSG, and diagrams are passed to the Deeds Registry. The office is responsible for title and lease registration for both rural and urban land.

Ministry of Local Government
The Ministry of Local Government (Government of Zimbabwe, 2020d) oversees urban and rural land administration. Its mandate and core business includes planning and allocation of vested land. Vested land includes the communal land presided over by Rural District councils and Traditional leaders.

4.1.3. Technologies

Conventional tools such as theodolites, electromagnetic distance measurement tools (EDM), total stations, tapes, chains, and GNSS are being used to carry out cadastral surveys. Intersections, traversing, and resection are methods used with the tools mentioned above to fix or coordinate points on the ground. None of these tools has been used to survey communal land for registration purposes. Few high-value properties situated in rural areas have been surveyed using current survey tools situated in communal land. This was highlighted by the MLAFWRR respondent.

Traditional aerial photogrammetric and satellite images are used to generate topographical maps by DSG for the whole country. The DSG respondent said the office is currently using UAVs to update street maps. The respondent from MLAFWRR highlighted the use of aerial photographs and, recently, satellite images for planning purposes in communal area mapping. These images are used to generate settlement layouts for the A1 model, which is organized communal land. Handheld GPS is also being used to map communal lands under MLAFWRR direct jurisdiction. Furthermore, the respondent stated that the maps are used for the sole purpose of planning and to attach to permit documents issued to A1 landholders.

4.1.4. The legal framework regarding UAVs and GNNS for cadastral mapping

Statutory Instrument 271 of 2018. Civil Aviation (Remotely Piloted Aircraft) Regulations, 2018
The regulations (Government of Zimbabwe, 2018) guide the operation of UAVs in Zimbabwe. The regulations require the registration of the UAV. The operator should be licensed, medically fit, and has no criminal record. CAAZ retains authority to physically examine the storage and maintenance of the drones. An application for UAV registration, flying license, and flying permission requires 30 days to obtain a response. The regulations further set conditions for UAV field operations, such as operating within the visual line of sight of operations (VLOS) and in clear weather conditions. The maximum flying height is 400 feet (approx. 122 meters) above ground. Furthermore, UAVs should be operated at a distance of 5556 meters from prohibited sites. Further approval is required if operations are within 30 meters of people and in the vicinity of property and structures.

Land Survey Act and Land Survey Regulations
The Land Survey Act is not specific on any tool to conduct cadastral surveying in Zimbabwe. That implies that GNSS and UAVs can be used as long as they adhere to land survey regulations. The LSR requires all measuring instruments used for cadastral surveying to be tested and registered by the DSG. It means both UAVs and GNSS, as long they can be registered by the DSG, they can be utilized for communal land surveys under the existing legal acts.

Survey Regulations Board Circular 1 of 2002

The circular was published in the year 2002 by the Survey Regulation Board. It provisionally provides a few guidelines for using GNSS for cadastral surveys (see Annex 1).

4.2. Comparisons of UAV and GNNS observations in a participatory survey and mapping in Zimbabwe

The suitability of UAVs for surveying and mapping communal land is compared to GNSS. Comparisons were made regarding cost, time, and accuracy obtained from primary data. Secondary data from other similar previous investigations will be compared to the findings of this case study.

4.2.1. Cost comparisons per land parcel using GNSS and UAV

The costs per hectare were derived from the SRB tariff, quotations, questionnaires by surveyors and landholders, and the researcher's experiences. Comparisons were made for a systematic survey of all the 15 plots and when an individual plot is to be surveyed. The costs presented are only for field data collection and data processing. They do not include the cost of preparing a complete survey record as required by LSR. The costs are per hectare of land and in US dollars are presented in Tables 1 and 2 below;

a) Systematic survey of 15 Stockholm plots.

Table 1: Cost per hectare comparisons of GNSS and UAV.

Source	GNSS (US$ per Ha)	UAV (US$ per Ha)
SRB tariff and Service providers	$32.03	$9.22
Researcher experience	$26.21	$11.25

b) Individual approach: a survey of 10 Ha plot in Stockholm

Table 2: Cost per hectare of GNSS and UAV for 10 hectares individual plot.

Source	GNSS (US$ per Ha)	UAV (US$ per Ha)
SRB tariff and Service providers quotations for orthophoto		
Land Surveyors	$120- $250 (50%), $ 50 – $80 (27%)	
Landholders	$50.00 - $200.00	Not aware
Experience	$187.60	$112.80

From Tables 1 and 2 above for both scenarios, a UAV-generated orthophoto is cheaper per hectare as compared to the GNSS survey. A systematic survey of the 15 plots costs an average of $9.22 to generate a UAV orthophoto and $32.03 using GNSS. The cost per hectare is high for individual surveys, as shown in Table 2. Results in Table 2 show that most land surveyors will charge between $120 and $250 per hectare to survey an individual plot.

4.2.2. Comparisons of cadastral data acquisition times for GNNS and UAV

The time comparison is based on primary data from estimated quotations based on SRB tariff, service providers, and researcher experience. Table 5 shows the days it takes to complete Stockholm's survey. From Table 3, the time taken to acquire Stockholm boundary data is less using UAVs compared to GNSS. The time period provided by service providers and the researcher's experience shares the same conclusion.

Table 3: Time taken to acquire data of Stockholm by GNSS and UAV.

Source	GNSS (Time in days)	UAV (Time in days)
SRB tarrif/ quotations for uAV	5	1
Reasearcher experience	4	3

4.2.3. Accuracy comparisons between UAV orthophoto extracted coordinates and GNSS coordinates.

Coordinate comparison of GNSS and UAV orthophoto (20GCPs)
Coordinates extracted from the orthophoto were compared to GNSS measured corresponding beacon points as shown in Table 4.

Table 4: Coordinate comparison of GNSS and UAVs orthophoto (20 GCP)

Beacon	Ygnss (m)	Xgnss (m)	Yuav (m)	Xuav (m)	dy (m)	dx (m)
1a	-46941.773	1955659.939	-46941.702	1955659.935	-0.071	0.004
1b	-47264.664	1955689.440	-47264.651	1955689.370	-0.013	0.070
2a	-47345.788	1956037.826	-47345.716	1956037.699	-0.072	0.127
2b	-47148.148	1956049.576	-47148.090	1956049.590	-0.058	-0.014
2c	-47112.261	1955907.826	-47112.267	1955907.710	0.006	0.116
2d	-47115.736	1955873.807	-47115.722	1955873.700	-0.014	0.107
2e	-47401.911	1955703.518	-47401.817	1955703.486	-0.094	0.032
4a	-47591.969	1956017.844	-47591.894	1956017.813	-0.075	0.031
4b	-47859.049	1955710.142	-47858.970	1955710.075	-0.079	0.067
4c	-47821.269	1956007.486	-47821.177	1956007.408	-0.092	0.078
5a	-47904.343	1955449.928	-47904.261	1955450.025	-0.082	-0.097
5b	-47595.273	1955712.662	-47595.190	1955712.512	-0.083	0.150
6a	-47657.988	1955412.489	-47657.923	1955412.455	-0.065	0.034
6b	-47675.768	1955131.301	-47675.711	1955131.221	-0.057	0.080
8A	-47464.913	1955391.141	-47464.855	1955391.176	-0.058	-0.035
9a	-47230.957	1955368.834	-47230.776	1955368.929	-0.181	-0.095
9c	-47403.677	1955696.674	-47403.641	1955696.689	-0.036	-0.015
9d	-46945.660	1955655.139	-46945.548	1955655.093	-0.112	0.046
10a	-47519.507	1955083.418	-47519.473	1955083.375	-0.034	0.043
10b	-47441.878	1955482.813	-47441.829	1955482.695	-0.049	0.118
11a	-47684.181	1954917.442	-47684.133	1954917.396	-0.048	0.046
11d	-47841.638	1955083.390	-47841.531	1955083.331	-0.107	0.059
12a	-47816.593	1955161.273	-47816.630	1955161.233	0.037	0.040
12c	-47955.478	1955284.495	-47955.404	1955284.520	-0.074	-0.025
13a	-47526.657	1955092.073	-47526.607	1955091.928	-0.050	0.145
14a	-47817.244	1954786.526	-47817.219	1954786.581	-0.025	-0.055
14b	-47892.348	1954716.172	-47892.373	1954716.261	0.025	-0.089
14c	-48148.715	1954914.101	-48148.700	1954914.155	-0.015	-0.054
14d	-48019.892	1955004.734	-48019.824	1955004.660	-0.068	0.074
15a	-46842.469	1956063.585	-46842.450	1956063.520	-0.019	0.065
15b	-46568.736	1956029.322	-46568.672	1956029.208	-0.064	0.114
15c	-46819.933	1955806.391	-46819.882	1955806.322	-0.051	0.069

The comparison shows the mean value of residuals in the Y direction of -.0.057m and 0.041m in the X direction. The residuals standard deviations are 0.041m in Y and 0.068m in X, and the positional accuracy (RMSE) is 0.106m. Descriptive statistics of the comparison were calculated, and a scatter plot of residuals was plotted, as shown in Figure 13. The scatter shows the spread of the residuals with potential outliers.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
dy	34	-0.181	0.037	-0.05668	0.041164	0.002
dx	34	-0.097	0.15	0.04068	0.067714	0.005
Valid N (listwise)	34					

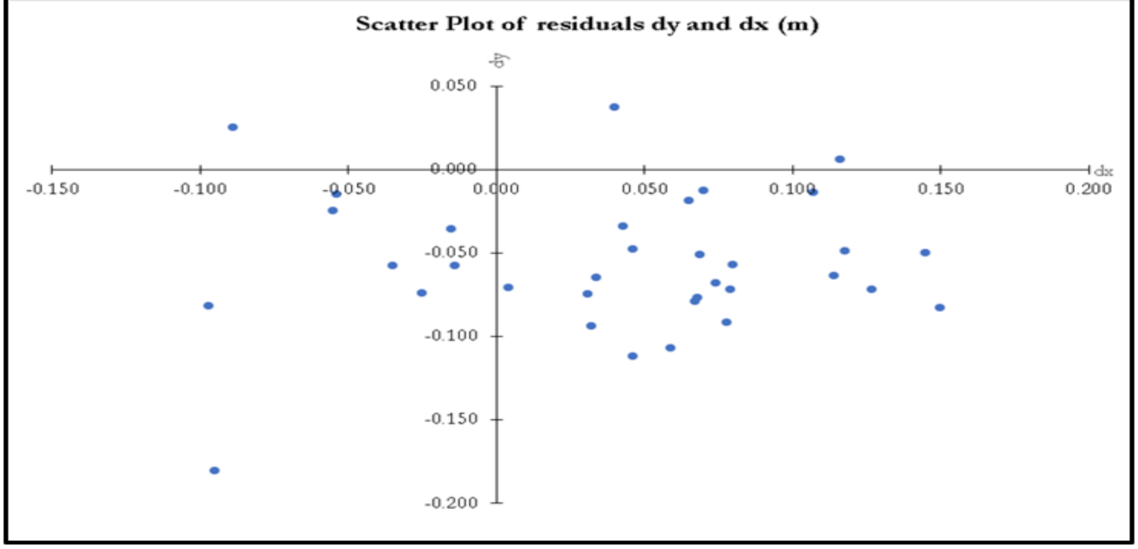


Figure 13: Descriptive statistics and scatter plot of the comparison residuals (20 GCP orthophoto)

Coordinate comparison of GNSS and UAV orthophoto (6 GCPs)

The orthophoto (see Annex 7) used for coordinate comparison was georeferenced with 6 well-distributed GCPS. The coordinate comparison was made, and the descriptive statistics of the comparison were calculated. The comparison shows the mean value of residuals in the Y direction is -0.046m and 0.109m in the X direction. The residuals standard deviations are 0.050m in Y and 0.068m in X. A positional accuracy RMSE of 0.096m was achieved.

Coordinate comparison of GNSS and orthophoto (placed beacons with cairn)

The accuracy assessment of the orthophoto (see Annex 7) generated after monumenting the beacons is presented. From the coordinate comparison of GNSS and beacons with a cairn, the residuals mean in Y is -0.011m and 0.010m in X, and positional accuracy RMSE of 0.144m was obtained. Even though the average means are very low, the higher standard deviations of the residuals of 0.091cm in Y and 0.112cm in X revealed that residuals are highly scattered around the mean values. The residuals are also on the higher side as compared to previous results for 20 and 6 GCPs orthophotos.

Error limits calculation as stated in the Second Schedule of the LSR

The error limits state that the displacement between beacons calculated from new and old survey coordinates should be less than the limits stated in the LSR. This study extracted the coordinates of the positions of found beacons (see Annex 7) from the orthophoto (20 GCPs). Join calculations were made from one beacon to every beacon found. The distances were then compared to the same corresponding distances derived from coordinates filed in SR31058 (old survey). Table 5 shows the displacements calculated and the error limits for Class B and C as set in the Second Schedule Limits of error of the LSR.

Table 5: Distance residuals and Class A and b error tolerances.

Limits of Error- Second Schedule of LSR of 1979 (meters)							
Beacons	GNSS	UAV	Survey Record (SR)	UAV-SR	Displacement	Class C Tolerance	Class B Tolerance
CY - G1	294.990	295.014	294.997	0.017	0.017	0.1186	0.0593
CY - G2	477.466	477.508	477.564	-0.056	0.056	0.1674	0.0837
CY - Rock	363.808	363.906	363.929	-0.023	0.023	0.1373	0.0687
CY - E	2364.035	2364.088	2364.336	-0.248	0.248	0.6374	0.3187
CY - F	2593.315	2593.303	2593.799	-0.496	0.496	0.6938	**0.3469**
G1 - G2	350.694	350.743	350.679	0.064	0.064	0.1338	0.0669
G1 - Rock	448.088	448.038	448.011	0.027	0.027	0.1596	0.0798
G1 - E	2069.075	2069.075	2069.340	-0.265	0.265	0.5647	0.2824
G1 - F	2584.487	2584.422	2584.797	-0.375	0.375	0.6916	**0.3458**
G2 - Rock	294.147	294.090	294.132	-0.042	0.042	0.1184	0.0592
G2 - E	2068.095	2068.202	2068.420	-0.218	0.218	0.5645	0.2823
G2 - F	2236.427	2236.303	2236.748	-0.445	0.445	0.6059	0.3030
Rock - E	2360.241	2360.292	2360.548	-0.256	0.256	0.6364	0.3183
Rock - F	2229.507	2229.397	2229.870	-0.473	0.473	0.6042	**0.3022**
E -F	3353.161	3353.097	3353.586	-0.489	0.489	0.8804	0.4403

The displacements obtained for all the tested joins are less than the allowable limit for Class C surveys. This result means that coordinates from UAV orthophoto can be used for all surveys under Class C as long the rightful monument is authorized by the DSG. Figure 14 shows a better visualization of the results shown in Table 5. The researcher further tested the displacements against error limits required for Class B surveys. The results showed that some of the displacements were outside the allowable limit.

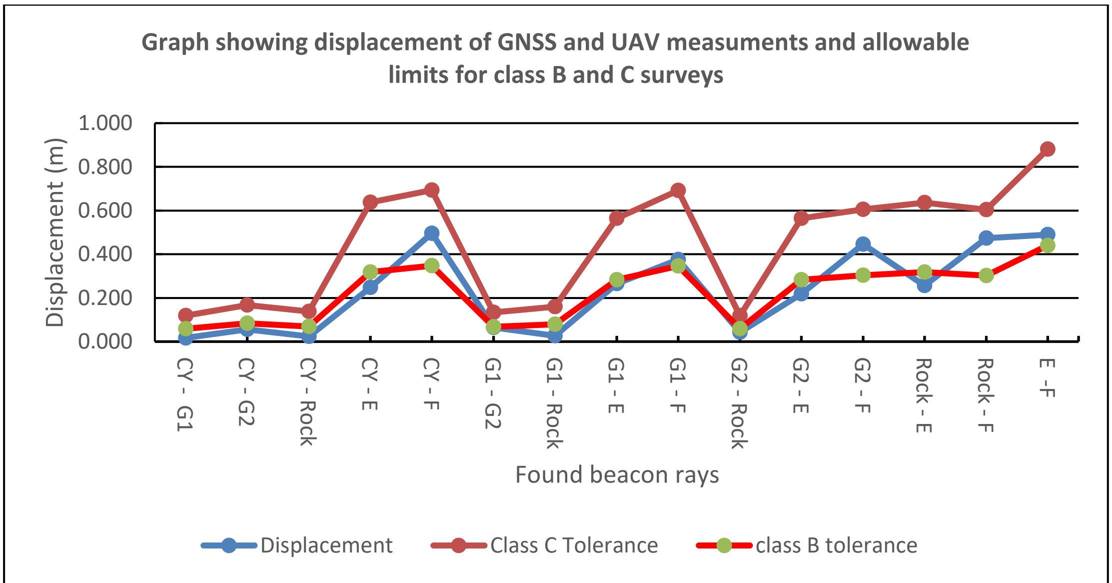


Figure 14: Displacement and allowable limits for Class B and C surveys.

4.2.4. How do results compare to previous investigations?

The accuracies derived from the calculations were further compared to other previous investigations. The findings are presented in Table 6 in Chapter 5. Several articles examined concentrated on GCPs, and CPs accuracies. The accuracy of extracted or digitized coordinates is rarely mentioned or presented. The researcher's RMSE and average mean results compared well and better to previous investigations.

4.3. Potential UAVs amalgamation in participatory Communal land recordation in Zimbabwe.

The stakeholders who are likely to benefit from the use of UAV-generated orthophoto in Zimbabwe are presented. In addition, an evaluation of the comparison of UAV and GNSS from surveying and mapping stakeholders is presented. Lastly, recommendations are presented.

4.3.1. Beneficiaries of the use of UAV high resolution generated orthophotos in boundary mapping

Zimbabwean citizens in communal areas will be the greatest beneficiaries as the use of UAVs will speed up the surveying and mapping of their land. Government ministries that play major roles in land administration, such as MLAFWRR and the Ministry of Local Government, will benefit from speedy data collection using UAVs. The DSG, which has started using UAVs to update topographical maps, will benefit from reduced costs in the collection of cadastral data using UAVs.

The professionals such as land surveyors, town and rural planners, and mapping agencies will benefit immensely from quick data collection tools at less cost. Other beneficiaries include the RDC and traditional leaders who will be able to account for the land under their jurisdiction.

4.3.2. Evaluation of UAVs and GNNS usage in cadastral mapping from surveying and mapping stakeholders (including Land Surveyors, mapping experts, academic institutions, DSG)

The responses show that 69% of the stakeholders agree that the legal requirement for GNSS allows them to conveniently use the tool as compared to 61% who disagree with UAVs use. Only 23% find it convenient to use UAVs under the existing legal requirements. Furthermore, 46% of the stakeholders agree that GNSS is covered by the land survey act and regulations, while 3% agree to UAV coverage. The majority, which is 80%, disagreed that the land survey regulations cover UAVs. Annex 14 shows the stakeholder's responses. However, the interview respondent from the DSG said that the Land Survey Act covers any surveying and mapping tool but admitted regulations have to be changed to incorporate UAVs. Further evaluations are presented in Figure 15. The results show a significant number of stakeholders, 38%, who are neutral in terms of UAV usage being less costly to GNSS. 38% agree that UAVs are less costly compared to GNSS. In terms of efficiency, 76% disagree that UAVs are more efficient in collecting data compared to GNSS. The perception that UAVs are able to collect data in less time than GNSS was rejected by 76%. However, 46% agree that UAVs are the tool of the future.

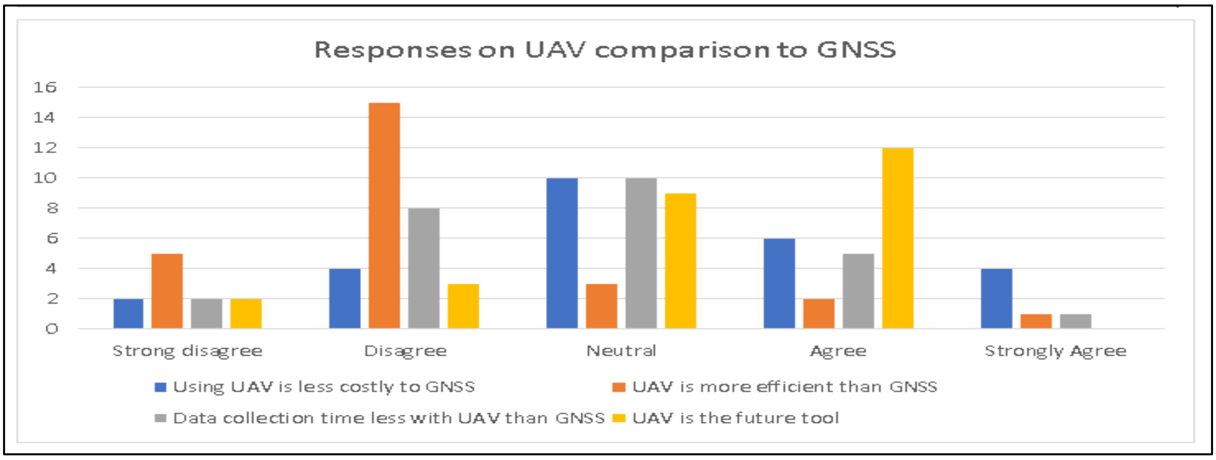


Figure 15: Comparison of UAV to GNSS

The researcher further investigated how the stakeholders rate the effectiveness of UAVs and GNSS for cadastral surveying and mapping. The rating was done from 1 (Not Effective) to 10 (most Effective). The results shown for each category in Figure 16 are the average of 26 individuals' rating responses.

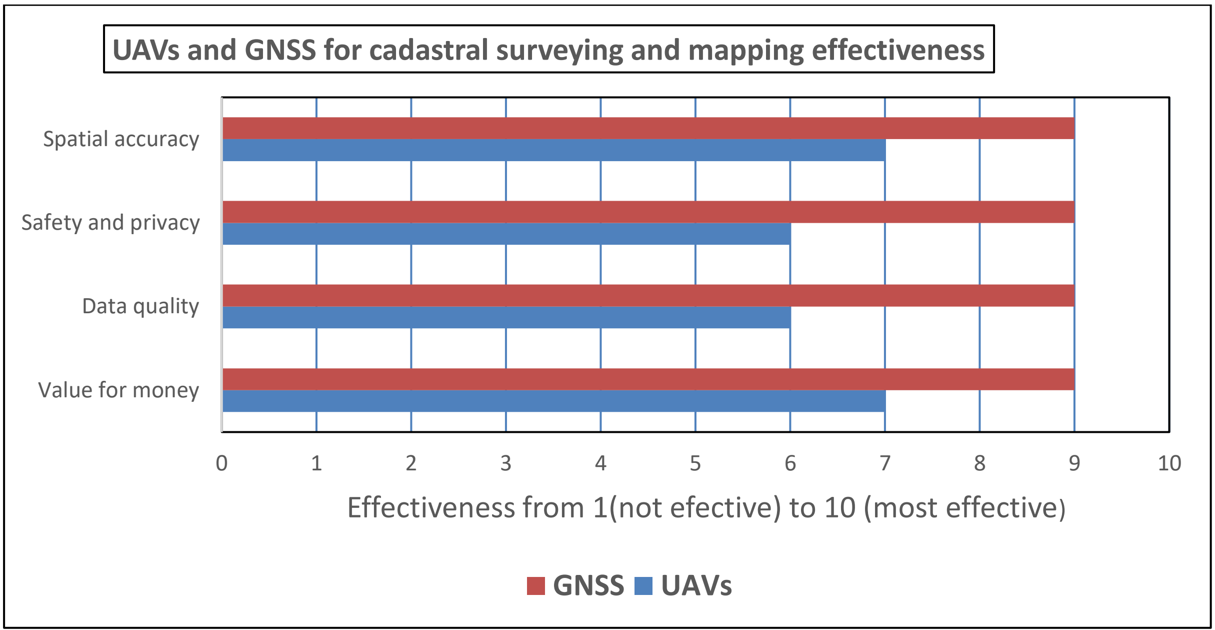


Figure 16: UAVs and GNSS effectiveness in surveying and mapping.

The GNSS is rated 9 for all the categories evaluated. The rating for the UAV was lower than GNSS for all the categories evaluated, as shown in Figure 16. The lowest rating of 6 was registered under the safety and privacy and data quality category.

4.3.3. Recommended stakeholder opinions for UAVs approach to communal surveying in Zimbabwe

The recommendations presented below emanated from the conclusions of the comparisons of UAVs and GNSS presented above, responses from land stakeholders, landowners of Stockholm, and interviews from officials of the Ministry of Land, DSG, and the University of Zimbabwe.

- The LSR regulations are to be amended to incorporate UAVs and orthophoto for cadastral surveying.
- A participatory approach to be used for UAVs to communal surveying only where outside boundaries are unsurveyed to avoid encroachments (see Annex 9), as discussed in sub-section 5.3.1.
- The SRB to include a new accuracy category under the error limits in the second schedule of the LSR that covers orthophotos.
- CAAZ to relax the strictness of UAV regulations which prohibit potential use by land professionals
- A fit-for-purpose concept to be applied in Zimbabwe for communal land surveying and registration with room to upgrade the tenure category.
- Enactment of legislation for communal land survey registration at the Deeds Registry.
- DSG to prescribe monumentation for communal land surveys visible from aerial images.

The chapter presented results following the order of the sub-objectives and subsequent questions. Chapter 5 will analyse and discuss the presented results in detail and how the results answer the research questions.

5. ANALYSIS AND DISCUSSION

This chapter analyses and discusses the results presented in Chapter 4. They are focused on assessing the suitability of the UAV as a cadastral surveying and mapping tool for Communal land. Therefore results are analysed and discussed to answer the possibility of UAV use for communal land surveying and mapping.

5.1 Laws, policies, technologies, and institutions regarding Communal land, surveying, and registration.

5.1.1. Legislative Acts, Policies, and government documents

The section analyses and discusses the results of reviewed various legislative acts, policies, and official government documents regarding Communal land establishment, surveying, and registration in Zimbabwe.

The Constitution of Zimbabwe 2013, Land Acquisition Act, Land Commission Act, Communal Land Act, Traditional Leaders Act, and National Land Policy

The supreme law, the Constitution of Zimbabwe 2013, protects the land rights of its citizens. Land rights under the constitution include acquiring, holding, occupying, using, transferring, leasing, or disposing of land. Although not specific about communal land, enabling acts and policies to protect communal land were also enacted. The Communal land Act established communal lands and is supposed to issue occupational permits. It is complemented by the Traditional Leaders act that mandates the surveying and issuance of village registration certificates to landholders. These two acts on paper already protect communal landholders. Surprisingly, the communal land continues to face evictions from various agencies. The main problem identified was that although the acts are available, they are not wholly implemented to protect communal land rights. The researcher found that they are no single village or communal land that has been surveyed and issued a village registration certificate (VRC). The VRCs and maps could have improved ownership rights and reduced boundary disputes and evictions without compensation. Sadly, even if the VRC were to be issued, the surveyed maps and VCRs are not recognized by DSG and Deeds Registry, respectively. In addition, both the Land Acquisition Act and Land Commission Act gives the MLAFWRR minister power to issue formal ownership documents to state land landholders. The two laws can be used to issue lease or deed of grant to surveyed communal land considered state land.

Discussions with the respondent from DSG and MALRR revealed that the government's previous policies were reluctant to survey and register communal land. The land is considered less valuable to incur huge survey and registration costs. The respondent from UZ echoed the same sentiments. Another contributing factor to zero communal surveys is that landholders believe their land is secured without any documentation as it is presided by local traditional leaders. In some instances, generations have passed without any land disturbance. The researcher found that 100 % of landholders in Stockholm are not aware of the Communal land Act, the Traditional Leaders Act, and how they protect their land rights. Furthermore, Annex 12 shows that 62% of land professionals who responded to questionnaires are not aware of the above acts. During the five interviews conducted, these acts were never mentioned by any of the respondents. The above stated shows a lack of awareness from the authorities to individual landholders. Subsequently, the communal land remains unsurveyed and unrecorded. The recent National Land Policy 2019 includes the government plan to account for every land, including communal lands. It is anticipated the implementation of the policy will further protect communal land rights, women's land rights, and land rights for minority groups.

Land Survey Act, Land Survey (General) Regulations of 1979, Deeds Registry Act, and Regional Town and Country Planning Act

In Zimbabwe, land can be formally registered at the Deeds Office after surveying is done under the guidance of the Land Survey Act and Land Survey Regulations. For communal land, the Deeds Registry Act is silent on the legality of VRC and other permits being issued by MLAFWRR under the Land Acquisition Act. It implies that the type of land recordation without a DSG-approved survey diagram is not recognised as formal, and the transfer of such land becomes a challenge. The challenge is that the cost of carrying out a survey using conventional methods and meeting the accuracies required by LSR is beyond most communal landholders. However, a loophole within the Land Survey Act may be exploited in the meantime to survey communal land using cheaper methods such as UAVs. Section 19 of the Act allows adjudication of lands under the DSG or minister's specific guidance using a specific method.

Although the results of this research in sub-section 4.2.3 proved that UAVs could produce class C accuracies, the survey was done under strict conditions. For communal land, another class of accuracy can be added by the Survey Regulation Board that will allow the use of orthophotos to survey the land. Another essential legal act is the Regional, Town, and Country Planning Act. Although it guides the development of both urban and rural areas, it is silent on surveying communal land. Subsequently, the communal lands are left unregistered.

The Manual for Systematic Land Registration 2019 (unpublished)
The manual aims to reduce survey and registration costs to US$ 150 per plot). However, the manual has never been implemented, and no communal land has ever been documented using this manual. All government respondents interviewed cited a lack of resources to implement the manual.

5.1.2. Institutions

The main institutions regarding Communal land registration are discussed in this section. Ministry of Agricultural, Land Water, and Rural Resettlement (MLAFWRR) administer A1 model farms also classified as organised communal lands. Landholders are issued with permits attached to the site plan, and permits can be inherited. In the case of Stockholm landholders, 28% of landholders inherited the land. The landholders want their land surveying and registered to have the confidence to erect boundary fences, add more livestock, and install electricity and water systems. Plans are underway to survey and register A1 farms as highlighted by the MLAFWRR respondent. A large part of communal land is under the Ministry of Local Government. Traditional leaders and RDCs under the ministry preside over the communal land. However, they have violated the Traditional Leaders Act since its enactment in 1998. They have not issued a single VRC, and no single document is available requesting surveying of communal land. Key institutions such as DSG and the Deeds office require surveys done under the Land Survey Act to effect registration. It implies that, at the moment, communal land can not be registered easily at less cost. A clear government policy to survey communal land has to be implemented.

5.1.3. Technologies

The conventional tools mentioned in the LSR are archaic, and the SRB has to publish new regulations that incorporate the usage of new tools and methods to collect cadastral data. The use of GNSS has become popular as the latest tool for surveying. All interview respondents agreed that GNSS speed up the collection of data. The UZ respondent also highlighted they had changed their academic curriculum to include the use of new technology, such as GNSS and UAVs. Satellite images are being used to generate layouts for planning purposes of communal land by MLAFWRR. The MLAFWRR mapping section uses handheld GPS to map communal lands under its direct jurisdiction. The DSG use of UAVs generated orthophoto to update topographical maps, and street maps is welcome development. Furthermore, the DSG respondent highlighted that the office is also keen to use UAVs for cadastral data acquisition, starting with A2 farms. All the above suggest a welcome development in the quest to improve surveying and mapping of communal land for registration purposes.

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5.1.4. The legal framework regarding UAVs and GNNS for cadastral mapping

Discussions below are based on questionnaires responses and Annex 12. The majority (90%) of land professionals respondents agree that a surveying tool has to adhere to a legal framework for use to collect cadastral data. It is the reason why this legal framework regarding UAVs and GNSS use has to be discussed. It was not surprising to find that 46% of the stakeholders agreed that the Land Survey Act and LSR cover GNSS use. That can be attributed to the fact most of them use GNSS to conduct surveys. The UAV is not yet popular in Zimbabwe, and a few have physically touched it. This has contributed to 3% of the respondents believing the LSR has to be amended to incorporate UAVs. In addition, it is astonishing that 80% of stakeholders do not believe any legal act covers the use of UAVs, yet the Civil Aviation (Remotely Piloted Aircraft) Regulations exist.

The DSG respondent who heads the SRB reiterated that regulations need to be amended to accommodate GNSS and UAVs. One major requirement of all measuring instruments for cadastral surveying is that DSG has to test and register them. It implies that the DSG should have the capacity to test both tools under discussion for them to be used in cadastral surveying. The challenge is that DSG has capabilities of only testing the chains, measuring tape, EDMs, and Total stations. That creates a problem if users opt for UAVs or GNSS. However, the Survey Regulations Board Circular 1 of 2002 provisionally provides guidelines for GNSS use, but they are not specific. To a greater argument, the current use of GNSS in Zimbabwe for cadastral data collection is illegal as the DSG has registered none. The researcher concludes that since GNSS is being used to conduct surveys accepted by DSG without clear regulations, ambiguities within the regulations can also be exploited to use UAVs for communal land surveys. The fieldwork results show UAV results conforming to the Class C surveys' requirements (see Figure 14). Therefore, according to the respondent from MLAFWRR and UZ, provisional survey regulations incorporating UAVs orthophoto can be published by SRB. Consequently, both tools could be used for communal land surveying.

5.2. Comparisons of UAV and GNNS observations in a participatory survey and mapping in Zimbabwe

The section analyses and discusses the results of comparing UAV and GNSS in terms of cost, time, and accuracy obtained from primary data presented in sub-section 4.2. Previous investigations will also be compared and discussed in this section.

5.2.1. Cost comparisons per land parcel using GNSS and UAV

Tables 1 and 2 show that conducting systematic surveys is more economical than individual surveys. Using UAVs, the cost per hectare is less than GNSS for both scenarios. The researcher estimate that the results obtained from this research apply to an area larger or smaller than the Stockholm area. Therefore, it is recommended to use UAVs to systematically adjudicate communal lands.

5.2.2. Comparisons of cadastral data acquisition times for GNNS and UAV

The UAVs proved to require less time to acquire data on the 306 hectares of land under survey. Results gathered showed that service providers require a day to generate an orthophoto compared to 5 days for GNSS based on the SRB tariff. It is important to point out that quotations for UAV orthophoto received stated that a day will be enough to calibrate the area, place GCPs, and image acquisition. The researcher found it doubtful based on his field experience. From the researcher's experience, 4 days were used to acquire the data using GNSS and three days using UAVs. The researcher's three days are summarized as follows: the first day is dedicated to bringing control to the site, the second day to placing of GCPs, and the third day to image acquisition. Even though the researcher doubted the period of a day provided by service providers, the researcher's own experience also showed the same conclusion. In that regard, UAVs can speed up the surveying of communal land at less cost.

5.2.3. Accuracy comparisons between UAV orthophoto extracted coordinates and GNSS coordinates.

20 GCPs and 6 GCPs orthomosaics

The coordinates extracted from the 20 GCPS, 6 GCPs, and beacons with cairn generated orthophotos compared well with GNSS coordinates (see Table 4). Figure 17 shows how the temporary UAV signal appeared on the 20 GCPs orthomosaic.

Figure 17: UAV beacon signal on orthophoto

A geometrical accuracy RMSE of 0.106m for the 20 GCPS and 0.096m for the 6GCPs are good enough to fix a boundary beacon for communal land. The mean values for both cases presented in Table 4 represent a moderate to a high quality of UAV coordinates. For communal surveys, the differences obtained above do not significantly affect the boundary line to cause loss of land or cause boundary dispute. The comparison is satisfactory to adopt UAV orthophoto for boundary mapping. Further examinations of the two above-stated comparisons revealed that the mean values and standard deviation obtained with 6 GCPs are slightly lower than those obtained with 20 GCPs. This is a significant result as this implies the use of fewer GCPS approximately yields acceptable results. The result conforms to Stocker (2019) conclusion that after 6 GCPS, the geometrical position accuracy tends to be constant. In that regard, communal land adjudication can be done using fewer GCPs, saving on time and costs.

Beacons with cairn orthomosaic

The low residuals obtained resulted from inconsistencies in extracting the coordinates from the orthophoto. It was a challenge to pick the extract the centre given that an uneven cairn (shown in Figure 18) was placed on the centre mark. However, the standard deviations in both y and x directions and the eventual RMSE of 0.144m still satisfy the use of UAVs for communal land surveying. Furthermore, the monumentation used for this study is deemed sufficient to beacon boundaries in a participatory mapping manner.

Figure 18: Visible cairn on orthophoto

Error limits calculation as stated in the Second Schedule of the LSR

The displacements obtained for all the tested joins are less than the allowable limit for Class C surveys. This result means that coordinates from UAV orthophoto can be used for all surveys under Class C as long the rightful monument is authorized by the DSG. The researcher further tested the displacement against error limits required for Class B surveys. The results showed that some of the displacements were outside the allowable limit, indicating that UAVs cannot be used for township surveys.

5.2.4. This research results compared to previous investigations

The comparisons to the previous investigation shown in Table 6 show that several articles concentrated on georeferencing (GCPs) accuracy, leaving the accuracy related to extracted or digitised coordinates. The researcher's RMSEs and the average mean results compared reasonably to previous investigations. Based on the comparison, the researcher's results add to evidence that UAVs can compare well to conventional surveying tools. The most important result is the accuracy after beaconing the boundaries.

Table 6: Researcher results in comparison to previous investigations.

Source document	**Georeferencing RMSE (meters)**		**Digitized or extracted coordinates (meters)**	
	x	**y**	**Mean dx**	**Mean dy**
Low-Cost Surveying Using an Unmanned Aerial Vehicle. (Pérez et al., 2013)	0.060	0.040		
Suitability of Unmanned Aerial Vehicles for Cadastral Surveys (Mantey & Tagoe, 2019)	0.053	0.031	0.120	0.111
Comparison of GNSS-, TLS- And different altitude UAV-generated datasets on the basis of spatial differences. (Yurtseven, 2019)	0.064	0.085		
Using UAVs for map creation and updating . A case study in Rwanda Using UAVs for map creation and updating (Koeva et al., 2018)	0.048	0.037		
Developing a Workflow for the Use of Unmanned Aerial Vehicles for Cadastral Mapping in Ghana(Amissah et al., 2021)			**Site**1 0.128 0.270 **Site 2** 0.111 -0.142	 0.095 0.541 0.082 0.245
The researcher (20GCPs)	0.007	0.013	0.040	-0.057
The researcher (6 GCPs)	0.003	0.002	0.109	-0.046
The researcher (beacons with cairn)	0.005	0.003	0.010	-0.011

5.3. Potential UAVs amalgamation in participatory Communal land recordation in Zimbabwe.

5.3.1. Beneficiaries from using UAV high resolution generated orthophotos in boundary mapping

The citizens will be the greatest beneficiaries as the use of UAVs may speed up the surveying and mapping of their land. In return, the registration of the land opens up opportunities such as access to bank loans, support for systematic land transfer, and sustainable development. For example, the Stockholm landholders believe the recordation of land will reduce unlawful evictions and reduce boundary disputes. It will give them the confidence to erect boundary fences, install electricity and water systems, add more livestock and build permanent houses. Additionally, the government ministries such as MLAFWRR will be able to survey or map communal lands (A1 farms) cost-effectively with community engagement. They will also be able to collect accurate data fast and flexible for proper land planning from UAV data and taxes collecting.

The DSG, which plays the role of the custodian of land in Zimbabwe, has already started using UAVs for updating its topographical and street maps. Plans are available to survey A2 farms using UAVs in the future. Interestingly, the DSG also awaits the results of this research to enable the office to consider the use of UAVs for surveying boundaries. The researcher is so positive and convinced UAVs orthophotos could be successfully used for cadastral surveys. For example, the main product of a cadastral survey, a survey diagram (see Annex 8), was framed using the orthophoto extracted coordinates. The calculated area of the plot named Village differs by only 2 square meters from the same plot using GNSS coordinates. The difference is insignificant and high unlikely to cause any boundary dispute or loss of land. Therefore, the observations support the use of UAVs. However, UAVs participatory mapping on land that has surveyed boundaries is highly likely to have encroachments, as shown in the plotted survey working plan (Annex 9). That means participatory mapping of UAVs is best done on land that does not have existing surveyed boundaries.

Land surveyors and other land professionals will benefit immensely from the use of UAV-generated orthophoto. This research found that 38% of surveyor respondents have already used UAVs for topographical surveys. None of the respondents has used UAVs for cadastral surveys. Therefore, this research has revealed another potential cadastral surveying tool adding to the existing tools. Moreover, UAVs collect multipurpose high-resolution images that benefit the professionals.

5.3.2. Evaluation of UAVs and GNNS usage in cadastral mapping from surveying and mapping stakeholders

Several stakeholders have debated the use of UAVs for cadastral data collection. From the UZ respondent, they seem to be no coordination between the relevant authorities or stakeholders researching UAVs. It's a hide and seek with each stakeholder anticipating collecting the honor of spearheading UAV use in cadastral surveying. On the other hand, other stakeholders, especially the Land surveyors fraternity, feel they are being sidelined in UAV discussions. The belief is that certain stakeholders are pushing for UAV surveys for their own benefit. Both key respondents from DSG and MLAFWRR showed enthusiasm for this research and await the result. The result will influence the stance on the use of UAVs in surveying. The MLAFWRR further highlighted that UAVs could be used in an FFT concept. The tenure documents of the landholders gradually upgraded to freehold title.

As shown in Figures 15, 16, and Annex 13, GNSS is still the tool of choice for cadastral surveys. A greater percentage of respondents agree that existing legal frameworks cover GNSS whilst UAVs are not. Further analysis of the UAVs and GNSS comparison in Figure 15 shows that 38 % of stakeholders are neutral about whether UAVs are less costly to use than GNSS. The majority of the stakeholders believe GNSS is more efficient and fast in collecting data compared to UAV. That result can be attributed to the high usage of GNSS in Zimbabwe compared to UAVs. Furthermore, results in Figure 16 show GNSS is considered the most effective in terms of spatial accuracy attained, safety and privacy, and data quality. The above-discussed outcome is attributed to the fact that the use of UAVs in Zimbabwe is still at the research level. Their use is currently dominant in topographical surveys. The responses given are mainly based on academic research. However, most respondents agree that UAVs are the future tool for cadastral surveys. Likewise, according to DSG respondents, the SRB will soon consider the amendment of regulations to incorporate UAVs. The above efforts require professional training on UAVs. It is positive to note that academic institutions such as the University of Zimbabwe survey department have incorporated UAVs in their curriculum. Consequently, that will promote the use of UAVs and GNSS in land surveying that include communal land.

5.3.3. Recommended opinions for the UAVs approach to communal mapping in Zimbabwe

This section discusses the stakeholders' opinions on technically enabling the use of UAVs for communal surveys. The researcher supplements the academic opinion based on the research.

The researcher found that there is a lack of UAV research collaboration among key land administration stakeholders. Technical and social recommendations presented in sub-section 4.3.3 require the cooperation of academic institutions, government ministries, and departments to be achieved. For example, the testing of UAVs requires both DSG and CAAZ to collaborate, complimenting the DSG's lack of capacity to test UAVs. The amendments to regulations require the consultation of major stakeholders in land surveying. Based on the existing situation in Zimbabwe, in terms of communal land registration, the researcher suggests adopting the continuum of land rights concept adopted by UN-Habitat. In the case of Zimbabwe, the derived UAVs orthophoto could be used as the basic product to deduce boundary data and issue either existing VRC or other upgraded rights to the communal land such as a lease. The desire is to allow the possibility of the tenure documents issued to be upgradable.

The researcher could have developed image analysis algorithms to automatically extract coordinates from the orthophoto. The procedure to manually extract coordinates is rigorous and prone to errors. It may work for small surveying projects but surely straining for large projects. A practical approach should be developed to check the correctness of extracted coordinates. The time to complete data processing will significantly be reduced. In addition, high overlaps used for this project are time-consuming. The researcher suggests further investigation using low side and end laps at high altitudes and deducing the relationship to spatial accuracy.

Summary Remarks

This chapter analysed and discussed the existing legislative acts, policies, and government-produced documents that support the establishment, surveying, and registration of communal land. The main acts and institutions supporting land surveying and issuance of ownership documents in Zimbabwe were analysed and discussed. Furthermore, the legal framework regarding the use of UAV and GNSS and comparisons of coordinates derived from orthophotos and GNSS were analysed in detail. Finally, the researcher discussed the potential beneficiaries of the use of UAV orthophotos and evaluated the use of UAVs and GNSS in boundary surveying. The next chapter presents the conclusion and recommendations of this research.

6. CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this research was to assess the suitability of the UAV as a cadastral mapping tool for Communal land by comparing it with traditional tools recognized by the existing legislation in Zimbabwe. In the previous chapter, the results of the three minor objectives of the thesis supporting the primary objective were analysed and discussed. This chapter, therefore, presents the derived conclusions and recommendations for possible further investigations. The conclusion starts with the sub-objective followed by the research questions answered by this research.

6.1. Conclusion

According to Zimbabwe's existing survey regulations, this research concluded that UAVs are suitable for surveying communal land under Class C stated in the LSR. However, the debate on whether the legal surveying framework covers UAVs remains vague. Based on the responses given, the use of UAVs to carry out cadastral surveys is not straightforward, and survey regulations need to be amended to incorporate UAVs. In general, the UAVs in cadastral surveys are welcome among all stakeholders. The researcher found possible sections within the existing legislation that can be utilised to use UAVs to adjudicate communal lands. However, total separation of UAV use and GNSS measurement is still a challenge if high spatial accuracies are required.

***Sub -Objective 1**: To review existing cadastral mapping methods for Communal Land in Zimbabwe*

***Research Question 1.1** What laws, policies, technologies, and institutions are involved regarding Communal land and mapping?*

The study revealed that they are various legislations supporting the surveying and registration of land in Zimbabwe. They are specific on the requirements and what should be submitted to the relevant departments until a landholder has ownership documents. The Communal Land Act establishes communal lands. They are supposed to be surveyed under the Traditional Leaders Act and issued village registration certificates. The research found that no village registration certificate has been issued in Zimbabwe. Furthermore, the VRC is not recognised by the Deeds Registry Act. For A1 communal land, such as the one used for the case study, records of ownership permits are kept by MLAFWRR.

The recognised surveying technology such as theodolites and measuring tapes are costly to employ and result in a high cost of surveys. However, GNSS is now widely used to survey land, although mainly private and state land. UAVs are not currently used in cadastral surveys, but technology is being used for mapping and topographical surveys. The major institutions are MLAFWRR, Ministry of Local Government, DSG, and Deeds Registry Office.

***Research Question 1.2:** What is the legal framework regarding UAVs and GNNS for cadastral mapping?.*

Existing regulations revealed that UAVs could be used in Zimbabwe under the strict conditions of the S1 no by CAAZ. A flight permission and operator licence are some of the requirements. In terms of surveying, the UAVs are not explicitly covered by the LSR. The GNSS use is covered by a circular published by SRB in the year 2002 but is not adequate. Research at DSG shows that no single GNSS machine has been registered with DSG yet it’s a requirement under the LSR. The conclusion is the use of GNSS is also debatable.

Sub-objective 2: *To compare UAV and GNNS observations in a participatory survey and mapping in Zimbabwe*

Research Question 2.1: *What is the total surveying cost per land parcel using GNNS and UAV?*

For block surveys, the cost per hectare by UAVs is $9.22 and $32.03 by GNSS. The cost rises to $112.80 for UAV and $187.60 for GNSS for individual surveys. UAVs are less costly for both systematic and individual surveys compared to GNSS. Furthermore, the result shows that it is more economical to conduct a block survey than an individual survey.

Research Question 2.2: *What is the total time taken to produce a surveyed diagram using GNNS and UAV?*

From the researcher's fieldwork experience, it takes 3 days using UAVs and 4 days by GNSS to survey the area under study. The conclusion is that it takes less time to acquire survey data using UAVs. Quotations from service providers also supported the researcher's conclusion.

Research Question 2.3: *What measurement accuracy is obtained, and does the UAV error fall within the accuracy tolerances in the Second Schedule of the LSR?*

The research found that using 20 GCPS and 6 GCPS for the same area coverage yields approximately the same geometrical accuracy. In that regard, communal land surveying time and cost can be reduced by the use of fewer GCPS. The mean, standard deviations, and RMSE obtained for all comparisons were satisfactory for surveying purposes. The differences do not substantially affect boundary lines or cause boundary disputes. Comparisons using relocated boundary beacons showed that UAVs accuracy is within class C surveys of the LSR. In that regard, UAV orthophoto-derived coordinates satisfy the accuracy requirement of the current LSR and can be adopted for communal land surveying.

Research Question 2.4: *How do results compare to previous investigations?*

The research results conform to other previous investigations done in other countries under different regulations in terms of GCPS accuracies. Previous studies have focused much on the accuracies of control points. However, this research further compared the accuracies of orthophoto-derived coordinates. The results proved satisfactory for communal land surveying.

Sub-objective 3: To recommend if and how UAVs can be amalgamated in participatory Communal land recordation in Zimbabwe

Research Question 3.1: *Who will benefit from the use of UAV high-resolution generated orthophotos in boundary mapping?*
Zimbabweans communal citizens, government, and departments involved in land admiration will benefit equally from the fast boundary surveying and mapping method. Land surveyors, land planners, and other relevant professionals will benefit from collecting accurate boundary and topographical data faster and at lower costs.

Research Question 3.2 : *How do surveying and mapping stakeholders (including Land Surveyors, mapping experts, academic institutions, DSG) evaluate UAVs and GNNS usage in cadastral mapping.*

The overall perception was that most stakeholders believe GNSS is more efficient to use, less costly, and its use is regulated compared to UAVs. Furthermore, most stakeholders believe GNSS is more effective in terms of all categories discussed in sub-section 5.3.2 than UAV. It is still regarded as the tool of choice when compared to UAVs for cadastral surveying. The restrictions on the use of UAVs are detrimental to the stakeholders. However, the consensus is that UAV supported by LSA is the future tool for surveying. The tool can be used along with concepts such as FFT and continuum of land rights and improve tenure security.

Research Question 3.3: *What are the recommended opinions for the UAVs approach to communal mapping in Zimbabwe?*

Research on the use of UAVs for cadastral surveying has to be coordinated among land stakeholders, government agencies, and academic institutions. The SRB to amend LSR to incorporate new methods of cadastral data collection such as UAVs. The government should spearhead the surveying and registration of communal land under the existing legislation or new acts and policies. An approach to automatically extract coordinates from orthophoto is to be developed.

6.2. Recommendations and further research

This research focused on assessing how UAVs can be used to survey communal land in Zimbabwe. The assessment was done by comparing UAVs to conventional methods, and in this case, the GNSS was used. The general perception on the use of UAVs and GNSS by land stakeholders was also analysed. An approach to collect the data outlined in Chapter 3 was used to survey 15 plots in the communal area of Stockholm. However, based on the findings, further research is suggested on the following:

1. Automatic coordinate extraction algorithms are to be developed to accurately and automatically extract coordinates from signals visible on orthophoto. This will help to quicken the process of surveying and reduce the inconstancies faced in digitizing the centre mark of required points from the orthophoto.
2. Since the primary aim is to continuously research cost-effective methods of boundary mapping, the same research can be done using a low-cost UAV and compare results.
3. Development of surveying fieldwork data collection approach that combines both GNSS and UAV by both academic and SRB. The approach could specify the required GSD, flying height, overlap, side lap, UAV drone camera resolution, and required number of GCPs per hectare.

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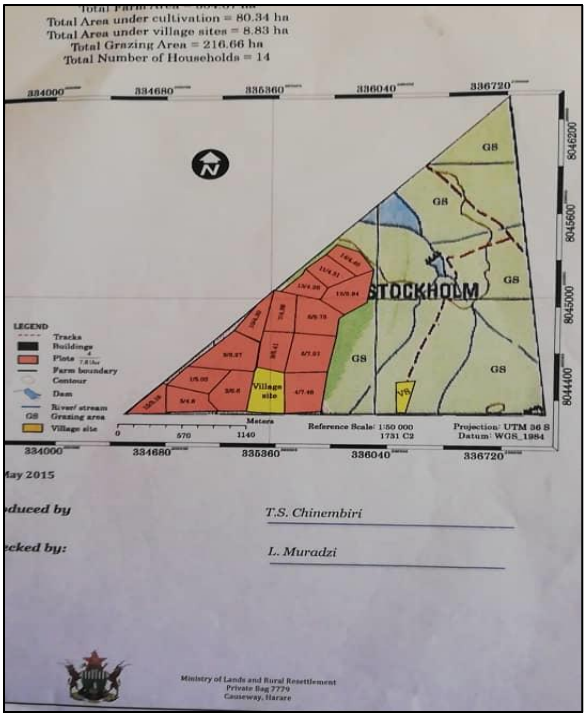
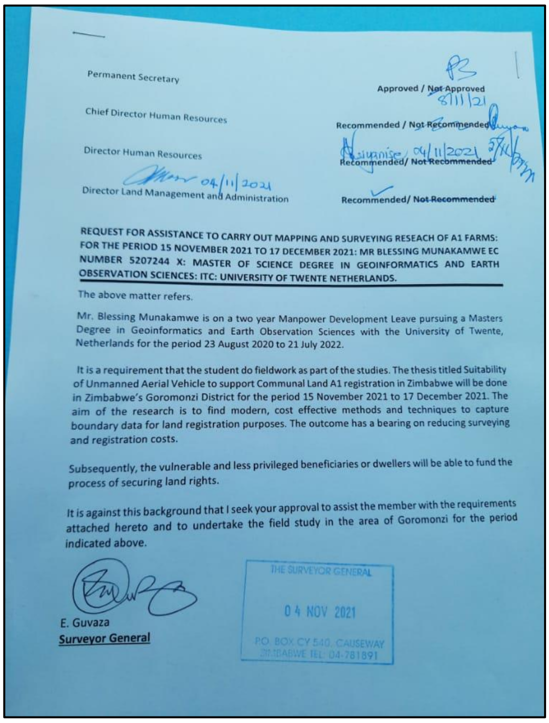
ANNEX 1

Stockholm Site Plan (Source: MLAFWRR)



Permission to carry out study from MLAFWRR



Permanent Secretary — Approved / ~~Not Approved~~ 8/11/21

Chief Director Human Resources — Recommended / ~~Not Recommended~~

Director Human Resources — Recommended/ ~~Not Recommended~~ 04/11/2021

Director Land Management and Administration 04/11/2021 — Recommended/ ~~Not Recommended~~

REQUEST FOR ASSISTANCE TO CARRY OUT MAPPING AND SURVEYING RESEACH OF A1 FARMS: FOR THE PERIOD 15 NOVEMBER 2021 TO 17 DECEMBER 2021: MR BLESSING MUNAKAMWE EC NUMBER 5207244 X: MASTER OF SCIENCE DEGREE IN GEOINFORMATICS AND EARTH OBSERVATION SCIENCES: ITC: UNIVERSITY OF TWENTE NETHERLANDS.

The above matter refers.

Mr. Blessing Munakamwe is on a two year Manpower Development Leave pursuing a Masters Degree in Geoinformatics and Earth Observation Sciences with the University of Twente, Netherlands for the period 23 August 2020 to 21 July 2022.

It is a requirement that the student do fieldwork as part of the studies. The thesis titled Suitability of Unmanned Aerial Vehicle to support Communal Land A1 registration in Zimbabwe will be done in Zimbabwe's Goromonzi District for the period 15 November 2021 to 17 December 2021. The aim of the research is to find modern, cost effective methods and techniques to capture boundary data for land registration purposes. The outcome has a bearing on reducing surveying and registration costs.

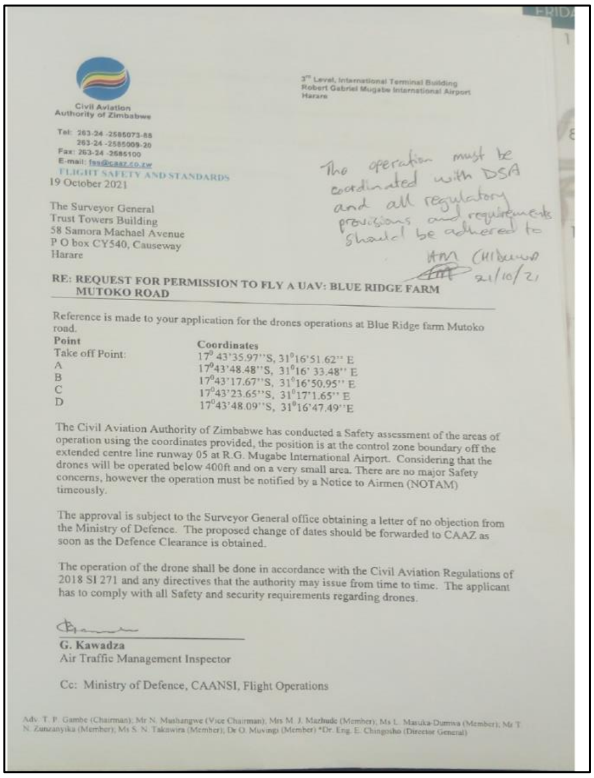
Subsequently, the vulnerable and less privileged beneficiaries or dwellers will be able to fund the process of securing land rights.

It is against this background that I seek your approval to assist the member with the requirements attached hereto and to undertake the field study in the area of Goromonzi for the period indicated above.

E. Guvaza
Surveyor General

THE SURVEYOR GENERAL
04 NOV 2021
P.O. BOX CY 540, CAUSEWAY
ZIMBABWE TEL: 04-781891

Permission to fly UAV from CAAZ



Civil Aviation Authority of Zimbabwe

3rd Level, International Terminal Building
Robert Gabriel Mugabe International Airport
Harare

Tel: 263-24-2585073-88
263-24-2585009-20
Fax: 263-24-2585100
E-mail: fss@caaz.co.zw
FLIGHT SAFETY AND STANDARDS

19 October 2021

The Surveyor General
Trust Towers Building
58 Samora Machael Avenue
P O box CY540, Causeway
Harare

The operation must be coordinated with DSA and all regulatory provisions and requirements should be adhered to
HM Chibuwa 21/10/21

RE: REQUEST FOR PERMISSION TO FLY A UAV: BLUE RIDGE FARM MUTOKO ROAD

Reference is made to your application for the drones operations at Blue Ridge farm Mutoko road.

Point	Coordinates
Take off Point:	17° 43'35.97''S, 31°16'51.62'' E
A	17°43'48.48''S, 31°16' 33.48'' E
B	17°43'17.67''S, 31°16'50.95'' E
C	17°43'23.65''S, 31°17'1.65'' E
D	17°43'48.09''S, 31°16'47.49''E

The Civil Aviation Authority of Zimbabwe has conducted a Safety assessment of the areas of operation using the coordinates provided, the position is at the control zone boundary off the extended centre line runway 05 at R.G. Mugabe International Airport. Considering that the drones will be operated below 400ft and on a very small area. There are no major Safety concerns, however the operation must be notified by a Notice to Airmen (NOTAM) timeously.

The approval is subject to the Surveyor General office obtaining a letter of no objection from the Ministry of Defence. The proposed change of dates should be forwarded to CAAZ as soon as the Defence Clearance is obtained.

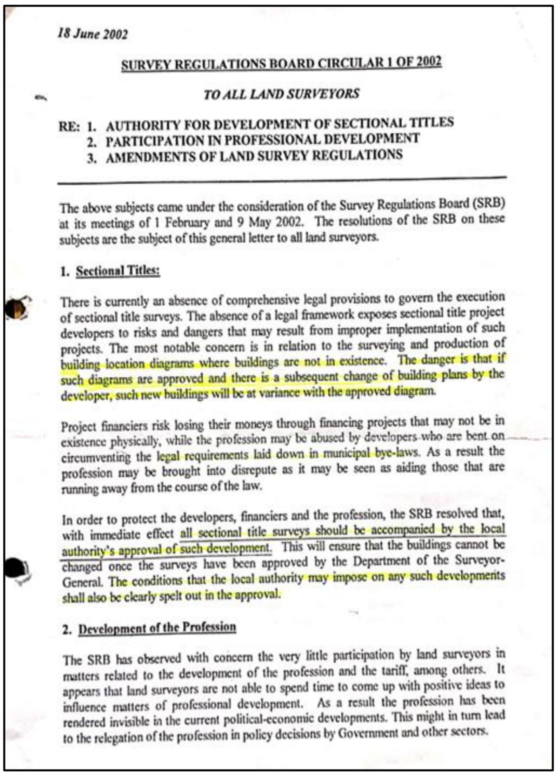
The operation of the drone shall be done in accordance with the Civil Aviation Regulations of 2018 SI 271 and any directives that the authority may issue from time to time. The applicant has to comply with all Safety and security requirements regarding drones.

G. Kawadza
Air Traffic Management Inspector

Cc: Ministry of Defence, CAANSI, Flight Operations

Adv. T. P. Gambe (Chairman); Mr N. Mushangwe (Vice Chairman); Mrs M. J. Mazhude (Member); Ms L. Masuka-Dumwa (Member); Mr T N. Zunzanyika (Member); Ms S. N. Takawira (Member); Dr O. Muvingi (Member) *Dr. Eng. E. Chingosho (Director General)

Survey Regulation Circular 1 of 2002



18 June 2002

SURVEY REGULATIONS BOARD CIRCULAR 1 OF 2002

TO ALL LAND SURVEYORS

RE: 1. AUTHORITY FOR DEVELOPMENT OF SECTIONAL TITLES
2. PARTICIPATION IN PROFESSIONAL DEVELOPMENT
3. AMENDMENTS OF LAND SURVEY REGULATIONS

The above subjects came under the consideration of the Survey Regulations Board (SRB) at its meetings of 1 February and 9 May 2002. The resolutions of the SRB on these subjects are the subject of this general letter to all land surveyors.

1. Sectional Titles:

There is currently an absence of comprehensive legal provisions to govern the execution of sectional title surveys. The absence of a legal framework exposes sectional title project developers to risks and dangers that may result from improper implementation of such projects. The most notable concern is in relation to the surveying and production of building location diagrams where buildings are not in existence. The danger is that if such diagrams are approved and there is a subsequent change of building plans by the developer, such new buildings will be at variance with the approved diagram.

Project financiers risk losing their moneys through financing projects that may not be in existence physically, while the profession may be abused by developers who are bent on circumventing the legal requirements laid down in municipal bye-laws. As a result the profession may be brought into disrepute as it may be seen as aiding those that are running away from the course of the law.

In order to protect the developers, financiers and the profession, the SRB resolved that, with immediate effect all sectional title surveys should be accompanied by the local authority's approval of such development. This will ensure that the buildings cannot be changed once the surveys have been approved by the Department of the Surveyor-General. The conditions that the local authority may impose on any such developments shall also be clearly spelt out in the approval.

2. Development of the Profession

The SRB has observed with concern the very little participation by land surveyors in matters related to the development of the profession and the tariff, among others. It appears that land surveyors are not able to spend time to come up with positive ideas to influence matters of professional development. As a result the profession has been rendered invisible in the current political-economic developments. This might in turn lead to the relegation of the profession in policy decisions by Government and other sectors.

ANNEX 2: Orthophoto generations quality reports from Pix4D Mapper

20 GCPs

Quality Report

Generated with Pix4Dmapper version 4.7.5

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	ebee_X_stockholm_20GCPs
Processed	2022-06-11 22:05:26
Camera Model Name(s)	S.O.D.A._10.6_5472x3648 (RGB)
Average Ground Sampling Distance (GSD)	3.38 cm / 1.33 in
Area Covered	5.677 km^2 / 567.7099 ha / 2.19 sq. mi. / 1403.5677 acres
Time for Initial Processing (without report)	01h:10m:53s

Quality Check

Images	median of 40621 keypoints per image	
Dataset	3055 out of 3056 images calibrated (99%), 1 images disabled	
Camera Optimization	1.17% relative difference between initial and optimized internal camera parameters	
Matching	median of 14113.32 matches per calibrated image	
Georeferencing	yes, 22 GCPs (22 3D), mean RMS error = 0.011 m	

Preview

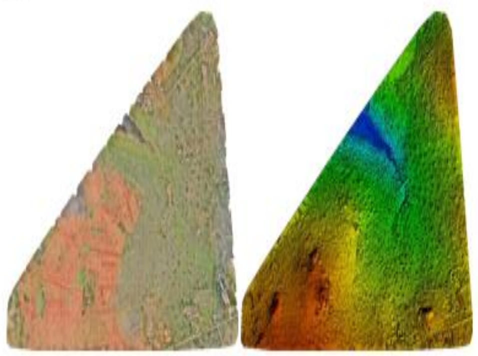


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	3055 out of 3057
Number of Geolocated Images	3057 out of 3057

Initial Image Positions

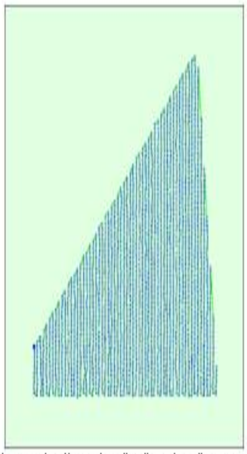


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions

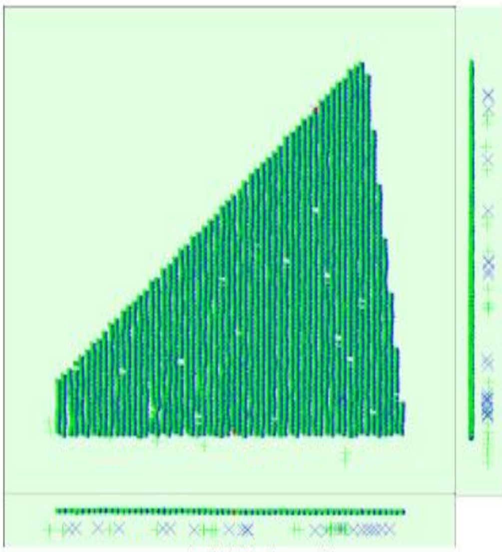


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.062	0.076	0.051	0.029	0.022	0.008
Sigma	0.014	0.017	0.012	0.007	0.006	0.003

Overlap

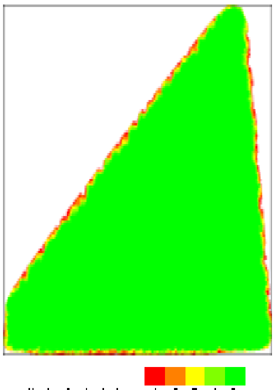


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.
[illegible]

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	4480944
Number of 3D Points for Bundle Block Adjustment	1474365
Mean Reprojection Error [pixels]	0.092

Geolocation Details

Ground Control Points

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
gcP8P (3D)	0.020/ 0.020	-0.003	0.004	0.003	0.299	9 / 9
GCP5P (3D)	0.020/ 0.020	0.005	0.002	0.003	0.235	13 / 13
GCP13P (3D)	0.020/ 0.020	0.004	0.004	0.008	0.145	12 / 12
GCP23m (3D)	0.020/ 0.020	0.010	0.004	-0.004	0.199	14 / 14
GCP29m (3D)	0.020/ 0.020	-0.001	0.009	0.005	0.262	8 / 8
GCP33m (3D)	0.020/ 0.020	0.001	0.004	0.006	0.241	11 / 11
GCP39m (3D)	0.020/ 0.020	0.007	0.007	0.006	0.242	13 / 13
GCP38m (3D)	0.020/ 0.020	-0.006	-0.005	0.015	0.289	11 / 11
GCP24m (3D)	0.020/ 0.020	0.004	0.002	0.030	0.226	14 / 14
GCP51m (3D)	0.020/ 0.020	-0.019	0.003	0.006	0.212	16 / 16
GCP52m (3D)	0.020/ 0.020	-0.006	-0.003	-0.006	0.210	16 / 16
GCP54m (3D)	0.020/ 0.020	-0.003	-0.002	-0.006	0.224	13 / 13
GCP55m (3D)	0.020/ 0.020	0.002	-0.008	-0.002	0.253	17 / 17
GCP57m (3D)	0.020/ 0.020	0.002	-0.000	-0.007	0.198	12 / 12
GCP58m (3D)	0.020/ 0.020	-0.000	0.002	-0.011	0.217	13 / 13
GCP59m (3D)	0.020/ 0.020	-0.001	-0.007	-0.012	0.173	10 / 10
GCP60m (3D)	0.020/ 0.020	0.002	0.002	0.000	0.223	11 / 11
airmark1 (3D)	0.020/ 0.020	0.016	-0.044	-0.016	0.592	14 / 14
airmark2 (3D)	0.020/ 0.020	-0.008	0.038	0.043	0.307	11 / 11
airmark3 (3D)	0.020/ 0.020	0.003	-0.002	-0.014	0.395	14 / 14
airmark4 (3D)	0.020/ 0.020	-0.009	-0.001	-0.011	0.434	13 / 13
Mean [m]		0.000020	0.000002	0.000592		
Sigma [m]		0.006924	0.013124	0.014616		
RMS Error [m]		0.006924	0.013124	0.014628		

[illegible]

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP18m		0.2006	0.0423	0.1129	0.2507	8 / 8
GCP34m		-0.0842	-0.1047	1.1544	0.1880	17 / 17
GCP30m		-0.0582	-0.0454	1.1312	0.2645	12 / 12
GCP17m		0.0862	-0.0757	0.7892	0.2421	14 / 14
GCP50m		0.0112	0.2404	1.0936	3.1942	15 / 15
GCP53m		-0.0438	-0.0196	-0.3589	0.2020	12 / 12
GCP56m		-0.0154	-0.0550	0.0444	0.2179	11 / 11
Mean [m]		0.013770	-0.002681	0.566703		
Sigma [m]		0.091878	0.108099	0.576523		
RMS Error [m]		0.092904	0.108132	0.808413		

[illegible]

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-10750H CPU @ 2.60GHz RAM: 16GB GPU: Intel(R) UHD Graphics (Driver: 27.20.100.9316), NVIDIA Quadro T1000 with Max-Q Design (Driver: 30.0.14.7236)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

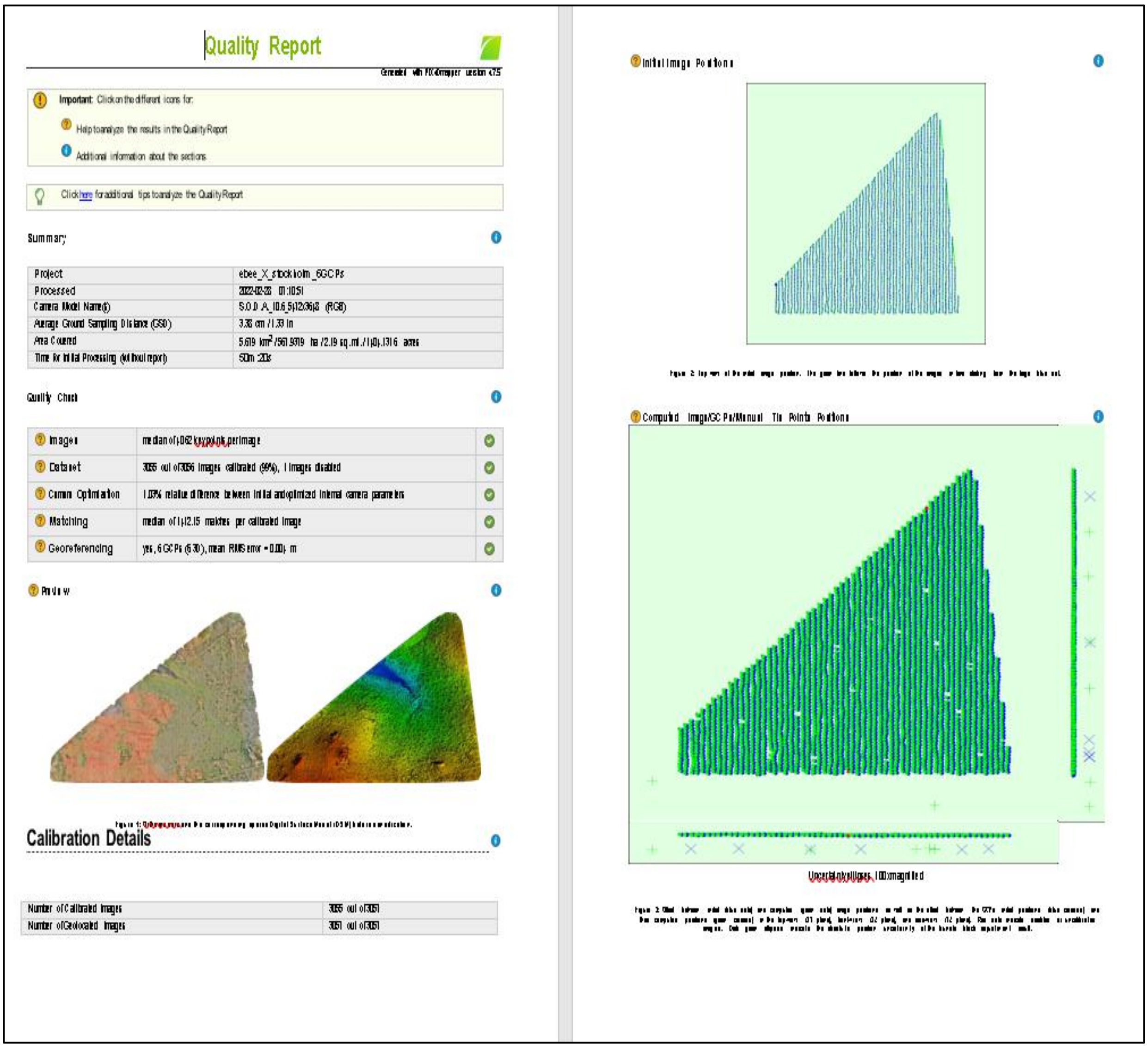
Image Coordinate System	WGS 84
Ground Control Point (GCP) Coordinate System	Cape / Lo31
Output Coordinate System	Cape / Lo31

Processing Options

Detected Template	No Template Available
Keypoints Image Scale	Rapid, Image Scale: 0.25
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, no

ANNEX 3: Orthophoto generations quality reports from Pix4D Mapper

6 GCPs



Quality Report

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	ebee_X_stockholm_6GCPs
Processed	2022-02-28 01:10:51
Camera Model Name(s)	S.O.D.A_10.6_5472x3648 (RGB)
Average Ground Sampling Distance (GSD)	3.38 cm / 1.33 in
Area Covered	5.619 km² / 561.9319 ha / 2.19 sq. mi. / 1388.1316 acres
Time for Initial Processing (without report)	50m 20s

Quality Check

Images	median of 59062 keypoints per image
Dataset	3055 out of 3056 images calibrated (99%), 1 images disabled
Camera Optimization	1.07% relative difference between initial and optimized internal camera parameters
Matching	median of 19912.15 matches per calibrated image
Georeferencing	yes, 6 GCPs (6 3D), mean RMS error = 0.00 m

Preview

Calibration Details

Number of Calibrated Images	3055 out of 3051
Number of Geolocated Images	3051 out of 3051

Initial Image Positions

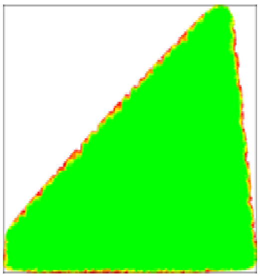
Computed Image/GCPs/Manual Tie Points Positions

Uncertainty ellipses 100x magnified

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.064	0.078	0.051	0.029	0.022	0.008
Sigma	0.013	0.017	0.010	0.007	0.005	0.003

Overlap



[illegible]

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	4481078
Number of 3D Points for Bundle Block Adjustment	1475013
Mean Reprojection Error [pixels]	0.092

Geolocation Details

Ground Control Points

GCP Name	Accuracy XY/Z [m]	Error X[m]	Error Y[m]	Error Z[m]	Projection Error [pixel]	Verified/Marked
GCP5P (3D)	0.020/ 0.020	0.003	-0.000	0.009	0.320	13 / 13
GCP52m (3D)	0.020/ 0.020	-0.005	-0.002	0.003	0.213	16 / 16
GCP51m (3D)	0.020/ 0.020	0.002	-0.003	-0.015	0.237	12 / 12
GCP60m (3D)	0.020/ 0.020	0.001	-0.002	-0.007	0.208	11 / 11
air mark3 (3D)	0.020/ 0.020	-0.001	0.003	0.004	0.402	14 / 14
air mark4 (3D)	0.020/ 0.020	0.001	0.004	0.009	0.442	13 / 13
Mean [m]		0.000128	-0.000028	0.000642		
Sigma [m]		0.002966	0.002493	0.008814		
RMS Error [m]		0.002968	0.002493	0.008838		

[illegible]

Check Point Name	Accuracy XY/Z [m]	Error X[m]	Error Y[m]	Error Z[m]	Projection Error [pixel]	Verified/Marked
GCP17m		0.0404	0.1642	2.3016	0.2395	14 / 14
GCP51m		-0.0388	0.0955	1.4938	0.1703	16 / 16
GCP53m		-0.0283	-0.0827	-0.7879	0.1807	12 / 12
GCP56m		-0.0094	-0.1125	-0.3667	0.2128	11 / 11
Mean [m]		-0.009034	0.016141	0.660214		
Sigma [m]		0.030412	0.116744	1.278706		
RMS Error [m]		0.031725	0.117854	1.439087		

[illegible] been automatically verified vs. manually marked.

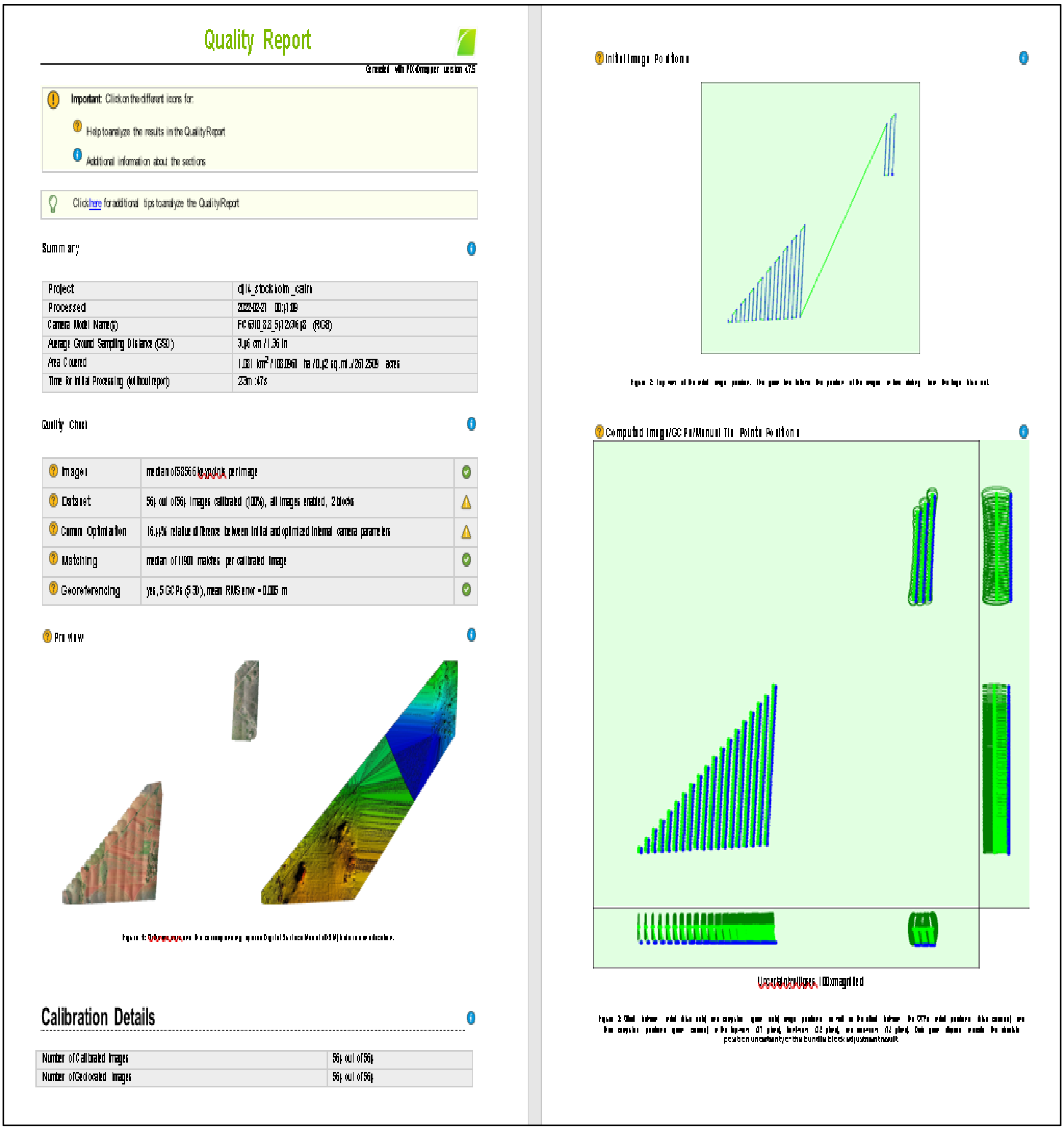
Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-4.47	0.00	0.00	0.00
-4.47	-3.58	0.00	0.00	0.00
-3.58	-2.68	0.00	0.00	0.13
-2.68	-1.79	0.00	0.00	1.93
-1.79	-0.89	0.07	0.10	19.08
-0.89	0.00	52.50	51.75	36.56
0.00	0.89	47.36	47.63	23.24
0.89	1.79	0.07	0.52	11.46
1.79	2.68	0.00	0.00	6.32
2.68	3.58	0.00	0.00	1.28
3.58	4.47	0.00	0.00	0.00
4.47	-	0.00	0.00	0.00
Mean [m]		5.495132	-18.849015	-3.676072
Sigma [m]		0.326975	0.243858	1.073570
RMS Error [m]		5.504851	18.850593	3.829629

[illegible] positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

ANNEX 4: Orthophoto generations quality reports from Pix4D Mapper

Beacons and cairn



Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.069	0.077	0.902	0.025	0.029	0.011
Sigma	0.038	0.037	0.059	0.027	0.041	0.019

Overlap

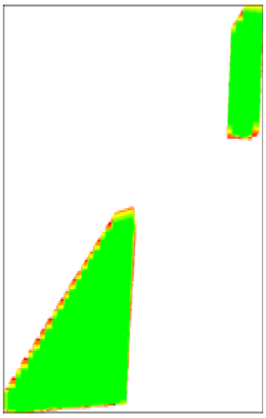


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.
[illegible]

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	7051331
Number of 3D Points for Bundle Block Adjustment	2435509
Mean Reprojection Error [pixels]	0.127

Geolocation Details

Ground Control Points

GCP Name	Accuracy XY/Z [m]	Error X[m]	Error Y[m]	Error Z[m]	Projection Error [pixel]	Verified/Marked
GCP53m (3D)	0.020/ 0.020	-0.002	0.001	-0.003	0.842	12 / 12
GCP5pm (3D)	0.020/ 0.020	0.005	0.000	0.004	0.339	16 / 16
GCP51m (3D)	0.020/ 0.020	-0.004	0.003	-0.001	0.352	20 / 20
GCP59m (3D)	0.020/ 0.020	0.008	-0.005	-0.011	0.322	21 / 21
GCP60m (3D)	0.020/ 0.020	-0.004	-0.004	0.015	0.159	1 / 1
Mean [m]		0.000527	-0.000983	0.000685		
Sigma [m]		0.004782	0.002891	0.008589		
RMS Error [m]		0.004823	0.003053	0.008634		

[illegible]

Check Point Name	Accuracy XY/Z [m]	Error X[m]	Error Y[m]	Error Z[m]	Projection Error [pixel]	Verified/Marked
GCP58m		0.0045	0.0058	-0.8509	0.3979	[illegible]

[illegible] been automatically verified vs. manually marked.

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.00	0.00	6.56
-3.00	0.00	49.29	47.16	44.86
0.00	3.00	50.71	52.84	40.43
3.00	6.00	0.00	0.00	8.16
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		6.164070	-18.368783	-105.231888
Sigma [m]		0.531074	0.575292	1.947498
RMS Error [m]		6.186906	18.377789	105.249907

[illegible] positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-10750H CPU @ 2.60GHz RAM: 16GB GPU: Intel(R) UHD Graphics (Driver: 27.20.100.9316), NVIDIA Quadro T1000 with Max-Q Design (Driver: 30.0.14.7239)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Image Coordinate System	WGS 84 (EGM96 Geoid)
Ground Control Point (GCP) Coordinate System	Cape / Lo31
Output Coordinate System	Cape / Lo31

ANNEX 5: Research Matrix

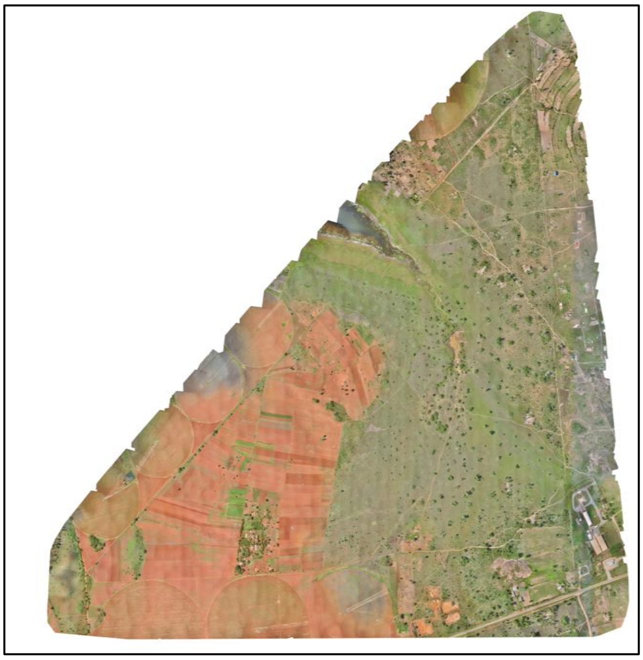
Objectives	**Research Questions**	**Methods and Analysis**	**Data Sources**	**Expected Outcome**
Objective 1: To review existing cadastral mapping methods for Communal Land in Zimbabwe	Q 1.1. What laws, policies, tenures, technologies, and institutions are involved regarding Communal land and mapping? Q 1.2. What is the legal framework regarding UAVs and GNNS for cadastral mapping?.	Literature review Interview with Department of Surveyor General Content analysis	Land Survey Laws Land legislative laws Surveying Manuals Government Documents Aviation Laws	Understandings of the current policies, laws, institutions, regarding Communal land surveying and registration Determination of requirements to operate UAVs and its recognition as a land surveying tool in Zimbabwe
Objective 2: To compare UAV and GNNS observations in a participatory survey and mapping in Zimbabwe	Q 2.1. What is the total cost per land parcel? Q 2.2. How long does it take to produce a land parcel diagram Q 2.3. What accuracy is obtained, and does the UAV error fall within the accuracy tolerances in the Second Schedule of the LSR? Q 2.4. How do results compare to previous research in the last five years?	Field Survey Comparisons Error Analysis Literature review Descriptive analysis Statistical analysis	Cadastral Data sets Pix4D Mapper SURPAC,ArcGIS UAV and GNSS (RTK), Leica Geo Office, UAV targets, Other fieldwork equipment Existing Literature	Cost per land parcel of UAV and GNNS Duration of Survey and data processing of UAV and GNNS UAV orthophoto Land Parcel boundaries Error Analysis report
Objective 3: To recommend if UAVs can be amalgamated in participatory Communal land recordation in Zimbabwe	Q 3.1 Who will benefit from the use of UAV high resolution generated orthophotos in boundary surveying Q 3.2 How do surveying and mapping stakeholders (Land Surveyors, mapping experts, academic institutions, DSG) evaluate UAVs and GNNS usage in cadastral mapping. Q 3.3 What are the recommendations for the UAVs approach to communal mapping in Zimbabwe?	Literature review Interviews Content analysis	Land Survey Laws Land legislative laws Surveying Manuals Government Documents UAV scientific articles DSG Memos and Circulars	Evaluation report of the UAVs to GNNS comparison Recommendations 1. Survey Regulatory Board, 2. Land, and registrations institutions 3. Department of Surveyor General 4. Academic Institutions.

ANNEX 6: Datasets, Instruments, and Software's used for the research

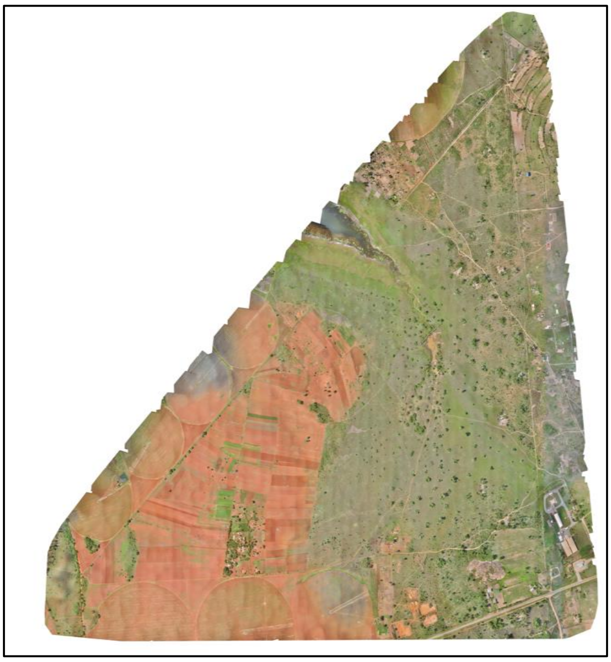
No	Dataset	Source	Relevance
1	Stockholm Parent diagrams	DSG	Retrieve coordinates for relocation of beacons
3	Trigonometric Stations coordinates	DSG	Calibration of GNSS set
4	Village Site Plan	MLAFWRR	Comparison with participatory survey diagram
	Instruments		
1	Vehicle	DSG	Field transport
2	RTK GNNS	DSG	Site calibration, beacons relocation, fixing of GCPs
3	Unmanned Aerial Vehicle	ITC/UZ	Image acquisition
4	White and black point	Purchase	Boundary monument marking
5	Field accessories	DSG	Beacon relocation ,monumentation ,vegetation clearing
6	Artificial targets	Designed	Signalization
	Software		
1	Pix4D Mapper	https://www.pix4d.com/product/pix4dcapture	Image processing
2	Pix4D Capture	https://www.pix4d.com/product/pix4dcapture	Mission Planning
3	AutoCAD	DSG	Drafting of Survey diagrams
4	SURPAC	DSG Licence	Calculations of coordinates, drafting of survey diagrams
5	Trimble Business Centre	DSG licence	Transformation parameters calculation, Point list generation
6	SPSS	ITC	Data Analysis
7	Epicollect	Open-source	Questionnaire design and data collection

ANNEX 7: Generated orthophotos

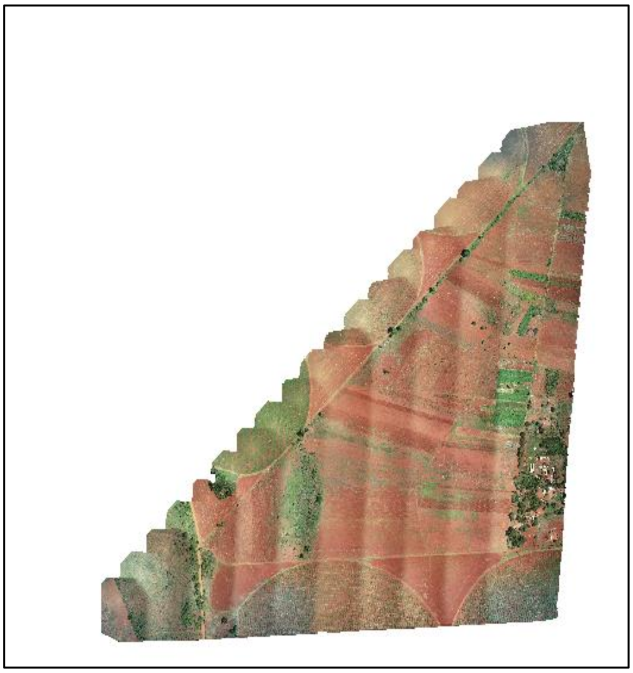
Orthomosaic (20 GCPs)



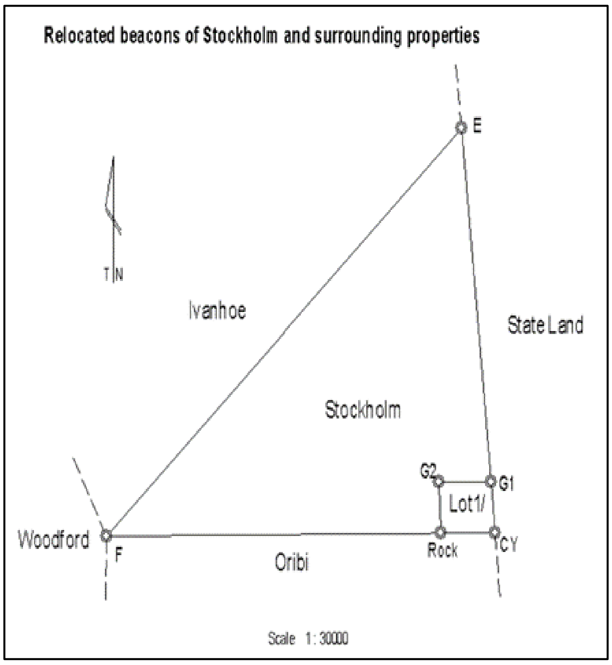
Orthomosaic (6 GCPs)



Orthomosaic (beacon with cairn)



Relocated parent beacons



ANNEX 8: Diagram of Village site framed from orthophoto coordinates

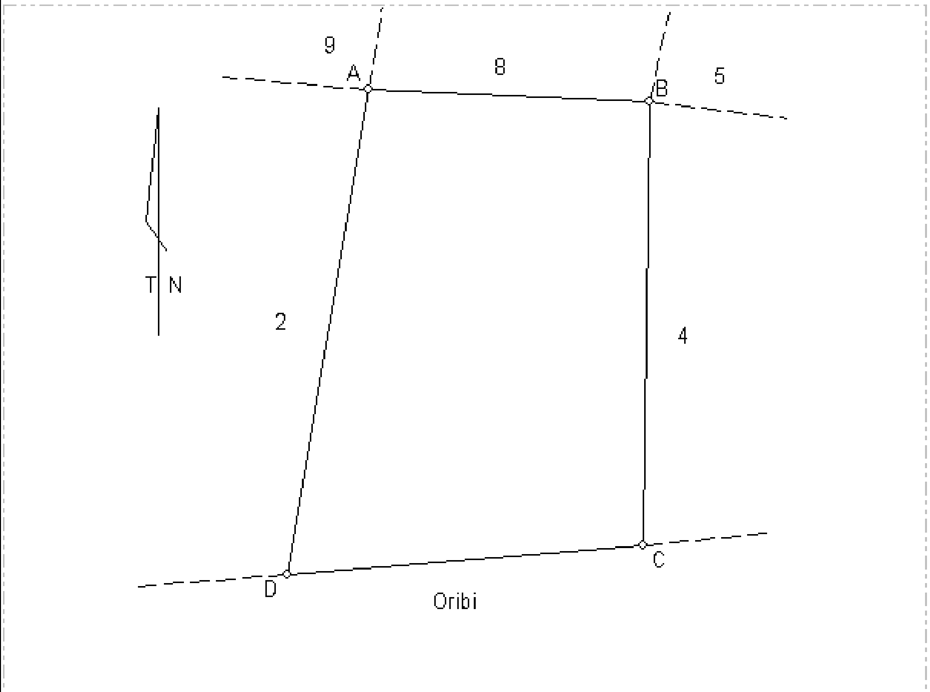
DEDUCTIONS FROM THIS DIAGRAM ARE MADE ON THE BACK HEREOF

	SIDES Metres	DIRECTIONS ° ' "	Lo 31°	CO-ORDINATES Y meters	X	DIAGRAM S.G. No.
		Constants:		± 0,00	± 0,00	Approved
AB	193,58	272 40 20	A	-47 401,82	+1 955 703,49	2e
BC	305,32	0 37 10	B	-47 595,19	+1 955 712,51	5b
CD	246,98	85 22 50	C	-47 591,89	+1 956 017,81	4a
DA	338,89	189 31 40	D	-47 345,72	+1 956 037,70	2a
						SURVEYOR GENERAL

Description of Beacons

A, B,C,D : 12mm iron peg and cairn

BINDING MARGIN NOT TO BE WRITTEN IN



Scale 1:4000

The figure ABCDA

represents 7,0111 hectares of land called

Village of Stockholm

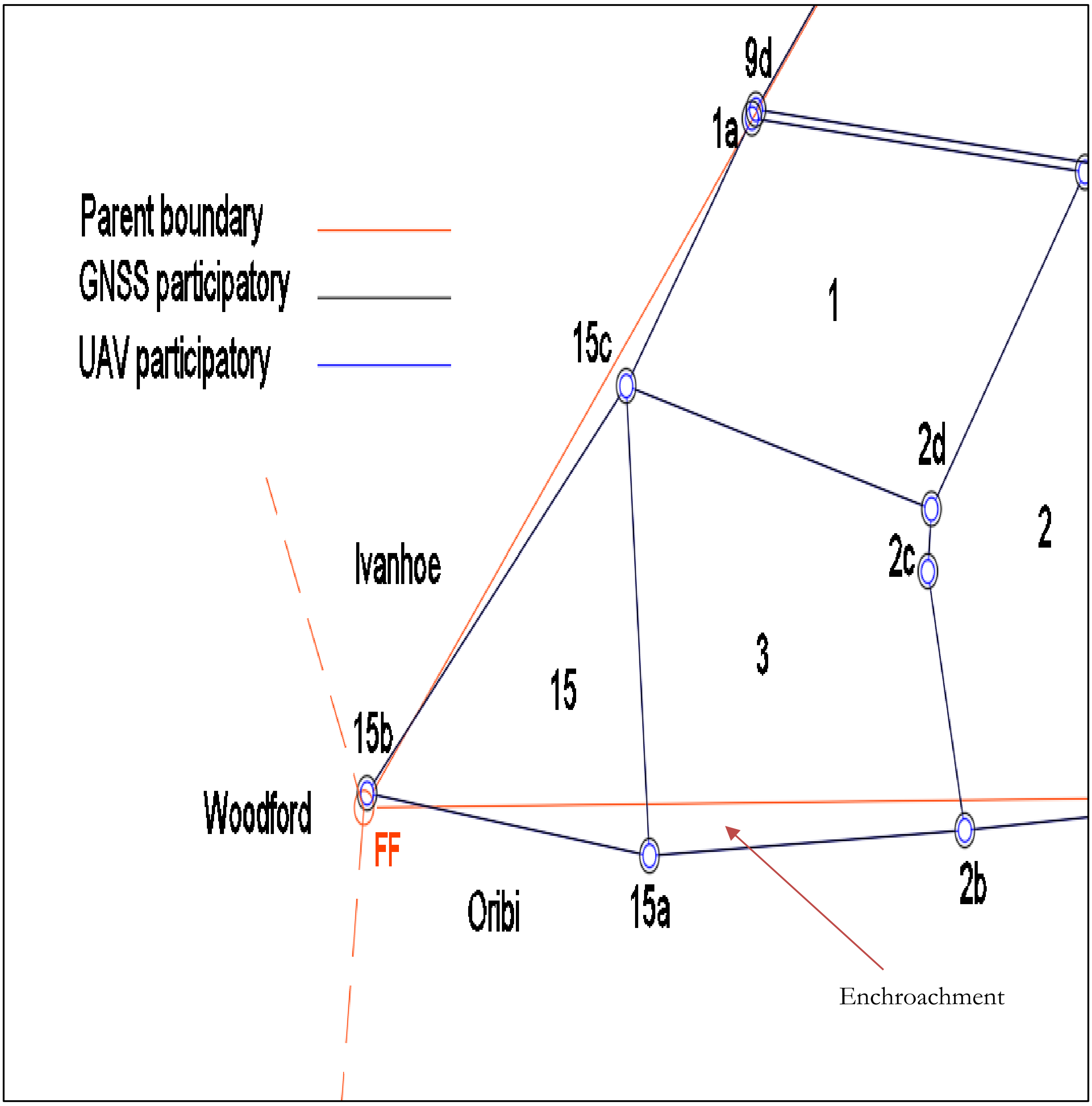
situate in Goromonzi district

Surveyed in November 2021 by me

Land Surveyor

This diagram is annexed to No. dated	The immediate parent diagram is No. annexed to No.		The original title diagram is No. annexed to No.
	File :	G.P.:	S.R.:
Surveyor-General.	Compilation :		

ANNEX 9: Part of General Plan of Stockholm plots showing possible encroachments



ANNEX 10 GNSS Quotations

SURVEY OF :LOTS 1 -16 OF Stockholm
GOROMONZI DISTRICT

	Unit price	Quantity	Total(Usd)
PART I : BASIC CHARGE			
Initial Charge			$ 1,110.00
Per Lot Charges			
Over 10 - 25Ha	$ 330.00	15	$ 4,950.00
Over 50 -100Ha	$ 590.00	0	$ -
Over 101 -200Ha	$ 690.00	0	$ -
Over 200 -500Ha	$ 350.00	1	$ 350.00
			$ 5,300.00
PART II : REIMBURSABLES			
Beacons (12mm iron peg and cairn)	$ 3.00	25	$ 75.00
Working Stations	$ 1.00	5	$ 5.00
			$ 80.00
PART III :TRAVELING, TRANSPORT AND SUBSISTENCE			
TRANSPORT			
Harare - Stockholm Farm - Harare	$ 1.00	160	$ 160.00
Site Mileage	$ 1.00	120	$ 120.00
			$ 280.00
SUBSISTENCE			
1 Land Surveyor	$ 120.00	1	$ 120.00
2 LSIT	$ 120.00	10	$ 1,200.00
3 Field Assistants	$ 120.00	10	$ 1,200.00
			$ 2,520.00
PART IV : CHARGES FOR MATERIALS			
General Plan	$ 200.00	1	$ 200.00
PART V : PROFESSIONAL FEES			
Land Surveyor	$ 50.00	2	$ 100.00
1 LSITs'	$ 40.00	4	$ 160.00
			$ 260.00
SUB-TOTAL			**$ 9,750.00**
Examination fees			**$ 50.00**
GRAND TOTAL			**$ 9,800.00**

APPROVED/NOT APPROVED

[redacted]

for Surveyor General

NB:This bill is US$ based and fees to be paid in ZWL$ at a prevailing Interbank auction rate

Survey of Plot 1 - 15 Stockholm, Goromonzi District
(Bill in US Dollars)

	Unit price	Quantity	Total(Usd)
Part I : Basic charge			
Initial Charge			
Per Lot Charges			$ 974.00
Over 10 - 25Ha	$ 330.00	14	$ 4,620.00
Part II : Reimbursables	$ 3.00	42	$ 126.00
Beacons (12mm iron peg and cairn)	$ 2.00	5	$ 10.00
Working Stations			
Part III :Transport	$ 1.00	200	$ 200.00
Harare - Stockholm Farm - Harare	$ 1.00	130	$ 130.00
Site Mileage			
Part IV: Labour	$ 10.00	12	$ 120.00
3 Labours for 4 days @$10 per day			
Part V : Charges for materials	$ 200.00	1	$ 200.00
General Plan	$ 20.00	14	$ 280.00
Diagrams in triplicate			
Part V1 : Professional fees	$ 50.00	8	$ 400.00
Land Surveyor	$ 40.00	24	$ 960.00
Land Surveyor in Training			
SUB-TOTAL			
Examination fees			**$ 300.00**
GRAND TOTAL			**$ 8,320.00**

Land Surveyor
B. Munakamwe

Survey of Plot 1 (GNSS)
(Bill in US Dollars)

	Unit price	Quantity	Total(Usd)
Part I : Basic charge			
Initial Charge			
Per Lot Charges			
Over 10 - 25Ha	$ 330.00	1	$ 330.00
Part II : Reimbursables			
Beacons (12mm iron peg and cairn)	$ 3.00	4	$ 12.00
Working Stations	$ 2.00	2	$ 4.00
Part III :Transport			
Harare - Stockholm Farm - Harare	$ 1.00	200	$ 200.00
Site Mileage	$ 1.00	130	$ 130.00
Part IV: Labour			
3 Labours for 3 days @$10 per day	$ 10.00	9	$ 90.00
Part V : Charges for materials			
Working plan	$ 50.00	1	$ 50.00
Diagrams in triplicate	$ 20.00	3	$ 60.00
Part V1 : Professional fees			
Land Surveyor	$ 50.00	6	$ 300.00
Land Surveyor in Training	$ 40.00	10	$ 400.00
SUB-TOTAL			
Examination fees			**$ 300.00**
GRAND TOTAL			**$ 1,876.00**

Land Surveyor
B. Munakamwe

ANNEX 11 UAV Quotations

ESTIMATE
Quote for Survey: 300ha Juru Growth Point

Grand Total (USD)
$2,820.00

BILL TO
Blessing Munakamwe
0773013237
blessingmunakamwe@gmail.com

Estimate Number: 052020003
Estimate Date: March 24, 2022
Expires On: March 31, 2022

ITEMS	QUANTITY	PRICE	AMOUNT
GCPs Ground Control Points	40	$10.00	$400.00
Drone Survey Drone Survey per Ha	300	$5.00	$1,500.00
Data Processing Data processing per Ha	300	$2.50	$750.00
Transport and Subsistence	1	$80.00	$80.00
General Assistant	1	$30.00	$30.00
GPS Hire	1	$60.00	$60.00
		Total:	$2,820.00
		Grand Total (USD):	**$2,820.00**

[redacted]

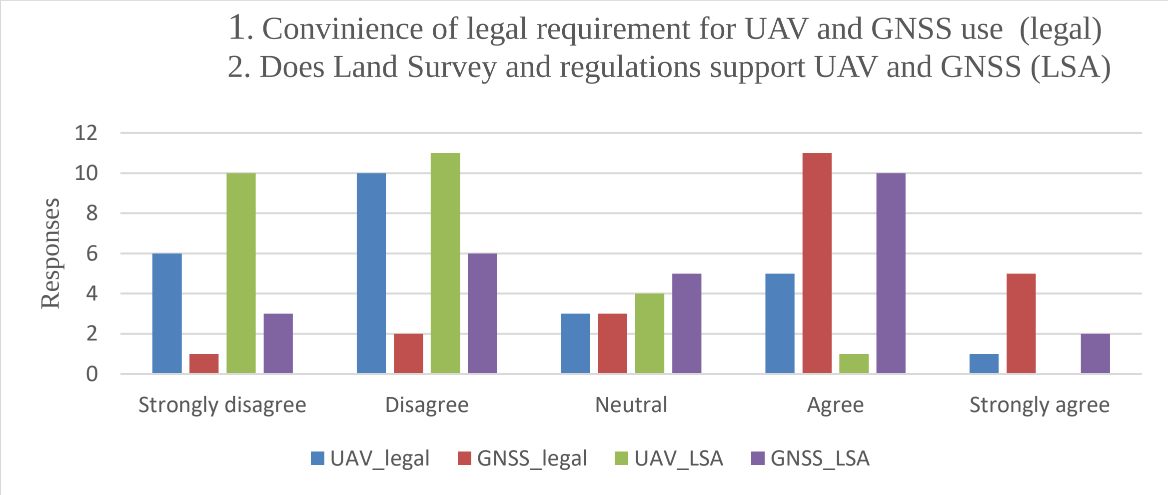
Contact Information
mcnallyp[redacted]

Drone Survey of Stockholm (UAV)			
(Bill in US Dollars)			
	Unit price	Quantity	Total(Usd)
Part I : Basic charge			
Initial Charge			
Per Lot Charges			
Charge per hectare (3cm GSD)	$ 5.00	306	$ 1,530.00
Part II : Reimbursables			
Placing GCPS and CPs	$ 6.00	20	$ 120.00
Working Stations	$ 2.00	2	$ 4.00
Part III :Transport			
Harare - Stockholm Farm - Harare	$ 1.00	200	$ 200.00
Site Mileage	$ 1.00	100	$ 100.00
Part IV: Labour			
3 Labours for 3 days @$10 per day	$ 10.00	9	$ 90.00
Part V :Data processing			
Orthophoto	$ 200.00	1	$ 200.00
Extraction of coordinates	$ 10.00	45	$ 450.00
Part V1 : Professional fees			
Land Surveyor	$ 50.00	15	$ 750.00
SUB-TOTAL			
GRAND TOTAL			**$ 3,444.00**
Land Surveyor			
B. Munakamwe			

Drone Survey of Plot 1 Stockholm (UAV)			
(Bill in US Dollars)			
	Unit price	Quantity	Total(Usd)
Part I : Basic charge			
Initial Charge			
Per Lot Charges			
Charge per hectare (3cm GSD)	$ 5.00	10	$ 50.00
Part II : Reimbursables			
Placing GCPS and CPs	$ 6.00	4	$ 24.00
Working Stations	$ 2.00	2	$ 4.00
Part III :Transport			
Harare - Stockholm Farm - Harare	$ 1.00	200	$ 200.00
Site Mileage	$ 1.00	100	$ 100.00
Part IV: Labour			
3 Labours for 2 days @$10 per day	$ 10.00	6	$ 60.00
Part V :Data processing			
Orthophoto	$ 150.00	1	$ 150.00
Extraction of coordinates	$ 10.00	4	$ 40.00
Part V1 : Professional fees			
Land Surveyor	$ 50.00	10	$ 500.00
SUB-TOTAL			
GRAND TOTAL			**$ 1,128.00**
Land Surveyor			
B. Munakamwe			

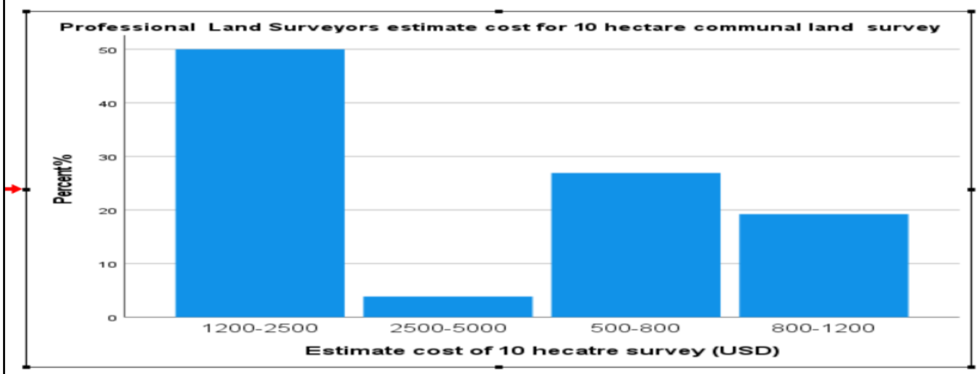
ANNEX 12

a) Comparison of GNSS and UAV interms of the convinience of legal requirement and usage adherence to Land survey act and Land Survey Regulations



b) Land surveyors estimate cost for an individual plot survey .

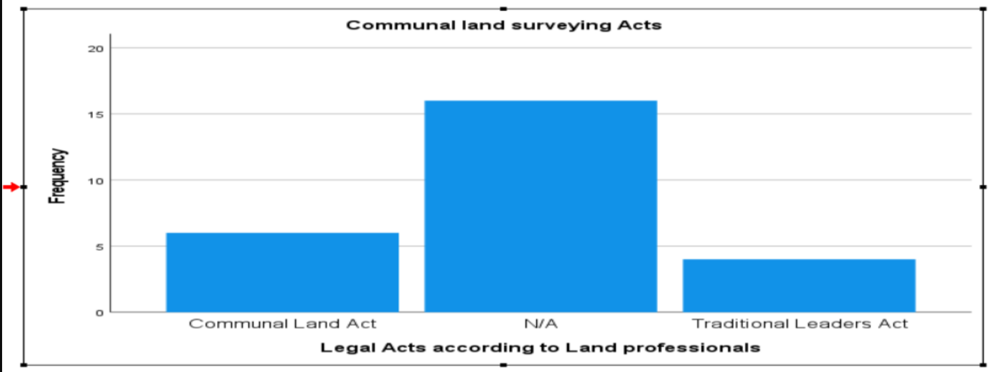
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1200-2500	13	50.0	50.0	50.0
	2500-5000	1	3.8	3.8	53.8
	500-800	7	26.9	26.9	80.8
	800-1200	5	19.2	19.2	100.0
	Total	26	100.0	100.0	



c) Legal acts for communal land surveying responses

Communal Land surveying Acts

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Communal Land Act	6	23.1	23.1	23.1
	N/A	16	61.5	61.5	84.6
	Traditional Leaders Act	4	15.4	15.4	100.0
	Total	26	100.0	100.0	



ANNEX 13 Random fieldwork photos