FIT-FOR-PURPOSE BOUNDARY MAPPING AND VALUATION OF AGRICULTURAL LAND USING UAVS: THE CASE OF A1 FARMS IN ZIMBABWE

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February, 2017

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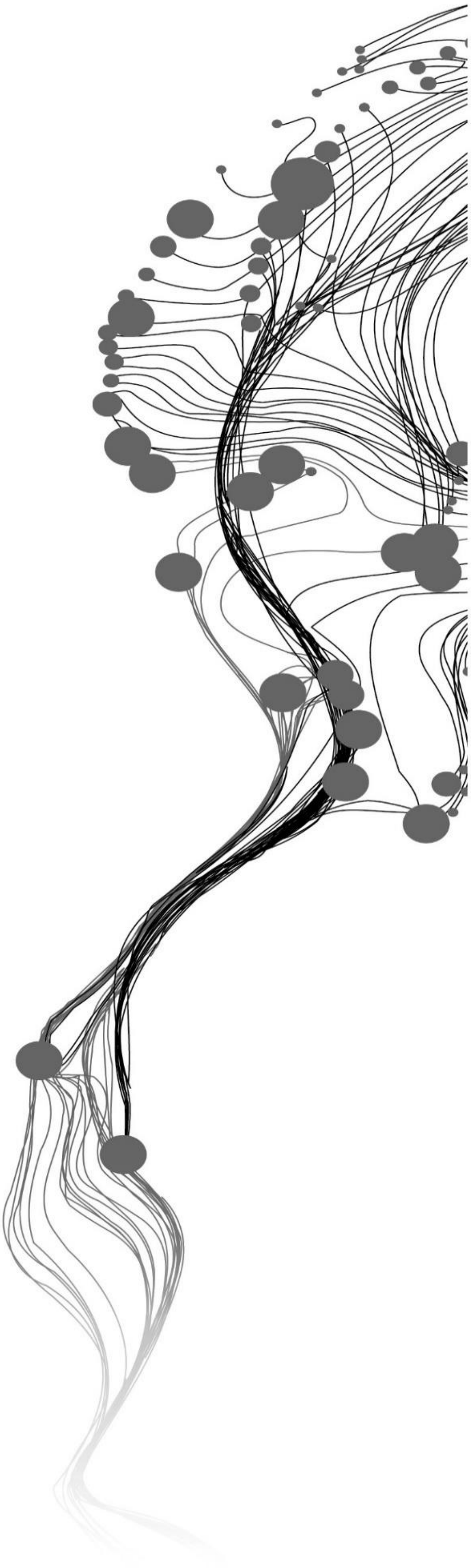

Fit-for-purpose boundary mapping and valuation of agricultural lands using UAVs: the case of A1 farms in Zimbabwe

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ABSTRACT

Recently, the use of Unmanned Aerial Vehicles (UAVs) in the collection of spatial data has increased due to their technological maturation in terms of manoeuvrability, cost and flexibility in geo-data acquisition. Although they have been trialled in cadastral mapping primarily with the view to support land tenure security and the creation of land certificates, in this research their utility for both boundary mapping and valuation of agricultural land was interrogated. Arguably, the large amounts of information provided by UAV imagery provide greater utility for valuation than for cadastral mapping. Consequently, a UAV-based workflow was developed and applied to agricultural land in Zimbabwe, mainly focusing on A1 farms. This involved image acquisition and processing to generate orthophoto used in parcel boundary mapping and describing improvements on land parcel for valuation purposes. Using the developed UAV-based approach, two orthophotos covering 28.73 ha and 11.59ha for study area in Marondera and Ruwa respectively were generated. The UAV images and the generated orthophotos provided an up-to-date representation of the investigated study areas and produced accurate results when compared to the existing approach. Based on the findings of this study, the developed UAV-based boundary mapping and valuation approach is applicable to agricultural land, particularly A1 farms, in Zimbabwe. The developed approach is useful in both boundary mapping and defining physical characteristics of improvements on land for valuation purposes. Given that the approach was applied on a single farm, further work should explore the use of the developed approach beyond a single farm and compare the results with aerial or satellite photogrammetry in terms of cost and time.

Keywords: *UAVs, Boundary Mapping, UAVs for Valuation, cadastral boundaries, A1 farm surveys, Zimbabwe*

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DEDICATION

I dedicate this thesis to my mother, Ms C Muvirimu and my mentor, Mr M.R.D Stonier for their unwavering support and dedicated partnership for success in my life.

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LIST OF ABBREVIATIONS

A1	Small-scale family farms
A2	Smaller-sized capitalist farms
DSG	Department of Surveyor General
DSM	Digital Surface Model
GCP	Ground Control Point
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
Ha	Hectare
IFAD	International Fund for Agricultural Development
IVSC	International Valuation Standards Council
MLRR	Ministry of Lands and Rural Resettlement
RTK	Real Time Kinematic
UAV	Unmanned Aerial Vehicle

1. INTRODUCTION

1.1. Background

The notion of land as an asset has occupied the mind of people for ages. Since early civilizations, the importance of land as a source of livelihood, mainly through agriculture, has been widely accepted. As expected, many governments today strive to ensure that land is accessible and rights of landholders are secured. Nowadays tenure security, especially in developing countries, sits atop land policies of many governments (Deininger, 2003; Holden & Otsuka, 2014; Simbizi, Bennett, & Zevenbergen, 2014; Toulmin, 2009). Incidentally, gravitating towards empowering landholders by ensuring tenure security induces confidence to invest in land and thereby become more productive (Atwood, 1990; Feder & Nishio, 1998). Despite the fact that tenure security is imperative, the present narrative is not reflective of this fact particularly in developing countries. A scanty 25% of the land is officially registered and this indicates that tenure insecurity is still a challenge yet to be overcome(Enemark, Bell, Lemmen, & McLaren, 2014). Furthermore, given the low amount of land officially recorded it is somewhat evident that the same tenure insecure people are unfortunately excluded from formal land markets. Such exclusion constrains the use of land for economic gain(De Soto, 2000).

Major challenges in ensuring tenure security and participation in land markets in developing countries have been attributed to high costs incurred during land registration due to the conventional methods used(Bujakiewicz, 1988; Deininger, 2003; Toulmin, 2009; Zevenbergen, Augustinus, Antonio, & Bennett, 2013). As a result, landholders or governments are faced with financial hurdle which slows down land registration and valuation processes. Recently, new approaches to land registration have been made available due to technological advancements in tools used for acquiring and disseminating land information. Rudimentary land surveying tools such as chains and tapes have been replaced by electronic distance measurement units, total stations and more recently GNSS and satellites imagery. Regarding the latter, advances in photogrammetric science and remote sensing shifts attention from ground based cadastral surveys to aerial-based methods have emerged as alternative cost-effective methodologies for data acquisition(Ali, 2012; Lemmen et al., 2009; Ondulo & Kalande, 2006; Onkalo, 2006; Yagol, Shrestha, Thapa, Poudel, & Bhatta, 2015). Recently, UAVs (UAVs) have been trialled in cadastral boundary mapping with sound results(Barnes, Volkmann, Sherko, & Kelm, 2014; Bendig, Bolten, & Bareth, 2012; Manyoky, Theiler, Steudler, & Eisenbeiss, 2012; Mumbone, 2015; Ramadhani, 2016).

Although UAVs have been trialled successfully in cadastral boundary mapping primarily with the view to support land tenure security and the creation of land certificates, it's yet to be seen if they can be used in land/property valuations (Dabrowski & Latos, 2015) and assessment of farms (Mumbone, 2015). Arguably, the large amounts of information provided by UAV imagery will provide much greater utility for valuation approaches than for cadastral mapping activities. At any rate, since land administration include aspects of land tenure and land value, the importance of innovative methods for acquiring both land value and tenure data cannot be overemphasised. High spatial resolution of UAV imagery, its ability to overcome access limitations in difficult terrain and the flexibility in image acquisition can be utilised in cadastral mapping and property valuation (Pérez, Agüera, & Carvajal, 2013).

However, finding the right approach to cadastral boundary mapping and valuation can be a daunting task especially for developing countries. Zimbabwe is no exception in this regard. Inspired by researches done in boundary mapping using UAV technology(Barnes et al., 2014; Cunningham, Walker, Stahlke, & Wilson, 2011; Mumbone, 2015; Ramadhani, 2016) , this research seeks to ascertain the utility of UAVs in both boundary mapping and valuation of agricultural land in Zimbabwe.

1.2. Research Problem

Zimbabwe conducted Fast Track Land Reform Programme (FTLRP) in 2000 and two resettlement models were created, A1 and A2[1] through subdivision of former large commercial farms (Moyo, 2013; S. Moyo, 2011a; Utete, 2003). Since the inception of the land redistribution, the government of Zimbabwe through the Ministry of Lands and Rural Resettlement has been conducting cadastral mapping, registration and valuation of A1 and A2 farms (Ministry of Lands and Rural Resettlement, 2013) through ground based methods.

Considering the high demand in terms of human and financial resources involved in conventional techniques, boundary mapping, registration and valuation of agricultural land (resettlement areas) in Zimbabwe continues to face challenges. Even though imagery has been trialled in other countries for boundary mapping, especially rural land, it is yet to be used in Zimbabwe. However, given high acquisition costs of obtaining boundary data using conventional aerial or satellite imagery it is imperative to find an affordable and scalable solution. Recently, the utility of UAVs in collection of spatial data has been explored in various fields of geospatial science including boundary mapping. Observations from such researches suggest that UAV-image based approach offer cost-effective alternative way to obtain spatial information such as boundary data. While results from previous studies bolsters this perception, the majority of these studies focused on rural contexts and few explored the utility of UAVs both boundary mapping and derivation of physical characteristics of improvements on agricultural land to support valuation activities.

The problem is that, it's unclear whether UAVs can be used in boundary mapping and extraction of physical characteristics of improvements on agricultural land to support valuation activities in the case of A1 farms in Zimbabwe

1.3. Research Objectives and Questions

Responding to the research problem, the main objective of this study is:

To assess whether UAVs can be used in the process of boundary mapping and valuation of agricultural land, particularly A1 farms whilst maintaining requirements of completeness, accuracy and up-to-datedness.

In order to achieve the main objective, sub-objectives and related questions are defined as follows:

1. To review current boundary mapping and valuation techniques regarding agricultural land particularly A1 farms and usage of UAVs in Zimbabwe
   1.1. *What is the current legal framework, technologies and characteristics of the existing approach in which A1 farms are mapped and valued?*

[1] A1 and A2 farms are agricultural models created in the Fast Track Land Reform Programme. A1 are either villagized or self-contained small farms with a minimum of 3 hectares and A2 are medium to large scale commercial farms(Government of Zimbabwe, 2016).

   1.2. *What are the policies and regulations regarding UAVs usage?*

2. To develop a UAV-image based approach for boundary mapping and valuation of agricultural land particularly A1 farms in Zimbabwe
   2.1. *What does the new UAV-based approach contain and what steps are involved in applying it?*
   2.2. *Can UAVs be imbedded in the existing approach for boundary mapping and valuation?*

3. To evaluate the developed new approach in Zimbabwe
   3.1. *What are the benefits offered by the new UAV-image based approach in terms of up-to-datedness, completeness and accuracy?*
   3.2. *What are the recommendations for future use of the proposed approach in Zimbabwe?*

1.4. Conceptual Framework

In this study, innovative tools for collecting boundary data and valuation of agricultural land in the context of Zimbabwe are explored. In particular, the utility of UAVs in the boundary mapping and valuation is explored. The study is guided by the conceptual framework depicted in Figure 1.

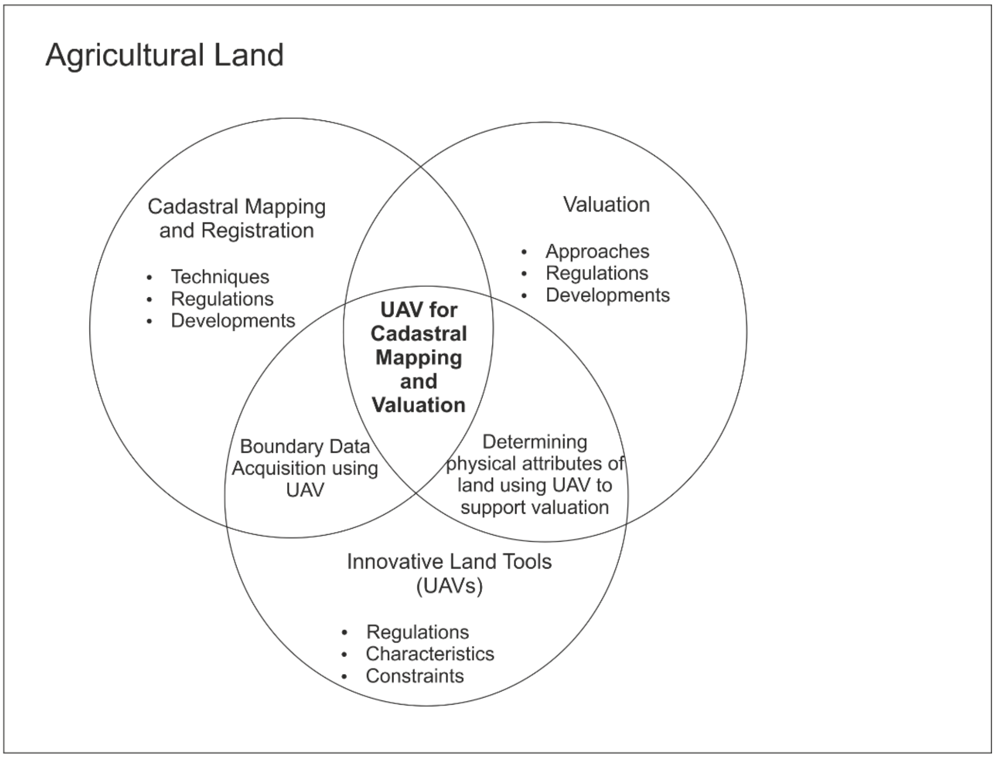


Figure 1: Conceptual Framework

1.5. Research Matrix

The research design matrix (Table 1) gives an overview of materials and methods used to achieve the set objectives. In addition, the expected results from the methods used and materials are given.

Table 1: Research Design Matrix

Research sub-objective	Research Questions	Method	Required materials	Expected Outcome
1. To review current boundary mapping and valuation techniques regarding agricultural land particularly A1 farms and usage of UAVs in Zimbabwe	1.1. What is the current legal framework, technologies and characteristics of the existing approach in which A1 farms are mapped and valued? 1.2. What are the policies and regulations regarding UAV usage?	Document Review Interviews (semi-structured with Ministry of Lands officials and farmers)	Surveying Manuals Land Surveying Laws Valuation Laws Aviation Acts UAV regulations Government publications	Insights into institutional arrangement, technical aspects and legal framework governing cadastral mapping and valuation of agricultural land, particularly A1 farms Insights into requirements for operating UAVs and restrictions of using the technology in the context of Zimbabwe
2. To develop a UAV image based approach for boundary mapping and valuation of A1 farms in Zimbabwe	2.1. Can UAVs be imbedded in the existing approach for boundary mapping and valuation? 2.2. What does the new UAV based approach contain and what steps are involved in applying it?	Document Review Interviews (semi-structured with Ministry of Lands) Designing/ prototyping	**Software**: Pix4D Mapper, ArcGIS, QGIS, Flight Planning Mission software (Pix4D Capture), **Hardware**: UAV, GNSS RTK Receiver, laptop **Auxiliary**: artificial targets, secondary datasets for farms	Processed UAV-derived products (orthophoto, DSM) Farm boundary data Insight into the usefulness of UAVs in aiding valuation of agricultural land.
3. To evaluate the proposed new approach in Zimbabwe	3.1. What are the benefits offered by the proposed new approach in terms of up-to-datedness, completeness and accuracy? 3.2. What are the recommendations for future use of the proposed approach in Zimbabwe?	Document Review Interview (semi-structured) Comparison/ Accuracy Assessment	**Software**: Pix4DMapper, ArcGIS	Accuracy report Evaluation report of the new approach (strengths and limitations) in terms of up-to-datedness, completeness and acceptable accuracy List of recommendations for the proposed approach

2. LITERATURE REVIEW

In this chapter, a broad review of concepts of boundary mapping and valuation of agricultural land is given. In boundary mapping and valuation processes, innovative acquisition techniques such as Unmanned Aerial Vehicles (UAVs) are explored and their applicability assessed. Boundary concepts and allied processes such as adjudication and participatory mapping are also discussed in this chapter. Furthermore, cadastral surveying methods available for parcel boundary demarcation is presented. This is followed by examination of the agrarian structure in Zimbabwe.

2.1. Cadastral Boundary Concepts

The relationship between mankind and land has always been dynamic and so has been the way in which rights to land are held. At any given time, these rights in land are fixed in space and sometimes in time. Amongst other things, the extent to which one enjoys rights to land are often defined by a boundary. Over the years, the term boundary has had various meaning in different jurisdictions. To date, the manner and form of what constitutes a boundary in one jurisdiction differ from another(Williamson & Ting, 1999).

Generally speaking, boundary is a surface which defines the extent of interests in land held by a landowner (UNECE, 2005). It defines where interests in land of a landholder starts and ends. Cole & Wilson(2016) defined boundaries as “lines which limit or separate ownership or jurisdiction”. While the general definition of land is widely construed by many, it goes without saying that different perceptions of boundaries are held. Legally speaking, a boundary can be defined as a surface extending from the centre of the earth to infinity in the sky (UNECE, 1996). It is however important to note that the legal definition is an abstract concept and it views a boundary as a three-dimensional concept.

Other definitions of boundary have been provided by various researchers. Central to these definitions is the concept of a cadastral parcel unit. Tuladhar (1996) defined a land parcel as a continuous area of land with unique and homogenous interests. In order to delimit these homogenous interests in land, a boundary can be defined using natural features, man-made features or mathematical models(Cole & Wilson, 2016). The separation between adjoining land parcels can be done using man-made features such as hedges , which forms part of the boundary line, or by erecting monuments (Dale, 1977). Thus, a boundary can refer either to physical objects or an imaginary line or surface defining division between adjoining land parcels(Williamson, Enemark, Wallace, & Rajabifard, 2010).

Cadastral boundaries of land parcels enable recognition and registration of landholder’s interests in land. Consequently, good boundaries should have the attributes of permanency and recognisability/ unambiguity(Cole & Wilson, 2016). This minimises potential boundary disputes, safeguards landholders’ interests in land and ultimately strengthens land administration systems. Depending on the approach used to define a parcel boundary, two broad groups for boundaries exists namely general and fixed boundary system.

Fixed Boundary

In this concept, a boundary of a land parcel is accurately surveyed, fixed and marked with monuments (Tuladhar, 1996). In this context, a boundary is determined mathematically using bearings and distances or coordinates by legal surveys(Williamson et al., 2010). Given the nature of fixed boundary, certainty of the boundary of a parcel is high and it is possible to relocate the boundary should there be changes(UNECE, 1996).

General boundary

In general boundary system, a precise line dividing adjoining parcels is left undetermined and physical features are used in demarcating a land parcel(Dale, 1977). Accuracy is not prioritized in general boundaries and low cost surveying tools such as imagery are used to obtain an up-to-date record of parcels(Dale, 1977; Zevenbergen, 2002b). The use of this type of boundary has been prevalent in countries such as Thailand and United Kingdom.

Cadastral boundaries play a pivotal role in shaping land administration systems in many societies. While the boundary can be described as either general or fixed, it does not imply that the former is uncertain and the latter is insusceptible to uncertainty(Williamson et al., 2010). Thus, in selecting the appropriate boundary approach reference should be made to the governing legislation and economic situation in the target jurisdiction. Furthermore, the purpose for conducting the boundary mapping should be established as this influences the choice of the boundary approach. In this research, an understanding of the two broad categories of boundaries is necessary to inform the researcher on their merits and suitability for agricultural land.

2.2. Cadastral Surveying and Mapping Tools

Cadastral surveying is a branch of surveying which specialises in creating plans for property boundaries for the purpose of registration(Bannister, Raymond, & Baker, 1998). It involves describing new or changed boundaries, recovery and restoration of lost boundaries(Silayo, 2005) and these plans can be used as a basis for administering tax (Bruce, 1998). The process of cadastral surveying is mainly concerned with setting and recording "turning points or corners of all property"(UNECE, 1996) and the main outcome of this process is a cadastral map(Williamson & Enemark, 1996).

Over the years, two approaches in cadastral surveying namely direct and indirect have been dominant (Craig & Wahl, 2003; Williamson, 1983). These approaches are also referred to as graphic and numeric(Williamson et al., 2010). In the direct approach, ground based survey techniques such as chains, total stations or GNSS are used to create property boundaries. Relative positions of points are located first and the distance measured subsequently(Ali, 2012). In contrast, aerial survey methods such as photogrammetry and satellite imagery are used in the indirect approach to delineate parcel boundaries.

While the survey approaches are broadly categorised into either direct or indirect, there exists a number of tools at surveyors' disposal for boundary demarcation. Williamson et al.(2010) generalises these tools into graphic and numeric tools. Graphic tools are often simple and low cost and these include plane table, stadia, use of orthomosaics, and satellite imagery. On the other hand, numeric tools are used to determine coordinates of boundary corners or distances and bearings of each boundary corner. Numeric tools include polar methods, Global Navigation Satellite Systems (GNSS) and offset methods (Williamson et al., 2010).

Given the variety of tools available, the choice of a cadastral method to use is highly dependent on the purpose, accuracy requirements and cost(Dale, 1976; Rao et al., 2014). Establishing property boundaries at a minimum cost without compromising accuracy and time has become the main focus of most land administration systems. The need to have complete register of land parcels at low cost in most countries has seen aerial survey methods being used to map land parcels, mainly rural areas(Binns, 1995; Lemmen et al., 2009; Ondulo & Kalande, 2006; Onkalo, 2006) where accuracy is of little concern to warrant use of high accuracy survey tools. Recent technological advancement have seen UAVs becoming ubiquitous in mapping science thus slowly permeating into cadastral mapping approaches(Barnes et al., 2014; Berteška & Ruzgienė, 2013; Kurczynski et al., 2016; Manyoky et al., 2012; Pérez et al., 2013). They have provided a way to collect geo-data in a flexible and cost effective way. These assertions are ascertained in this research and the use of UAVs for obtaining boundary data for agricultural land is explored.

2.3. Adjudication

Landholders' land rights must be authoritatively established and recorded as accurately as possible. This process of establishing land rights is known as adjudication(Haldrup, 1996). Adjudication can be regarded as a process in which an inventory of rights in land are compiled and registered(Zevenbergen, 2002a). This process, in theory, do not create new rights in land but rather establishes the existing ones thus providing certainty and finality to land records (Silayo, 2005; UNECE, 1996). Two approaches to adjudication exists namely systematic and sporadic.

Systematic Adjudication

Taking an inventory of rights in land is imperative especially in first registration and often requires a methodical approach if a complete register of land parcels in a certain jurisdiction is envisioned. This methodical and orderly sequence of ascertaining rights in land for registration in known as systematic adjudication(UNECE, 1996). In this approach, there is huge involvement of the government and mandatory participation of landholders once a certain territory has been declared open for registration(Zevenbergen, 2002b). As expected, landholders of neighbouring land parcels must be present to indicate their boundaries to the adjudication officers thus minimising future potential boundary disputes.

Sporadic Adjudication

In sporadic adjudication, it is not always the case that registration of every land parcel is treated with the same level of importance or urgency. In most instances, focus is placed on certain adjudication of land where priorities are high such as disputed land or when there is agrarian reform. In these cases, adjudication is often done haphazardly and on a case-by-case basis (UNECE, 1996). Zevenbergen (2002b) noted that sporadic adjudication has two variants, obligatory and voluntary. The distinction between these two variants is rather fuzzy. In the former, landholders are obliged to participate in the adjudication process whilst in the latter landholders act in response to their perceived importance or urgency of land registration.

In essence, the process of adjudication establishes with certainty the land rights of landholders. It involves the participation of landholders in identifying their parcel boundaries and their associated rights, restrictions and responsibilities in land. In this study, usefulness of UAVs is explored in mapping land boundaries and it is against this background that the concept of adjudication is reviewed as it is the first stage in land registration.

2.4. Participatory Mapping

The last decade has seen wide use of participatory mapping in most data collection activities(Chambers, 2006; IFAD, 2009; Reyes-García et al., 2012) and has become an undeniably powerful tool for understanding local natural resources(Lipej & Male, 2015). Participatory mapping can be defined as a "map-making process that attempts to make visible association between land and local communities by using the commonly understood and recognized language of cartography"(IFAD, 2009). Thus, participatory mapping is both an investigative process and tool which allows rapid gathering of information such as land parcel boundaries though the participation of the landholders. It is highly an interactive process and it relies on the knowledge of local people; it allows landholders to give a visual representation of their land using mediums at their disposal such as aerial photographs, satellite images and Geographic Information Systems(Brodie & Cowling, 2010; Lipej & Male, 2015).

The use of participatory mapping in establishing cadastral boundary is not new. It has been in existence for decades and has been adopted in various jurisdictions around the world(Ali, 2012; Lipej & Male, 2015; Rao et al., 2014). Participatory mapping empowers communities by transforming their 'cognitive geographical knowledge' into maps depicting their land parcels(Bernard, Barbosa, & Carvalho, 2011; FAO, 2013; Herlihy, 2003).

Participatory mapping enables landholders to give a graphical depiction of their land parcels. With the proliferation of high resolution UAV-based orthophotos, identification of landholder's parcel boundaries is greatly increased. In this study, participatory mapping forms the basis upon which boundary data of land parcels is derived.

2.5. Valuation

Valuation is a process in which an opinion of the value of an asset or property is expressed as objectively as possible. Generally, valuation can be viewed from two angles; it can refer to "the estimated value (the value conclusion) or the preparation of the estimated value (the act of valuing)"(IVSC, 2013). In the process of valuation, all pertinent data is used "to develop well-supported estimate of the worth of a property"(UNECE, 1996). Such pertinent data include economic, social trends, government regulations and environmental conditions among others. In real property, valuation usually refers to determination of property's present worth of future benefits derived from ownership of the property. Wyatt & Ralphs (2003) asserts that property value reflects its capacity to fulfil a function.

In valuing property, the term 'value' is generally prefaced by descriptions such as fair value, market value or intrinsic value(Yomralioglu & Nisanci, 2004). Market value is predominantly used value since it refers to the amount for which a property would transact on a particular date between a willing buyer and seller dealing at arm's length with each party acting knowledgably and without compulsion(IVSC, 2013). While the importance of valuation is construed, it is a complex process which requires consideration of various underlying market, economic, political and social factors(Walacik, Grover, & Adamuscin, 2013). Wyatt (1996) observed that factors influencing property/land values can be broadly categorised into two groups, internal factors and external factors (Figure 2).

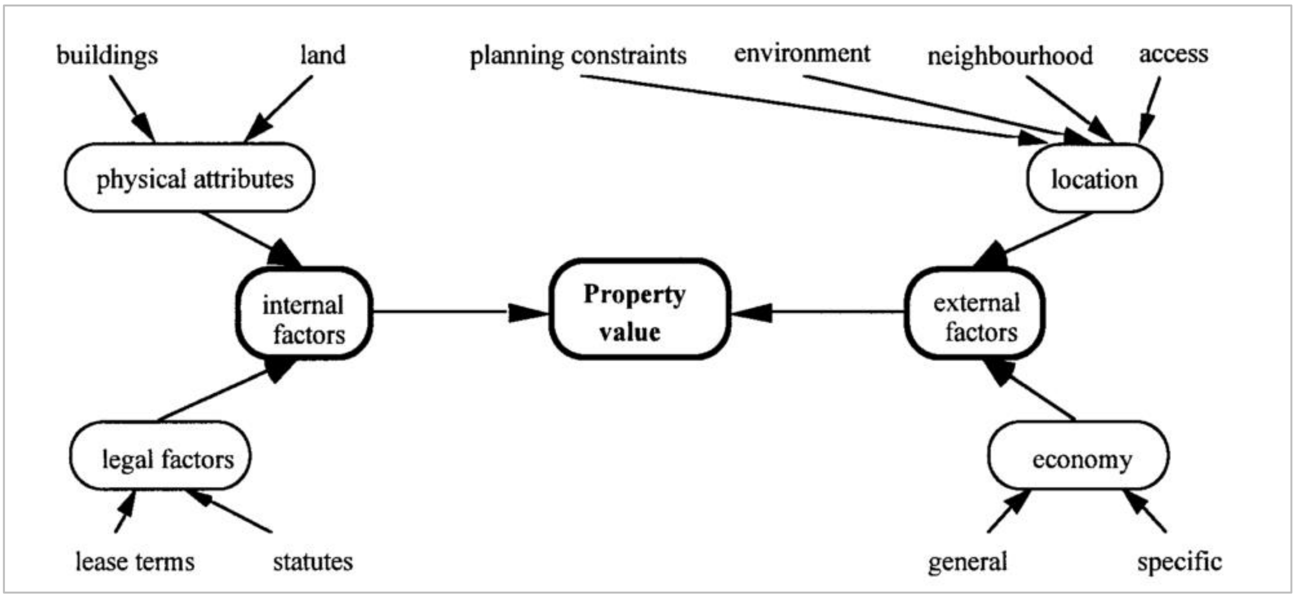


Figure 2: Factors affecting property value (Wyatt & Ralphs, 2003)

In Figure 2, Wyatt (1996) asserts that value of a property is a function of physical, economic, locational and legal factors. Incorporating these factors when conducting valuation is often challenging due to unavailability or inaccessibility of data.

In this research, focus is placed on the utility of UAVs in determining mainly the physical attributes and to a lesser extent the locational factors depicted in Figure 2. As mentioned earlier, valuation is a complex undertaking and it requires up-to-date data and experienced valuer.

2.5.1. Approaches to valuation

Three main traditional approaches are used in valuation namely cost approach, sales comparison and market capitalization(UNECE, 2005). While the choice of a suitable valuation approach depends on the type of property, purpose of valuation or data available, the use of more than one approach is often recommended for a better estimate.

Cost Approach

In this approach, value of a property is estimated using the principle that the price a buyer would pay for an asset being valued would be not more that the cost to purchase or construct an equivalent(IVSC, 2013). In many instances buyers and sellers relate value to cost and this understanding is utilised in cost approach. In order to estimate the value of a property using cost approach, summation of the value of land and cost of constructing a replica of what is already on the land is done taking into consideration depreciation of the improvements(UNECE, 1996). Cost approach is mainly used in instances where the property under valuation is rarely transacted in the market; such properties include churches, stadiums and schools among others.

Sales Comparison

This approach to valuation involves comparing a property to other properties with similar characteristics that have been sold recently(Cupal, 2014). Using this approach, a valuer estimates the degree of similarity or difference between recently transacted properties and the target property by considering factors such as physical characteristics, real property rights, location and market conditions(UNECE, 2005). Depending on the degree of similarities between the property under valuation and those recently transacted on the market, a value is estimated for the target property. In instances where there is more heterogeneity in characteristics, adjustments are made. Sales comparison approach reflects market value and is commonly used in valuation of property.

Income Capitalization

In this approach, the value of a property is estimated by considering the amount a property will generate in its lifetime through capitalization process(IVSC, 2013). It is based on the principle that the value of the investment on a property is reflected by the income it generates over its life time(Asian Development Bank, 2007). This involves measuring the present value of the future inflows from property and capitalized into present value(UNECE, 2005).

Regardless of the valuation approach adopted, comprehensive market analysis is a pre-condition to an objective value of a target property. The approaches discussed in the preceding paragraphs differ in applicability depending on the purpose of the valuation as well as the prevailing market conditions. It is thus imperative to comprehend the underlying property characteristics considered when using any of the traditional valuation approaches.

2.5.2. Valuation Approaches for Agricultural land

As mentioned earlier, obtaining an objective value for a property is a complex undertaking and these same challenges equally apply to agricultural land. To date, valuation of agricultural land continues to be a complex subject due to the diverse definitions of agricultural land in different jurisdictions and factors which determine its value(Feichtinger & Salhofer, 2011a). Valuation can be conducted for various reasons such as compensation, taxation purposes and loan security from financial institutions and this has influence on the valuation procedure (Walacik et al., 2013). Accordingly problems of methodological objectivity and selection of comprehensive set of variables which affect land value are encountered by the majority of valuation officers(Garcia & Grande, 2003).

Various valuation approaches for agricultural land exist in different jurisdictions. The most notable approaches are sales comparison and those based on production potential of the land with adjustments for socio-economic conditions (Verheye, 2011). Thus, land value can refer to either productive value or its economic value. The former is closely related to the physical factors such as soil type and terrain while the latter deals with expected returns from the land regardless of present use or production potential(FAO, 2003).

In valuation of land, modelling tools continue to be used to determine the influence of chosen characteristics on the value of land. The popular models are the Hedonic Pricing Model or the Net Present Value. In the Hedonic model, the value of land is assumed to be a summation of characteristics which a valuer associates with the target land important as being important in influencing the value. Examples of such characteristics include soil quality, climate, farm size and access to markets (Maddison, 2000). The magnitude of influence on each identified characteristics on land value is subsequently estimated statistically. These models perform well when data from previous sales is available(Brondino & Silva, 1998). In cases where land markets are not fully functional or active, the applicability of these tools is greatly compromised.

It can be observed that selection of an appropriate valuation technique for agricultural land is influenced primarily by the purpose of valuation. In addition, comprehensive market analysis as well as availability of data such as physical characteristics of land are preconditions to a good estimation of land/property value. The physical characteristics of properties are often collected through physical inspection. In this study, a new approach is proposed. This approach involves extracting the physical characteristics from high resolution UAV-based images.

2.6. Unmanned Aerial Vehicles (UAVs)

UAVs have gained prominence in the geospatial field as an alternative tool for data acquisition (Nex & Remondino, 2014). They continue to be used in various domains such as mapping coastal areas(Turner, Harley, & Drummond, 2016), agriculture(Bendig et al., 2012) and 3D modelling(Remondino, Barazzetti, Nex, Scaioni, & Sarazzi, 2012).

Various definitions of UAVs have been suggested in the past. van Blyenburgh (1999) defined UAV as "uninhabited and re-useable motorised aerial vehicles, which are remotely controlled, semi-autonomous, autonomous, or have a combination of these capabilities". In this regard, UAVs are fundamentally aircrafts without a pilot on-board(Azmi et al., 2014). It is important to note that various synonyms are used for UAVs such as Remotely Piloted Aircraft, Remotely Operated Aircraft and Unmanned Vehicle Systems(Colomina & Molina, 2014; Eisenbeiß, 2009).

There are two broad categories UAVs used in civilian work namely fixed wing and multi-rotor (Figure 3). Other classifications exist depending on the characteristics considered. Nex & Remondino (2013), classifies UAVs based on engine/propulsion system and aerodynamic features. This further gives classes of unpowered platforms such as balloon or powered platforms such as airships and gliders. Furthermore, van Blyenburgh (1999) classifies UAVs based on their range and altitude and gives three classes namely tactical UAVs, strategical UAVs and Special tasks. However, classification given by van Blyenburgh (1999) applies to military UAVs and in this research civilian UAVs are explored.

a) b)

Figure 3: Broad categories of UAVs, (a) fixed wing UAV (SenseFly, 2017), (b) multirotor UAVs(DJI, 2017)

Each category of UAVs has advantages and disadvantages associated with it. Siebert & Teizer (2014) compiled advantages and disadvantages and these are given in Figure 4. An understanding of strengths and weakness of each category enables an informed selection of the appropriate tool for a specific job.

Aircraft Type	Efficiency and range*	Flexibility and maneuverability	Weather dependency	Payload	Safety	Complexity and simplicity	Running costs	Setup time
Airships	Very good	Average	Poor	Very good	Good	Good	Poor	Poor
Fixed wing aircraft	Very good	Poor	Good	Good	Average	Average	Average	Average
Helicopters	Average	Very good	Good	Very good	Poor	Poor	Average	Good
Multicopters	Poor	Very good	Good	Average	Average	Good	Very good	Very good

Figure 4: A comparison of UAV platforms (Siebert & Teizer, 2014)

In addition to the merits of each UAV category given in Figure 4, Colomina & Molina (2014) brings the issue of endurance and flying altitude into perspective. Generally, fixed wing UAVs have a longer endurance and usually flight at higher altitudes when compared to multi-copters(Tahar & Ahmad, 2013). Unsurprisingly, a higher flying altitude translates to large ground coverage and this warrants the use of fixed wing UAVs when mapping large areas.

As mentioned in the preceding paragraph, the use on UAVs in geospatial data collection has increased recently. The increase in use has been attributed to cost-effectiveness and flexibility in spatial data capture offered the UAVs (Barnes et al., 2014; Eisenbeiß, 2009; He, Li, & Zhang, 2012; Rango et al., 2009; Tahar & Ahmad, 2013). In addition, the ground coverage and the associated accuracy of UAVs is satisfactory. This relationship between coverage and accuracy for UAVs is depicted in Figure 5. It can be noted that the area covered by UAVs ranges from around a hundred square metres to about ten hectares. Given such coverage and accuracy, UAVs promise to be an alternative tool for acquisition of spatial data when compared to the available tools on the market.

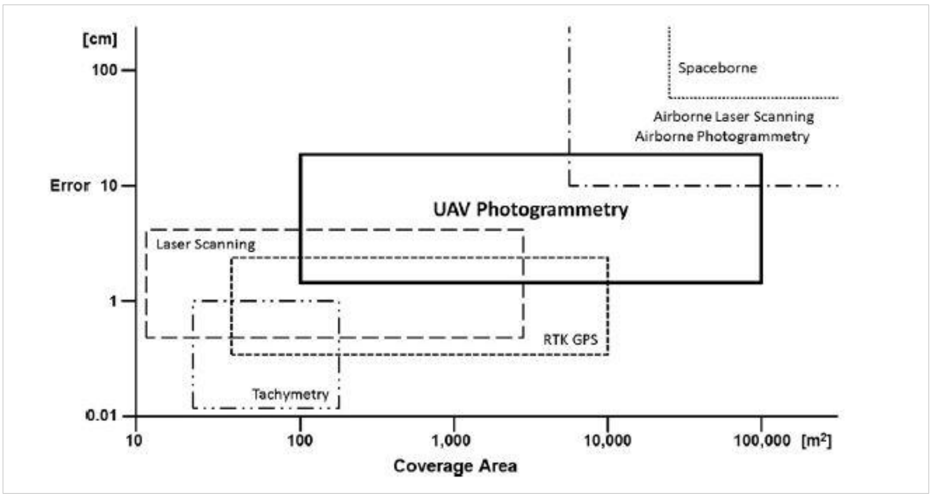


Figure 5: UAV application in surveying tasks(Siebert & Teizer, 2014)

In this research, advantages offered by UAVs are explored in the context of Zimbabwe. Thus, a review of the concepts around UAVs is important in understanding how they function and conduct an appraisal of their strengths and weaknesses regarding their use in boundary mapping and aiding in valuation processes.

2.7. Agricultural land in Zimbabwe

2.7.1. Agrarian Reform

In order to understand the present agrarian structure in Zimbabwe, it is important to take cognisant of the historical events. Zimbabwe inherited a racially-skewed land distribution at its independence in 1980 and subsequently pursued land re-distribution(Juana, 2006; S. Moyo, 2011c; S. A. M. Moyo, 2010; Rutherford, 2012). This was implemented in three phases to resettle the previously marginalised population. The first resettlement phase was carried from 1980 to 1985 through acquisition of land by state on a willing buyer willing seller principle dictated by the Lancaster House Agreement. An acquisition of 8.3 million hectares for settling 162 000 families in the first phase was anticipated (Thomas, 2003). Given the low success in the first phase, the government embarked on the second phase from 1986 until 1999 with the intention of resettling more families. However, by the end of 1999 only 71 000 families were resettled on 3.6 million hectares (Juana, 2006). In 2000, the third phase of resettlement was carried out and it entailed radical agrarian reform through extensive expropriation of land by the government in order to acquire 8.3 million hectares it had previously targeted in 1980 (S. Moyo, 2011b).

The third phase of land reform, commonly known as Fast Track Land Reform Programme (FTLRP), resulted in two resettlement models namely A1 and A2[2] (Figure 6 & 7). In this phase about 7.6 million hectares of land was re-distributed to over 145 000 farm households in A1 schemes and a further 16 500 households in A2 schemes(Scoones et al., 2011). However, the exact amount of land redistributed to date continues to increase as more larger A2 farms were allocated and Moyo (2011a) claims that the land allocations amount to about 9 million hectares. The rationale for creating A1 model was to decongest the communal areas and promote small scale farming.

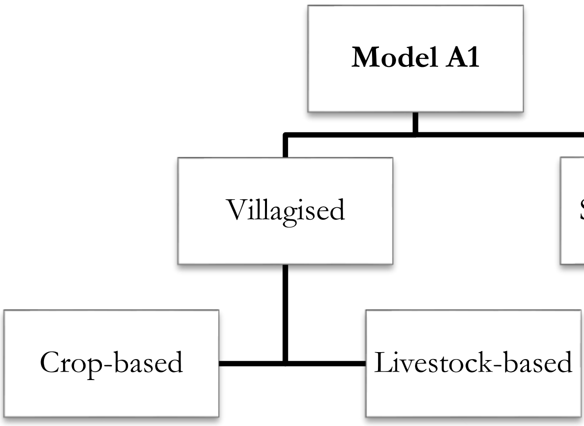


Figure 6: Structure of A1 Model

Resettlement Model A1 was created with two variants namely villagized and self-contained(Masiiwa, 2004; Scoones et al., 2011). The Crop-based category under villagized variant was designed to overcome overpopulation in communal lands thus providing people with land to cultivate their crops. On the other, livestock –based category was created for drier parts of the country to provide commercial grazing(Masiiwa, 2004). The principal tenure type for A1 model is a permit to occupy and use the land in perpetuity(Moyo, 2013). On the other hand, Model A2 was designed to allow previously marginalised farmers to venture into medium and large scale commercial farming(Scoones et al., 2011). The land tenure for this model is a 99-year lease contracts (Moyo, 2013)

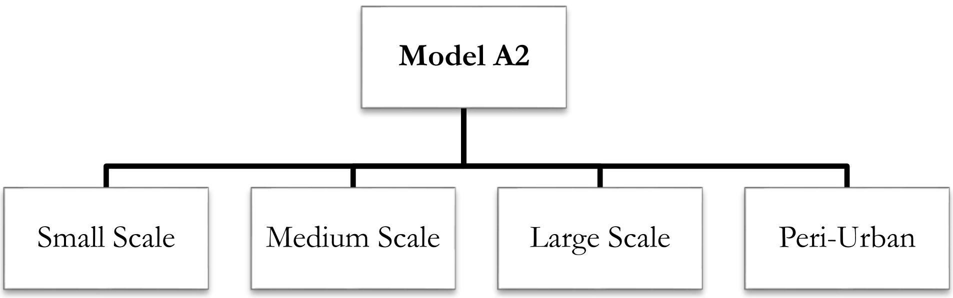


Figure 7: Structure of A2 Model

[2] A1 and A2 are agricultural models created in the Fast Track Resettlement Programme. A1 has 2 variants which are villagized or self-contained small farms with a minimum of 3 hectares and A2 are medium to large scale commercial farms(Government of Zimbabwe, 2016).

. **Concluding Remarks**

This chapter presented the concepts of boundaries, cadastral mapping, valuation and UAVs. In this chapter, it was noted that the selection of a boundary type to use in a particular context is dependent on the available tools and resources; both human and capital. Even though the selection of appropriate boundary type or tool seems to be straightforward, in reality it's challenging. However, some of the challenges can be overcome by conducting adjudication and participatory mapping. This gives autonomy to the landholders to give a depiction of their land parcels thus expediting the process of boundary mapping. With advances in technology, innovative tools such as UAVs play a pivotal role in generating mediums such as orthomosaics which can be used by landholders to depict their parcels. In addition to boundary data, the generated orthophoto and acquired images may be useful in extracting physical characteristics of property essential for valuation purposes. This, has to be done within the confines of the prevailing legislation in the target jurisdiction.

3. RESEARCH METHODS

In this chapter, the methods used to achieve the objectives of this study are discussed. In addition, a description of the study area and the selection criteria used is presented. Details of the techniques used in acquiring and processing the collected data are subsequently given. The chapter concludes by highlighting some of the challenges encountered and how they were surmounted.

3.1. Research Approach

This exploratory study was conducted from a post-positivism paradigm using a deductive approach and a case study strategy as proposed by (Baxter & Jack, 2008) was used. A case study strategy adopted in this research enabled the testing of the theoretical concepts of boundary mapping and extraction of physical attributes of improvements to support valuation of agricultural land using UAVs and their applicability in Zimbabwe. In this research study, primary data was gathered through semi-structured interviews with respondents employed by Ministry of Land and Rural Resettlement and the resettled farmers. In addition, images were acquired using an unmanned aerial vehicle and were used in boundary mapping and assessed for valuation purposes. Secondary data was obtained from policy documents and reports. Scholarly articles on the utility of UAVs in boundary mapping and valuation of land from other case studies were also utilised in this research.

The study was conducted in three stages namely: pre-fieldwork, fieldwork and post-fieldwork. A flowchart of the stages followed is given in Figure 8.

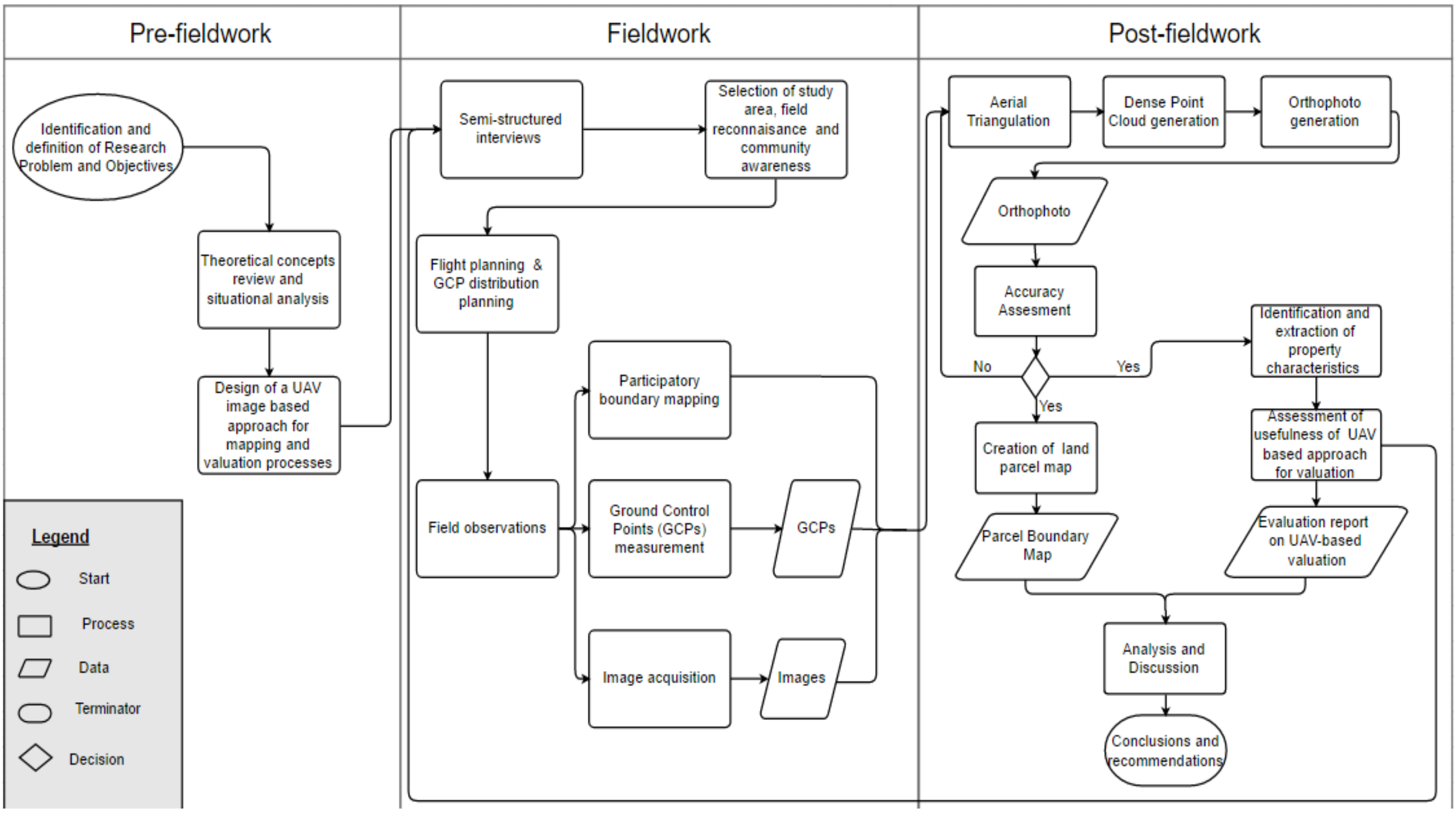


Figure 8: Methodology Flowchart

3.1.1. Pre-fieldwork

During the pre-fieldwork stage, concepts of boundary mapping and valuation of agricultural land were reviewed focusing on the use of UAVs to support boundary mapping and valuation activities. Similar studies in which UAVs where used were reviewed to give a general understanding of the application of UAVs in boundary mapping and valuation processes. The review of documents was done in order to answer research questions to sub-objectives 1 and 2.

Since sub-objective 1 aimed at understanding the current legal and technical situation regarding boundary mapping and valuation, a review of legal and technical documents pertaining to Zimbabwe was done. This included legislation governing boundary mapping and valuation of agricultural land as well as use of UAVs. Key literature reviewed regarding the legislation governing boundary mapping and valuation of agricultural land in Zimbabwe are summarized below:

Legal situation

Document reviewed	Description and relevance to research
Constitution of Zimbabwe Amendment (No. 20) Act, 2013	*The constitution is the supreme law of the country and all laws are subservient to it. Chapter 16 of the Constitution of Zimbabwe gives an interpretation of agricultural land and its alienation while an overview of rights to agricultural land is given in Section 72. These interpretations are important in this research in enabling an in-depth understanding of the meaning of agricultural land and how it is held in the context of Zimbabwe.*
Land Survey Act (Chapter 20:12)	*This act prescribes the manner in which cadastral surveys are done in Zimbabwe for the purpose of effecting land registration in the Deeds Registry. An understanding of this act gives insight into the required cadastral mapping technique and the manner in which cadastral mapping ought to be executed.*
Land Survey (General) Regulations of 1979	*The land survey regulations gives the technical and procedural details for conducting cadastral surveys in Zimbabwe. It specifies the accuracy, manner and form of the produced survey documents. These regulations enables one to understand how cadastral surveys are conducted in terms of accuracy, method and expected outcome.*
Agricultural Land Settlement (Permit Terms and Conditions) Regulations, 2014	*These regulations prescribe the way in which the resettlement land held under permit systems is used. In this research, A1 farm model is held under the permit tenure system. These regulations were reviewed to understand the permit tenure system and its implications on rights, restrictions and responsibilities of landholders.*
Land Acquisition Act (Chapter 20:10)	*This act empowers the President to compulsorily acquire land or immovable for the purpose of public purposes such as land redistribution. It also dictates the manner in which valuation of land/immovable is done in cases of compulsory acquisition. This act is important because it gives the procedure for conducting valuation of land in cases of compulsory acquisition.*
Valuer's Act (Chapter 27:18)	*This act provides for the registration of valuers and regulation of the profession in Zimbabwe. It is important to consider this act because it is the guiding legislation for valuation profession and processes in Zimbabwe.*
Civil Aviation Act (Chapter 13:16) 7/1998 as amended, Civil Aviation (Air Navigation) (Amendment) Regulations, 2010 (No. 1) and Regulations for Remotely Piloted Aircraft/ Unmanned Aerial Vehicle Systems (UAVs) Part 180 (draft regulations)	*The Civil Aviation Act provides for the establishment of Civil Aviation Authority of Zimbabwe and its subsequent functions. It makes provisions for control, regulation and development of aviation in Zimbabwe.* *Civil Aviation (Air Navigation) (Amendment) Regulations, 2010 (No. 1) and the DRAFT regulations provides for the registration of UAVs and their use in Zimbabwe. In this research UAVs are used to acquire imagery and an understanding of the requirements to fly in the airspace of Zimbabwe is essential.*

Additional publications besides legal documents were also reviewed during the pre-fieldwork stage to understand the technical aspects involved in boundary mapping and valuation of agricultural land. The publications selected highlighted the available techniques for conducting boundary mapping in Zimbabwe and other countries. Some of the publications reviewed are listed below:

Document reviewed	Description and Relevance
An Analysis of Data Handling Techniques in Zimbabwe(Kurwakumire & Chaminama, 2012)	*This paper presents the survey data collection techniques currently used in Zimbabwe. It gives an overview of the current methods used in cadastral mapping and it also highlights their associated strengths and weakness.*
Proposed GPS Survey Method for Cadastral Surveying of A2 Model Farms in Zimbabwe(Paradzayi, Chirigo, Goodwin, & Matyukira, 2008)	*In this paper, the use GNSS receivers for conducting cadastral data is presented as a solution to challenges faced in expediting cadastral mapping Weaknesses of the current methods are highlighted and this enabled the identification of the gap which the UAV-image based approach fulfils.*
Agricultural land valuation methods used by financiers: the case of South Africa(Middelberg, 2014)	*This article gives an overview of the preferred valuation techniques for valuation of agricultural land in South Africa. Though not specific to the case study used in this research, a review of this article highlights the existing valuation techniques and*
The Valuation of Agricultural Land and the Influence of Government Payments(Feichtinger & Salhofer, 2011b),	*In this article, valuation approaches are presented and the effect of government policies on the objectivity of the estimated value are explored. In addition, a valuation model and the characteristics of land considered in valuation are presented.*
Voluntary Guidelines on the Responsible Governance of Tenure Responsible Governance of Tenure of land, fisheries and forests in the context of national food security(FAO, 2012)**,** Overview of Land Value conditions(FAO, 2003)	*These articles present best practices in valuation activities and broader overview of conditions influencing valuation under different purposes (e.g. for sale, taxation, compensation and securing funding from agricultural financiers).*

Designing UAV-based approach for boundary mapping and valuation of agricultural land

The design process involved modifying the generic UAV-based boundary mapping used in similar studies to fit agricultural land, particularly A1 farms in Zimbabwe. Requirements of the existing approach were incorporated in the designed approach. The new UAV-based new approach for cadastral mapping and valuation of agricultural land was modelled in Enterprise Architecture and is shown in Annex 6. The documents which were reviewed to enable the design of the UAV-based approach are listed below

Document Reviewed	Description and Relevance
Part 1 of 2 Design and Testing of UAV-based Cadastral Surveying and Mapping Methodology in Albania(Barnes et al., 2014)	*In this article a methodology for conducting cadastral surveying using a UAV is presented. Findings from this articles informed the design process on the steps involved in creating a methodology generating cadastral boundary data using a UAV*
The possibility of using images obtained from the UAS in cadastral works(Kurczynski et al., 2016)	*In this article, a methodology is presented for measuring land parcels and buildings using products of processed UAV images. The methodology presented in this article informed the design of the UAV-based approach developed in this study.*
Unmanned Aerial Vehicle in Cadastral Applications, Cadastral Audit and assessments using Unmanned Aerial Systems(Cunningham et al., 2011),	*This article presents findings from boundary mapping of rural land using UAVs in Alaska, USA. In addition, the potential of UAVs in inspection of properties to support valuation processes is explored.*
Possibilities of practical application of the remote sensing data in the real property appraisal(Dabrowski & Latos, 2015)	*This article examines the utility of imagery from a variety of sources such as conventional aerial photogrammetry, satellites and UAVs for valuation purposes. Findings from this article highlighted merits and demerits of imagery in real property appraisal and these were explored in the study area used in this research.*

3.1.2. Fieldwork

Fieldwork was conducted to answer research questions to sub-objectives 2 and 3. The fieldwork stage involved collection of primary data and was aimed at applying the newly designed UAV-based approach in the study areas. Taking cognisance of the involvement of government institutions and ethical issue, comprehensive preparation was done prior collection of primary data. Permission to conduct the research was sought from the Ministry of Lands and Rural Resettlement (MLRR), Civil Aviation Authority of Zimbabwe and farmers through formal applications.

During the fieldwork stage, semi-structured interviews were conducted with four respondents from the mapping and valuation sections of the Ministry of Lands and Rural Resettlement to ascertain current technical situation regarding boundary mapping and valuation of agricultural land. The semi-structured interviews were aimed at ascertaining their perception of conducting boundary mapping of A1 farms using UAVs and identifying criteria to evaluate the approach thus determining the possibility of embedding UAVs in the existing approach. During these interviews, sample of UAV images acquired in other case studies were shown to respondents to demonstrate the level of detail obtainable using images acquired using UAVs. This was done to make the respondents aware of the UAV technology and appreciate the technology as most of them had never used it before. Findings from the interviews with respondents from MLRR were used to assist the researcher in identifying suitable study area(s). Selection of study area prior fieldwork stage proved to be difficult due to uncertainty of the researcher concerning the situation on the ground. Two study areas were subsequently selected to evaluate the UAV-image based approach for boundary mapping and valuation.

After semi-structured interviews were conducted with MLRR, a visit was made to the study areas to mobilise farmers. It is, however, important to note that community mobilisation was done through the village head after granting the permission to conduct the research in his jurisdiction. Preparation for data collection (image acquisition and boundary data mapping) was done and this included flight planning and plan creation of Ground Control Points (GCP) distribution for the two study areas. Additionally, a list of trigonometrical beacons in the vicinity of the study area were identified to facilitate the set-up of GNSS base station for establishing the GCPs. It is worth mentioning that the coordinates of the identified trigonometrical beacons which were a reasonable distance from the study areas were in local coordinate system (Gauss Coordinate System based on the modified Clarke 1880 Ellipsoid) and these were transformed to World Geodetic Systems 1984 (WGS 84) coordinate system (Annex 3). This involved selection of trigonometrical beacons with both local and WGS 84 coordinates around the study areas and transformation to obtain parameters which were used in the localisation process of GNSS receiver. Similarly, coordinates of the parent properties (Annex 1) used in this research were in local system measured in Cape feet and English feet and were transformed first into local system and subsequently into WGS 84 coordinate system. The rationale behind defining the boundary of the parent property was a precautionary measure to ensure that the research was conducted within the targeted study area.

Following the flight planning procedure were field observations and engagement of farmers in participatory mapping in one of the study area in Marondera (Carolina Farm). In the study area in Ruwa, the concept of identifying and extracting physical attributes of improvements on land for valuation using UAV-image based approach was tested. During participatory mapping in Marondera (Carolina Farm), boundaries of land parcels were marked on the ground using white paint prior to image acquisition. The marks were approximately 30cm long crosses (Annex 12). The signalisation enabled the boundaries to be easily identified on the images acquired. Ideally, participatory process should be done by identifying parcel boundaries on a medium such as orthophoto by landholders. However, in this research, the study area was devoid of visible physical features on the ground to assist the farmers in identifying their boundaries. On the other hand, the concept of identifying and extracting physical attributes of improvements on land for valuation using UAV-image based approach was tested in the study area in Ruwa. Dimensions of a sample of improvements on land were measured using a tape. This was done to enable comparison of the area of improvements based on UAV-based approach with those measured in the field. Measurement of GCPs and image acquisition subsequently followed. Finally, interviews with farmers were conducted to ascertain their perception on the newly developed UAV-image based approach for boundary mapping and valuation.

3.1.2.1. Location of study area

The research took place in two study areas located in Mashonaland East Province, Zimbabwe. The first study area is Lot 1A Nil Desperandum (A2 farm) located in Ruwa and the second is Carolina farm (Remainder of subdivision B of Alexandra) situated in Marondera. Carolina farm has a total area of 404 hectares with 188.60 hectares dedicated for cultivation, 26.03 hectares for village sites and 171.34 for grazing area. It has 27 A1 villagised farm units. Carolina farm was chosen because it was recently mapped and landholders were issued with land permits. This arrangement allowed the researcher to compare the proposed UAV-based approach with the current methodology. On the other hand, an A2 farm was chosen as a study area because valuation of agricultural land is currently being done for A2 farms and the selected farm was recently valued. The study areas for this research are shown in Figure 9 below;

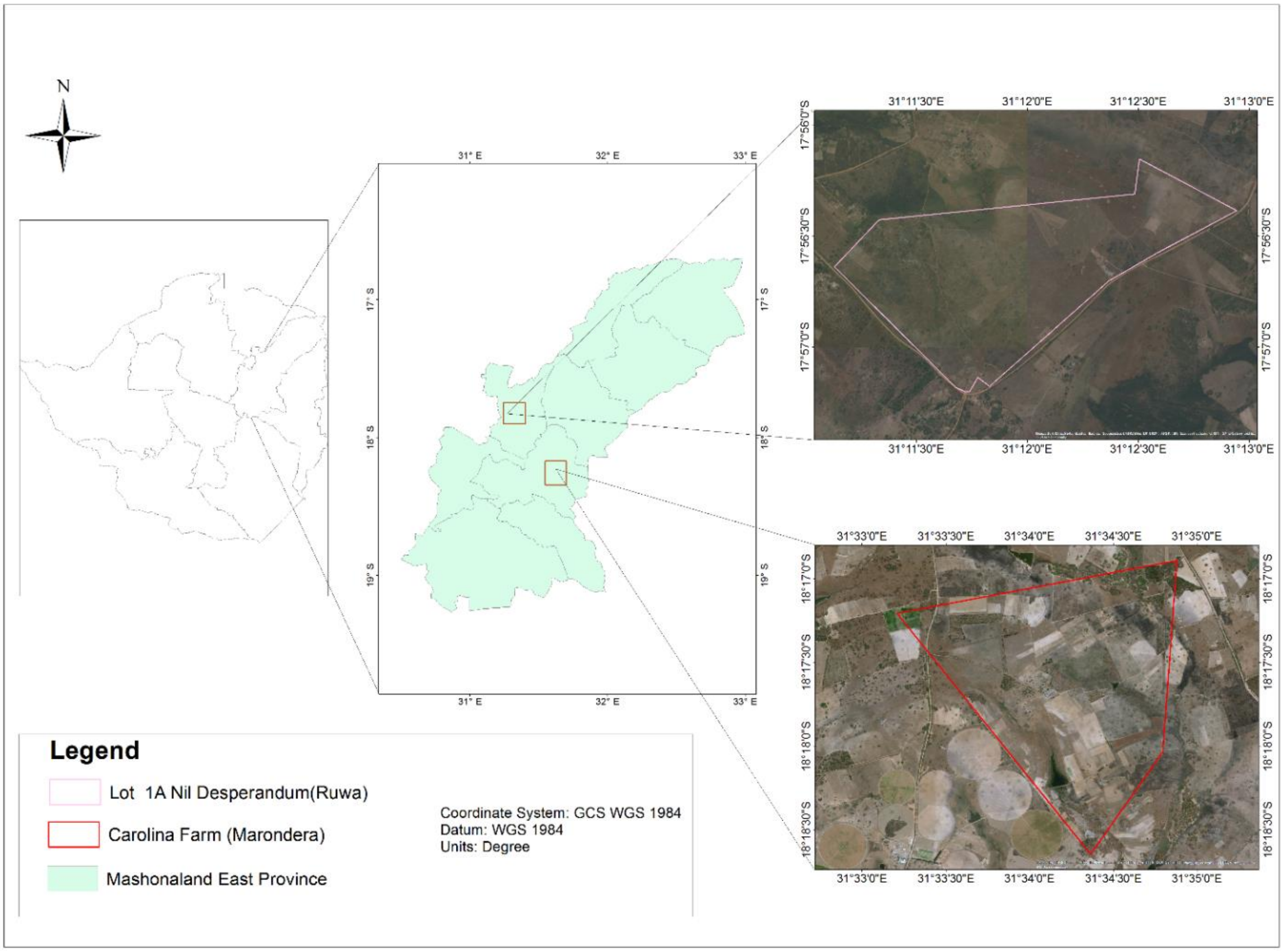


Figure 9: Case study location

3.1.2.2. Materials used during fieldwork

The fieldwork stage involved collection of primary data in the study areas. Images were acquired using a DJI Phantom 4 UAV and were subsequently processed to create boundary data. In order to achieve this, materials for the research were secured prior fieldwork. The equipment used in the collection of data are given in Table 2.

Table 2: Equipment and datasets used during fieldwork

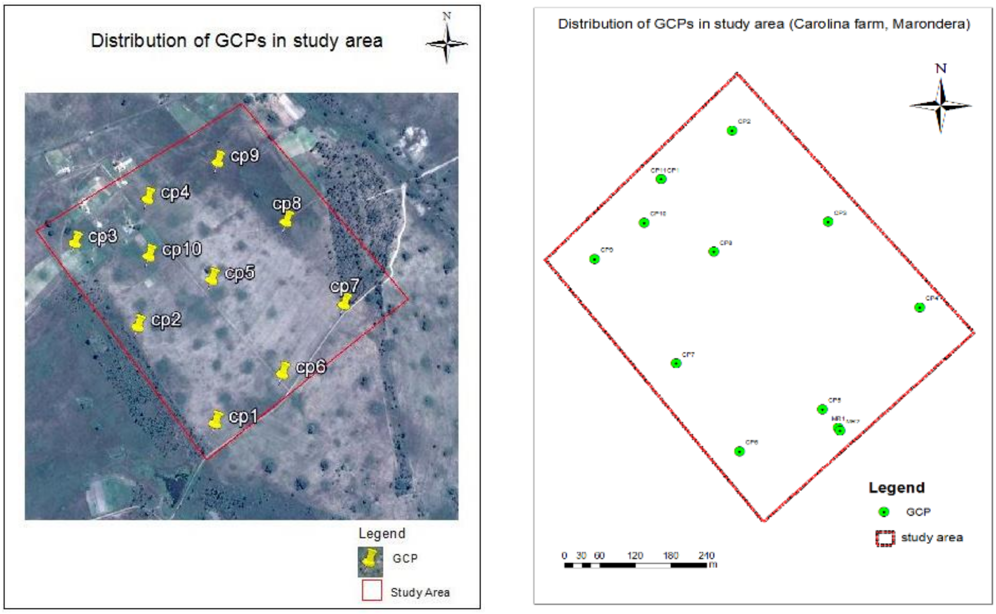
Equipment	Function	Source
GNSS RTK Base and Rover	Measuring ground control points	*Private Survey firm*
Unmanned Aerial Vehicle (DJI Phantom 4)	Image acquisition	*Private company*
Artificial Targets	Signalisation	*ITC*
Vehicle	Transport during field	*Family*
White paint	Marking boundary points	*Private Survey firm*
Measuring Tape	Making field measurements	*Private Survey firm*
Software		
Google Earth	Preliminary field reconnaissance	*https://www.google.com/earth/*
Pix4D Capture	Mission planning	*https://pix4d.com/product/pix4dcapture/*
Pix4D Mapper	Image processing	*https://pix4d.com/product/pix4dcapture/*
Surpac (Survey Package)	Survey calculations, coordinates transformation and computation of calibration parameters	*Private survey firm*
Datasets		
Coordinates of trigonometric stations	For setting the GNSS base and coordinate transformation and calibration of GNSS receiver	*Department of Surveyor General*
Diagrams/general plans/Coordinates of parent properties (farms)	For beacon reconstruction	*Department of Surveyor General*

3.1.2.3 Ground Control Points measurement

Preliminary distribution of ground control points was done using Google Earth. Ten GCPs were placed in the study area and their coordinates measured using Leica GPS900 receiver working in RTK mode (Figure 10). During this stage, attention was given to the topography of the agricultural land and locality of trigonometrical beacons. A base station was set up at a trigonometrical beacon 330/T with WGS 84 coordinates (31 ° 35' 41" S, 18 ° 19' 50" E) for Carolina Farm study area (Annex 4) and 232/S (31° 08' 57" S, 18 ° 01' 10" E) for Lot 1A Nil Desperandum in Ruwa (Annex 5) and a receiver/rover was used to measure the coordinates of ground control points. In RTK mode, the Leica GPS900 has a manufacturer's stated accuracy specification of ± 1cm + 1ppm RMS horizontal and ± 2cm + 1ppm RMS vertical.

Figure 10: Signalisation and GCP measurement

During the establishment of GCPs, effort was made to systematically distribute them in the study area in order to obtain photogrammetric products with acceptable accuracy. Figure 11 shows the distribution of GCPs initially done using Google Earth and later measured in the field. This same procedure of establishing and measuring GCPs was replicated in both study areas.



a) b)

Figure 11: Ground control points distribution in Marondera case study, (a) preliminary GCPs using Google Earth, (b) GCPs measured on the ground

3.1.2.4 Image acquisition and preliminary image processing

Pix4D Capture was used for flight planning and execution of the autonomous flights for both study areas. A DJI Phantom 4 was used for image acquisition (Figure 12) with specifications given in Table 4. A test flight was conducted to ascertain the quality of the imagery and behaviour of the unmanned aerial vehicle whilst following the pre-defined flight path. Initially a flying height of 70m was adopted in the test flight and the captured images had poor radiometric quality. Consequently a lower flying height (50m) for Carolina farm was chosen to increase the ground sampling distance thus making the signalled parcel boundaries more visible. The summary of the parameters for the two study areas are given in Table 3 below:

Table 3 Study area flight details

Item	Study area 1 (Carolina Farm)	Study area 2 (Lot 1A Nil Desperandum)
Flying height	50m	40m
Number of flights	6	4
Area mapped	28.73 ha	11.59 ha
Overlap (forward, side overlap)	80%	80%
Number of images acquired	840	955

Preliminary processing of imagery was performed during fieldwork to ascertain the quality of the acquired imagery using a trial version of Pix4D Mapper Pro. This process, proved futile as the software crashed several times. However, after several attempts, satisfactory results were of satisfactory results were obtained.

Table 4: UAV properties

Model	DJI Phantom 4
Camera model name	FC330_3.6_4000x3000
Resolution	12.4 MP
Image size (width & height)	4000*3000
Focal length	3.64 mm
Flight time	28 min

Figure 12: UAV (DJI Phantom 4) used in the research

3.1.3. Post-fieldwork

Images acquired during fieldwork were processed and analysed in order to answer research questions regarding sub-objectives 2 and 3. The processing was done using PIX4D Mapper Pro software following the photogrammetric pipeline given in Figure 13. The orthophotos generated were used in the parcel boundary digitization and extraction of quantitative land/ property characteristics relevant for valuation purposes. On the other hand, the raw images acquired during fieldwork were used to determine and assess the technical condition of improvements on agricultural land. This was followed by evaluation of the proposed approach in terms of completeness, up datedness and accuracy.

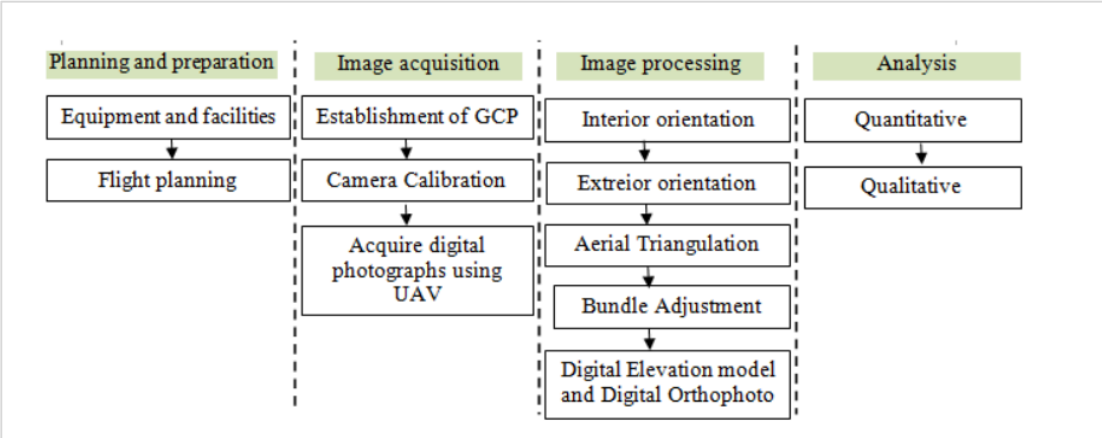


Figure 13: Adopted photogrammetric pipeline (Udin & Ahmad, 2014)

Image processing followed the photogrammetric workflow briefly described below:

Aerial Triangulation &Bundle Adjustment
During aerial triangulation, geometric relationships of overlapping images were established. The resultant blocks of relatively oriented images were absolutely oriented using the bundle adjustment. GCPs were used to establish the relationship between image block and the ground.

Dense Image matching and Digital Surface Model generation
The process of bundle block adjustment yielded point clouds of the tie points, intrinsic and extrinsic camera parameters. A densification of the point cloud followed to generate a dense point cloud using Pix4D Mapper. Through interpolation and formation of triangulated irregular networks on the dense point cloud, a Digital Surface Model (DSM) was obtained.

Orthophoto Generation
In this process, a DSM was used to ortho-rectify the produced mosaic. This ensured that the mosaic was relief and tilt displacement free. The generated orthophoto was used to create parcel boundary map and extraction of physical characteristics of improvements on agricultural land.

Quality Assessment
The orthophotos generated were quantitatively assessed for accuracy using the ground control points and check points. Quality reports for both study areas were generated by Pi4D Mapper and they gave an indication of the accuracy of the resultant orthophoto. On the other hand, qualitative assessment was done by visually identifying radiometric errors and deformations in the resultant orthophoto.

Parcel boundary digitization and extraction of physical characteristics of improvements
In this stage, parcel boundaries were extracted from the orthophoto through manual digitising. In this process, use was made of parcel boundaries marked during participatory mapping. In the extraction of spatial data for valuation purposes both raw images and orthophoto were utilised.

3.2. Assessing utility of UAV-image based approach in valuation process

One of the research question to sub-objective 2 aimed at ascertaining the possibility of imbedding the UAV-based approach in the valuation of agricultural land. To achieve this, results from the semi-structured interviews were analysed to determine the characteristics of land/property considered in the valuation processes. Quantitative and qualitative attributes of improvements were considered. In the identification of improvements on land, raw images were used to determine the general conditions (external) of improvements on land whilst the orthophoto was mainly used for quantitative measurements such as area and perimeter of improvements. In conducting quantitative analysis of the targeted (sample) improvements, ArcGIS 10.3 software was utilized to obtain dimensions of improvements from the generated orthophoto. These were compared with those measured in the field during fieldwork

Based on findings obtained during semi-structured interviews with respondents from MLRR, an evaluation was made on the usefulness of UAV-image based approach for valuation of agricultural land in Zimbabwe.

3.3. Research Challenges

The main challenge encountered in this study was the bureaucracy involved in getting approval to conduct research. Given the fact that the research involved government departments (MLRR), permission had to be sought prior commencing the study. Frequent visits were made to the offices of MLRR in order to obtain the approval. In addition, the use of UAVs in research purposes, especially in land matters, is still in infancy stage. Consequently, permission to use a UAV in Zimbabwe had to be sought through the Civil Aviation Authority of Zimbabwe and Ministry of Defence. Furthermore, due to ethical issues, permission to conduct the research in the targeted study areas was sought from Provincial Administrator, Provincial Chief Land Officer, the village head and farmer(s). This resulted in long travelling distances as the researcher had to travel to their respective offices, in the case of Provincial Administrator and Provincial Chief Land Officer.

Another challenge was the delay in sourcing a GNSS receiver and UAV .This was caused by delays in getting approval to conduct the research .The date that the researcher and firms providing of GNSS receiver and UAV had agreed to use the equipment passed before permission could be granted. Consequently the period taken to conduct the research became unusually long. In order to surmount this challenge, another private survey firm was engaged to supply a GNSS receiver.

Furthermore, acquisition of images using UAV posed challenges during fieldwork due to lack of familiarity of the UAV pilot to acquisition of images for photogrammetric processes. In addition, technical problems of short span of batteries of UAV impeded acquisition of imagery for a large area.

Concluding Remarks

UAVs have become ubiquitous in the field of geosciences and have been embraced as an alternative data acquisition tool in various domains. In this chapter, a methodology for acquiring parcel boundary data and physical characteristics of improvements on land was designed and implemented. This was executed in three sequential stages namely pre-fieldwork, fieldwork and post-fieldwork. Preparation for data acquisition was completed during the pre-fieldwork stage, followed by fieldwork and analysis of data collected in post-fieldwork stage. During the fieldwork stage, permission was sought from MLRR and related government departments to conduct the research. Subsequently semi-structured interviews were conducted with respondents from MLRR and farmers (landholders), and a pilot study was conducted.

UAV images were acquired for both study areas and processed to obtain orthophotos used in parcel boundary mapping and extraction of physical characteristics of improvements for valuation purposes. As expected, the ideal way to conduct participatory mapping is to use an orthophoto as a medium through which landholders identify their parcel boundaries. However in the study area in Marondera there were no visible features on the ground to enable parcel boundary delineation on the orthophoto. As a result, boundaries were physically marked on the ground prior image acquisition. The marked parcel boundaries on the ground identified on the orthophoto and digitized to generate the land parcel boundaries. This approach proved to be a useful way in unambiguously identifying parcel boundaries on the generated orthophoto. Furthermore, usefulness of the UAV-based approach for valuation of agricultural land was assessed, guided by the findings from the semi-structured interviews with respondents from MLRR and farmers.

4. RESULTS AND DISCUSSION

This chapter presents the results obtained from the collected, processed and analysed data. It starts by highlighting the legal and technical situation regarding cadastral mapping and valuation of agricultural land in Zimbabwe. A presentation of the results from the two study areas is given, followed by a discussion on the utility of UAVs in cadastral mapping and valuation of agricultural land in Zimbabwe.

4.1. Existing situation regarding Cadastral Mapping and Valuation of Agricultural Land and usage of UAVs

In order to answer research questions to sub-objectives 2 and 3, a review of legal and technical situation regarding usage of UAVs in cadastral mapping and valuation of agricultural land in Zimbabwe was done.

4.1.1. Legal situation

Legal documents regulating cadastral surveying, usage of UAVs and valuation of agricultural land were gathered and reviewed. These are presented as follows:

Cadastral surveying

Land Survey Act (Chapter 20:12) and Land Survey (General) Regulations of 1979

The Land Survey Act (Chapter 20:12) regulates surveys conducted to effect registration in the Deeds Registry, re-determination of the position of a curvilinear boundary or any beacon defining a piece of land registered in the Deeds Registry. In the case of agricultural land, this act is most applicable to cadastral surveying of A2 farm model and other agricultural land held under long leasehold or freehold tenure system. In this research, A1 farms are considered and they are not registered in the Deed Registry but rather recorded in a land information system under the Ministry of Lands and Rural Resettlement. Thus, this principal act does not explicitly regulate the cadastral surveying of A1 farms. However, given that A1 farms were derived by sub-dividing former large commercial farm (e.g. Carolina Farm, see Annex 1), it can be noted that the parent property is recorded in the Deeds Registry. Thus, implicitly the Land Survey Act (20:12) does have an effect if one considers the boundary of the parent property from which the A1 farm units are derived.

Regarding technical issues of cadastral surveying such as accuracy of surveys and form in which survey diagrams are prepared or fieldwork procedure reference should be made to the Land Survey (General) Regulations of 1973. However, these technical requirements are implicitly applicable to A1 farm since they are not registered in the Deeds Registry. It is not clear in the Land Survey (General) Regulations with regards to accuracy required when mapping A1 farms. The survey classes given in the Land Survey (General) Regulations (see Annex 13) are fundamentally based on traverse distances and photogrammetric techniques are placed in class D. Given that these regulations were enacted in era where methods of surveying were primarily ground-based, their applicability in photogrammetric survey where photo-control is established using GNSS receivers is not clear. Consequently, the required accuracy for mapping A1 farms in the available legal documents could not be ascertained with certainty.

Valuation of agricultural land

The FTLRP conducted in 2000 changed the agrarian structure and it resulted in two models namely A1 and A2 resettlement models. Consequently, there was change in tenure system to accommodate these two resettlement models which was previously predominantly freehold prior land redistribution. This resulted in the introduction of the 99-year leases for A2 farm beneficiaries and permits for A1 beneficiaries. The researcher observed that after FTLRP, the land belongs to the state and majority of valuations being done for agricultural land are for compensation purposes to the former farmers. It is thus unsurprising to see the heavy presence of the Ministry of Land and Rural Resettlement in virtually all valuation activities of agricultural land in Zimbabwe where compensation to former owners is involved.

In order to understand the legal situation regarding valuation of agricultural land the following acts were reviewed:

Land Acquisition Act (Chapter 20:10)
In the Constitution of Zimbabwe Amendment (No.20) Act 2013 Chapter 16 and Section 72 make provisions for compulsory acquisition of agricultural land for public purposes such as land resettlement. The procedure for alienating the acquired land and valuation for compensation purposes is given by the Land Acquisition Act (Chapter 20:10) in Section 29C. A review of this act revealed that compensation is done for improvements of land only. Parts (I) and (II) of the act details the elements to be considered when conducting valuation .In Part (I), the primary valuation techniques or approach to be used is Depreciated Replacement Cost (DRC). However, more often than not valuation officers use a mixture of techniques to arrive at a better estimate.

Meanwhile, the researcher observed that valuation of agricultural land by MLLR is currently being done for compensation purposes, majority of which are presently A2 farms. This process is guided by the Land Acquisition Act (20:10) and is conducted by Ministry of Lands and Rural Resettlement.

Valuers Act (Chapter 27:18)
This act provides for the registration of valuers and regulation of their practice in Zimbabwe. It is important to observe that valuation in Zimbabwe can only be performed by a registered valuer. As far as the procedure or manner of conducting valuation of agricultural land is concerned, no mention is made in this act.

Usage of UAVs

Regulations for Remotely Piloted Aircraft/ Unmanned Aerial Vehicle Systems (UAVs) Part 180 (draft regulations) and Civil Aviation Act (Chapter 13:16)
The use of UAVs is permitted to registered UAVs only and their use is implicitly regulated by the Civil Aviation Act (Chapter 13:16). Information gathered from Part 2 and 3 of the DRAFT Regulations for Remotely Piloted Aircraft/ Unmanned Aerial Vehicle Systems (UAVs) reveals that the operation of an unmanned aerial vehicle in Zimbabwe requires the operator to first register the UAV with Zimbabwe Civil Aviation Authority of Zimbabwe (CAAZ) and obtain a letter of approval. Furthermore, an operator of UAV should be in possession of a valid remote pilot licence. However, these draft regulations are not yet official and they are not applicable at the moment.

Currently, the procedure to pursue when using a UAV in Zimbabwe is still unclear. One should register the UAV with CAAZ and get permission to fly through formal application. In the formal application, purpose of the flight, location and technical details of the UAV intended to be used should be availed to Civil Aviation Authority of Zimbabwe. Depending on the discretion of the civil authority (CAAZ) and Ministry of Defence, the outcome is communicated to the applicant.

4.1.2. Technical situation

Cadastral surveying
Determination of parcel boundaries of A1 farms have been done in the past using various surveying methods such as taping, pacing, use of aerial orthophotos and more recently handheld GPS. This process is carried out by the mapping section of the MLRR and is the prerequisite for the preparation of a layout by the Surveyor General Department to facilitate the issuance of permits to A1 beneficiaries.

Recently, handheld GPS (Garmin H72) have been used to delineate parcel boundaries on A1 farms. This process of boundary mapping starts by adjudication process and is mainly carried out systematically in the targeted area. Through the assistance of the landholders, boundaries are measured by the mapping officers using handhold GPS. This surveying exercise involves marking a waypoint at each corner of the parcel boundary in WGS84 coordinate system. These waypoints are marked ingeniously to simplify the process of generating polygons to depict the land parcels. Once the waypoints of the parcel boundaries have been captured in the field, they are then downloaded and polygons are generated using ArcGIS software in office. The process of creating the permit maps for A1 beneficiaries involves scanning topographic maps covering the target parcel and overlaying it with the generated polygons depicting the parcel projected on UTM Zone 36 on a WGS84 datum. The scanned topographic map serves as a backdrop to show topographic features (see Annex 2). Subsequently, attributes such as parcel area and unique parcel ID number are generated and appended to the land parcel.

Valuation

Valuation of agricultural land is currently being conducted for two fundamental purposes. The predominant purpose is for compensation to former land owners. The other reason for conducting valuation is for rental determination purposes wherein beneficiaries of land with improvements are expected to pay rentals for their use.

The process of valuation starts by identifying a target farm(s) and conducting field inspection of farm improvements. This involves identification and ascribing a description to all improvements found on the target farm. Attention is given to the technical condition of the improvements on the valuation date. Subsequently a preliminary valuation report is prepared by the valuation officer and presented to the Compensation Committee (see section 29A of Land Acquisition Act) for approval. In essence, the Compensation Committee "determines compensation payable in respect of the acquisition of agricultural land required for resettlement purposes". Once the preliminary estimate of compensation is approved, an invitation is made to persons entitled to compensation in terms of Section 16 of the Land Acquisition Act (Chapter 20:10) for a dialogue and reach a consensus. It is important to note that even though an estimate of compensation is provided by the Compensation Committee, provisions are made in the same act for appeals in instances where disputes arise with parties involved.

In the estimation of the value of improvements, Depreciated Replacement Cost (DRC) is primarily used. However, in reality various approaches are often utilised to arrive at a better estimate. When using DRC method, the condition of improvements is categorised and depreciation rates are assigned to each group. Based on these rates, the replacement cost of an improvement is depreciated to obtain the depreciated replacement cost at the valuation date. Thus, the valuation procedure is somewhat highly dependent on the judgement of the valuation officer who is assessing the technical condition improvements.

4.2. Design Results of UAV-based approach for boundary data acquisition and valuation

A UAV-based approach for boundary mapping and valuation of agricultural land was developed through reviewing similar workflows and adapting them to the context of Zimbabwe. The developed approach (Figure 14) has four segments described as follows,

Field Preparation

Field preparation involves gathering materials required to conduct the project and ensuring that legal requirements regarding usage of UAVs are satisfied. In addition, flight planning is done during this stage and technical details of the project such as required accuracy and purpose are determined

Community Notification and Mobilisation

The developed UAV-based boundary mapping and valuation approach involves participatory mapping by landholders. Therefore landholders have to be informed of the mapping process prior to conducting the process. This gives the landholders time to mobilise themselves and prepare for the boundary mapping activity

Image Acquisition and Participatory Mapping

In this stage, GCPs are established and images subsequently acquired by a UAV. Depending on the topography, signalisation of the parcel boundaries may be required in instances where there are no substantial visible features on the ground. The signalisation process is done through participatory mapping of landholders. However, when there are enough distinct features on the ground to enable parcel boundary delineation on an orthophoto the signalisation process can be skipped. Thus, the process of signalisation is dependent of the physical characteristics of the area being mapped.

Image Processing and Output Generation

This stage entails processing of the acquired images and subsequently generating land parcel boundary map through digitisation of parcel boundaries as identified by landholders. The overall process involved in image processing is given is section 3.3.1. Additionally, the generated orthophoto and images acquired are used in the identification of improvements to support valuation activities.

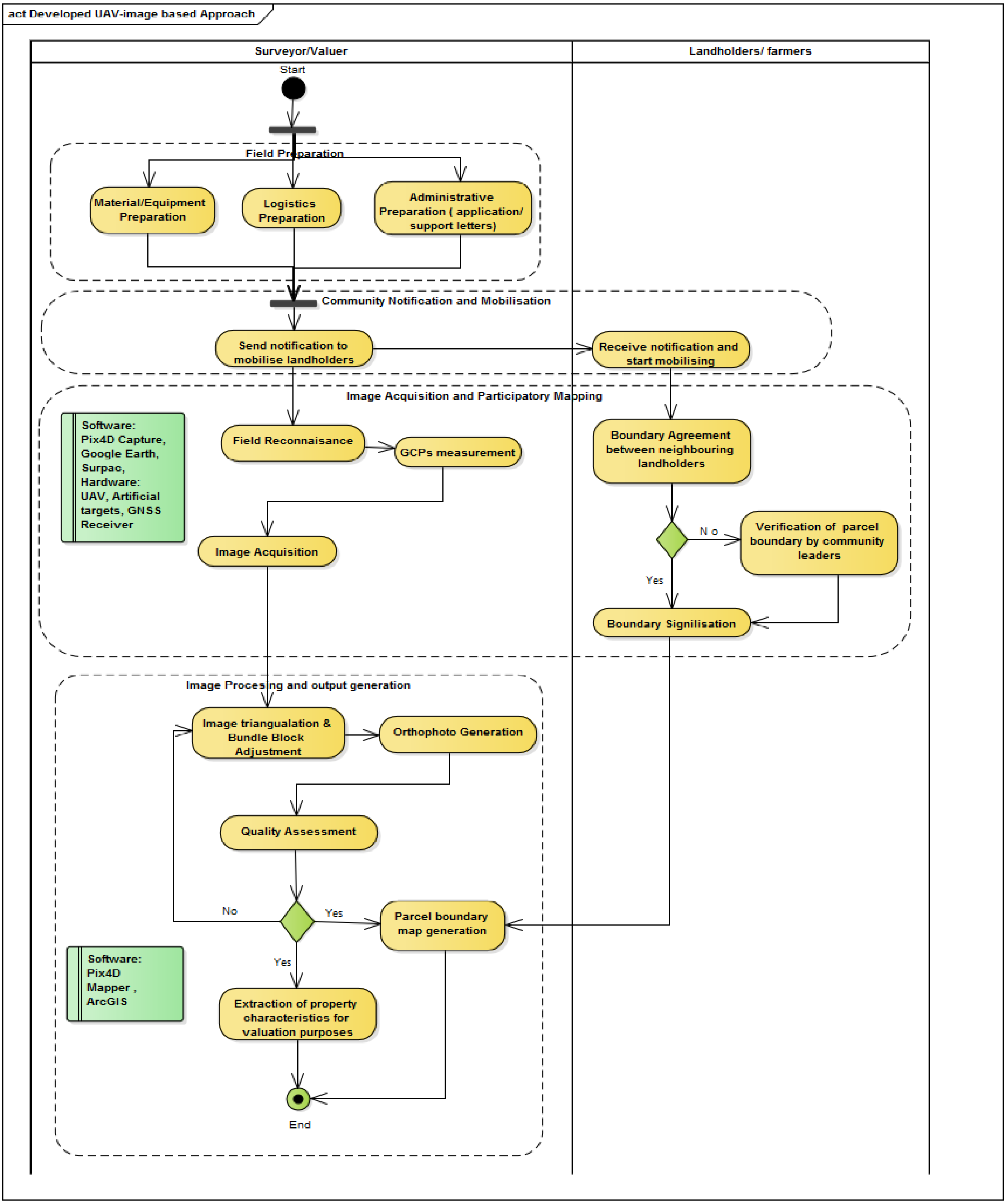


Figure 14: Flowchart of the developed UAV-based boundary mapping and valuation approach

4.3. Pilot Test Results

Two study areas were selected in this research to ascertain the utility of images acquired using UAVs in boundary mapping and valuation of agricultural land, more specifically A1 farms. Images were acquired (Figure 15) and processed using Pix4DMapper Pro to generate orthophotos (Annex 6 & 7) used in parcel boundary mapping and quantitative analysis of improvements on land to support valuation activities

a) b)

Figure 15: Sample of images captured with UAV, (a) study area in Marondera, (b) study area in Ruwa

It can be observed in Figure 15 that the UAV produced images with spatial resolution and improvements on land can be identified.

4.3.1. Boundary mapping using UAVs

Creation of parcel boundary map using the new UAV-based approach

The orthophoto generated using Pix4D Mapper was digitised in ArcGIS 10.3 and three land parcels (agricultural fields) were mapped (figure 16). This was achieved through the developed UAV-image based approach given in Figure 14. The process of generating land parcel boundary data involved identifying the marked parcel boundaries on the orthophoto and connecting them to produce a 2D representation of the land parcel. The centre point of the signalised parcel boundary marks were used in the digitization process.

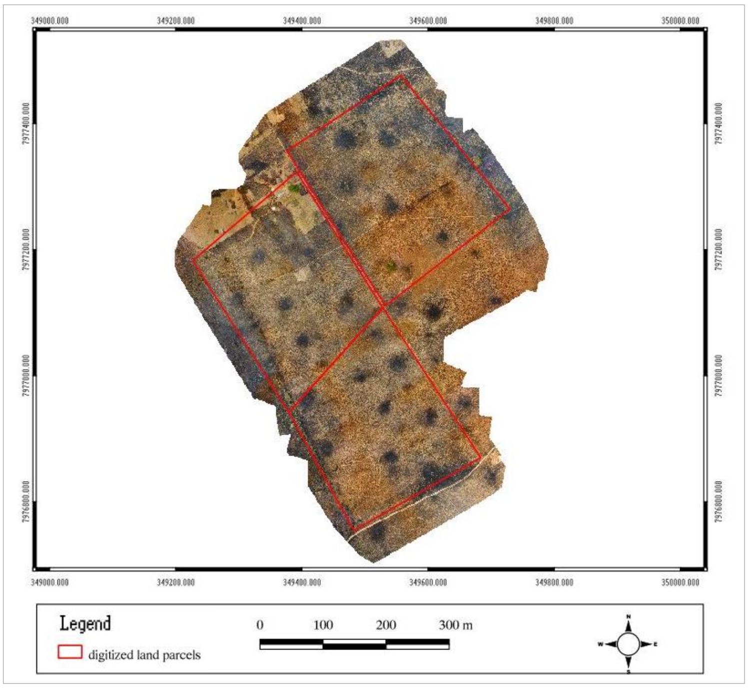


Figure 16: Digitized parcel boundaries from UAV-imaged based approach

4.3.2. Extraction of physical attributes using UAVs to support Valuation activities

High resolution images were acquired and used in the identification and determination of the exterior technical condition of improvements on land. Sample of the acquired images using a UAV are shown in Figure 12.

Figure 12: Sample images captured with UAV

In valuation processes, identification and determination of physical characteristics of improvements is imperative. Some of the physical characteristics obtainable from UAV images and orthophoto are summarised in Table 5.

Table 5: Physical characteristics of improvements identifiable on UAV images and orthophotos

Type of data	Area	Roofing material	Technical Condition	Building and material elements
Orthophoto	Yes	Yes	Yes/No	Yes/No
Raw images	No	Yes	Yes	Yes

From Table 5, it can be noted that an orthophoto and raw images obtained from UAVs are useful in determining some of the physical characteristics of improvements on land. High information content in UAV images can be utilised in qualitative analysis of improvements. Depending on the orientation of the camera (inclined or oblique) during image acquisition, information on the technical condition of building's facades, for instance, can be obtained. Such information enables valuation officers to remotely evaluate technical conditions of an improvement with a high degree of accuracy. Besides qualitative information on improvements, quantitative information such as area and perimeter can be obtained from an orthophoto. Dimensions of improvements are often measured in the field using tapes and this can equally be done in the office using an orthophoto (Table 5) thus reducing field visits for physical inspection of improvements.

UAV images can also be used to compare the state of improvements at the valuation date with imagery from other sources such as Google Earth. Such comparison enable the valuation officers to identify changes in improvements and incorporate them in the valuation process. In Figure 17, changes in selected improvements can be observed using Google Earth from year 2000 to 2010. However, due to low resolution of Google Earth, technical conditions of the improvements cannot be ascertained with high degree of accuracy. This inadequacy in terms of spatial resolution can be overcome by using high resolution imagery acquired using UAVs.

Figure 17: Overview of the changes in the selected improvements from 2000-2016

4.3 Evaluation of the developed UAV-based approach for boundary mapping and valuation

The developed UAV-based approach was evaluated to answer sub-objective 3 of this research. In the evaluation of the developed approach, elements of up-to-datedness, accuracy and completeness were used as elements of evaluation. The selection of the elements of evaluation was based on findings from the semi-structured interviews conducted with MLRR taking into consideration the problem definition of the research. Enemark et al., (2014) identified fit-for-purpose elements and these were adjusted and adopted in this research as shown in Figure 18.

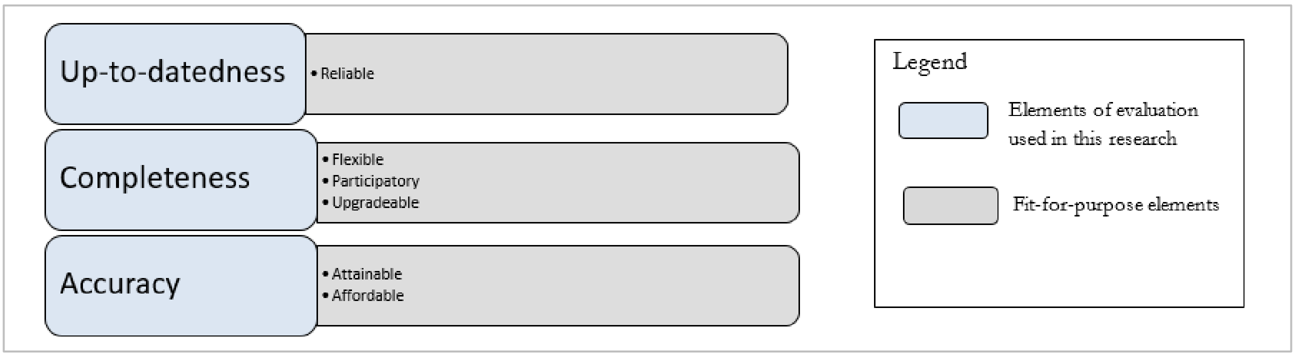


Figure 18: Elements of evaluation

4.3.1. Up-to-datedness

The extent to which the developed UAV-based approach gives up-to-date boundary data was ascertained using the interview transcripts collected from MLRR officials. Five respondents provided answers to questions regarding the up-to-datedness of the data collected using current approach and this was compared with the UAV-based approach. Findings from the conducted semi-structured interviews indicate that the confidence is high (3 out of 4 respondents) regarding the products derived from UAV-based approach in terms of up-to-datedness.

4.3.2. Completeness

Evaluation of completeness was done using findings from the semi-structured interviews with MLRR officials and field measurements. Findings from the research revealed that boundary data collection on a farm with 10 to 15 A1 farm units using the handheld GPS is 2 to 3 days. In contrast, using the UAV-based approach 3 land parcels were mapped within 1 day taking into consideration the time taken to process the acquired imagery. Even though it is difficult to quantify the exact time required to collect boundary data using handheld GPS, as evidenced by varying responses from mapping officials from MLRR, it is evident that more time is required to produce a parcel boundary map as compared to the UAV-based approach. The fact that the collected data using UAV-based approach offers already a graphical (true) background of the target parcel removes the need of scanning topographical maps and overlaying them with the polygons generated using waypoints captured using handheld GPS to produce parcel map (Annex 2). Regarding improvements on land, the UAV-based approach gives an aerial view of the target land/farm thus enabling the identification of improvements.

4.3.3. Accuracy

Quantitative Assessment of generated orthophotos

After image processing, quality reports were generated using Pix4D Mapper Pro for both study areas. A summary of the results are presented in Table 5. Root Mean Square Error (RMSE) of the check points was used to evaluate the overall accuracy of the produced orthophoto. The rationale for using check points to assess the quality of the orthophoto is based on the fact that they're independent of the processing and calibration of the model thus providing a way to assess the accuracy of the project.

Table 6: Summary of accuracy reports generated by Pix4D Mapper Pro

Characteristics	GCP	Study area	
		Lot 1A Nil Desperandum (Ruwa)	Carolina farm (Marondera)
Mean GSD (m)		0.016	0.020
Check Points	RMSE X (m)	0.012	0.018
	RMSE Y (m)	0.021	0.070
	RMSE XY(m)	0.024	0.072
Control Points	RMSE X (m)	0.014	0.020
	RMSE Y (m)	0.009	0.032
	RMSE XY(m)	0.017	0.038

The generated orthophotos have high planimetric accuracy of 1.7cm and 3.8cm for the two study areas. This level of accuracy surpasses the existing approach (handheld GPs) and it satisfies the needs of the project. Given the accuracy of the generated orthophotos, it is possible to perform quantitative analysis of improvements on land such as measuring area or lengths.

Evaluation of accuracy was also done through comparison of the area of the parcels generated from UAV images and handheld GPS. Unsurprisingly, large deviations were obtained due to differences in accuracy of the tools used to acquire boundary data. In this case, a comparison was done to ascertain the direction of this difference. The results of the comparison (Table 7) shows that the UAV-image based approach used in generating three parcels gives area greater than those produced using handheld GPS except parcel 09. The large difference can also be attributed to the slight differences in the boundary position marked during the UAV based approach and those initially determined using handheld

Table 7: Comparison of UAV image based approach and the conventional approach (Handheld GPS)

Parcel ID	Area using UAV-image based approach (ha)	Area based on Handheld GPS (ha)	Difference in Area (ha)
06	5.80	5.42	0.38
07	6.57	6.32	0.25
09	5.55	5.63	0.08

Given the high accuracy of coordinates obtained using UAVs, it is possible to resurvey parcel boundaries with high degree of accuracy for instances in cases of boundary disputes. Acquisition of boundary data using the UAV-image based approach give accurate results comparable to ground based methods.

Regarding the accuracy of UAV-based approach for supporting valuation activities, evaluation was done through comparison of areas of selected improvements (Figure 19) obtained using UAV-image based approach to those obtained using measuring tape in the field. The comparison revealed that areas of the selected improvements generated using an orthophoto are comparable to those measured in the field using a measuring tape. However a huge difference of 8.744m^2 is observed for structure 3. This can be attributed to the fact that roof area was measured on the orthophoto instead of the outside walls of the structure.

Table 8: Physical characteristics of selected improvements based on raw images and generated orthophoto

Item	Improvement	Unit	Area using orthophoto (m2)	Area using tape (m2)	Difference in Area (m2)	Roofing material	Wall/ Building material
1	Tobacco Barn(with furnaces)	1	5584.114	N/A	N/A	Corrugated iron sheet	Common Bricks and concrete
2	Structure 1	1	524.948	525.00	0.052	Asbestos sheets (but destroyed)	Common bricks
3	Structure 2	1	43.971	44.00	0.029	None	Common bricks
4	Structure 3 (workers living quarters)	1	190.994	182.25	8.744	Asbestos sheets	Common bricks

In Table 8, roofing and building material were determined from raw UAV images and the generated orthophoto. The UAV-based approach yields satisfactory results of areas when improvements have simple shape and roof. This is shown for Structure 1 and 2 in Table 8.

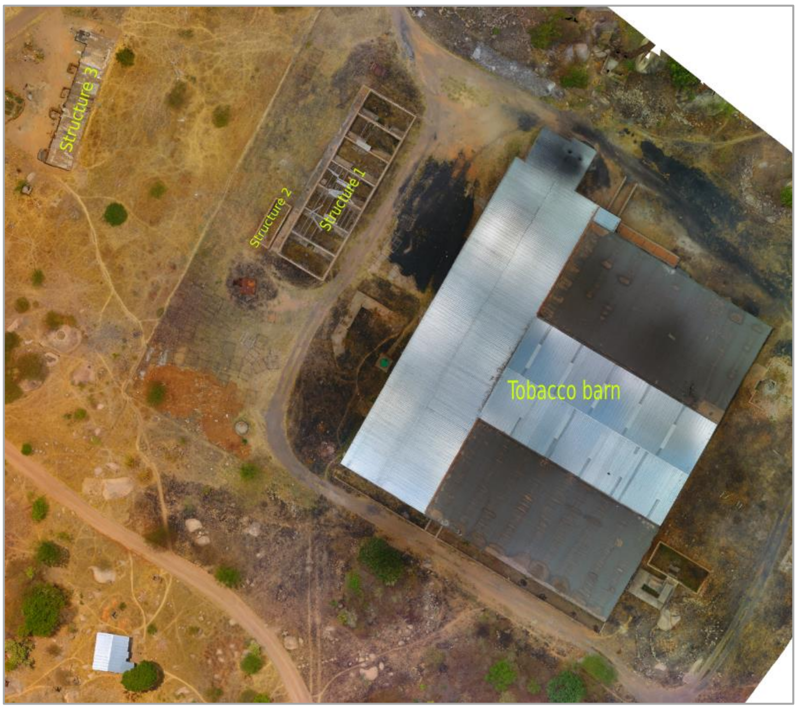


Figure 19: Sample of infrastructure measured in the field and compared with the UAV-based approach

The compliance of the developed UAV-based approach for boundary mapping and valuation of agricultural land to the evaluation elements is summarised in Table 9

Table 9: Developed UAV-based approach compliance to adopted evaluation elements

Element of evaluation	Result compliance
Up-to-datedness	***Yes***. *The UAV-derived images give a detailed up-to-date representation of the target land and its improvements for both boundary mapping and valuation processes*
Completeness	***Yes for boundary mapping***. *The UAV-based approach gives an aerial view of the land and improvements. The aerial view enables land parcel boundaries (if visible enough) to be identified on an orthophoto and mapped.* ***Partially for valuation purposes*** *In the case of valuation activities, UAV-based approach enables improvements on land to be identified and described However, some information such as interiors of improvements cannot be adequately ascertained using UAV-derived products only*
Accuracy	***Yes*** *The UAV-based approach produces images with high radiometric and spatial resolution. The GSD of 1.6cm and 2.02cm for the produced orthophotos allows identification of both parcel boundaries and improvements on land. In addition, the produced orthophotos have accuracies of 1.7cm and 3.8 cm which enable parcel boundaries and improvements to be determined with high accuracy*

Concluding Remarks

In this chapter, the results obtained in this study are presented and discussed. Images collected during fieldwork were processed to generate orthophotos. Parcel boundaries were created from the generated orthophotos and a sample of improvements on land were identified. The developed UAV-based approach was evaluated in terms of completeness, accuracy and up-to-datedness. The evaluation revealed that UAVs offer a flexible way of acquiring accurate and up-to-date boundary data and extraction of some of the characteristics of improvements on land used in valuation activities.

5. CONCLUSIONS AND RECOMMENDATIONS

In the preceding chapters, a UAV-based approach for conducting boundary mapping and valuation of agricultural land was developed, applied and evaluated in terms of completeness, accuracy and up-to-datedness. This was achieved through three sequential stages namely pre-fieldwork, fieldwork and post-fieldwork. During pre-fieldwork, preparation for data collection was done and it involved the design of the UAV-imaged based approach. The designed approach was tested during fieldwork and the collected data processed and analysed during post-fieldwork. Thus, based on these results conclusions are drawn and presented in this chapter. Finally recommendations for future research are presented.

5.1. Conclusion

Main Objective: *To assess whether UAVs can be used in the process of boundary mapping and valuation of agricultural land, particularly A1 farms whilst maintaining requirements of completeness, accuracy and up-to-datedness.*
Results obtained in this research were evaluated in terms of completeness, accuracy and up-to-datedness and were presented in section 4.3. Based on the findings and the expectations of MLRR, UAVs can be used for boundary mapping of A1 farms. Regarding the use of UAVs to support valuation activities, findings from the study revealed that the technology is not yet applicable in Zimbabwe.

Sub-objective 1*: To review current boundary mapping and valuation techniques regarding agricultural land particularly A1 farms and usage of UAVs in Zimbabwe*

Research Question 1.1*: What is the current legal framework, technologies and characteristics of the existing approach in which A1 farms are mapped and valued?*
In order to answer this research question, a review of legal, institutional and technical aspects of the existing approaches was done. The examination of the existing legal situation revealed that the boundary mapping and valuation of A1 farms is not explicitly prescribed in the policies and laws. The prevailing Land Survey Act (20:12) and its allied Land Survey (General) Regulations apply to cadastral mapping of land parcels for the purpose of registration in the Deeds Registry. However, A1 farms are not registered in the Deeds Registry but rather maintained in a database at the Ministry of Lands and Rural Resettlement. Such inadequacy in prescribed technical approach regarding cadastral mapping of A1 farms merited the investigation of UAVs in obtaining parcel boundary data.

Regarding valuation, the underlying legislation is the Land Acquisition Act (20:10) which prescribes the manner in which the process should be executed. In this Act, the preferred valuation method is the Depreciated Replacement Cost and valuation officers physically inspect improvements on land on the target farm. A preliminary valuation report is prepared and presented to the Compensation Committee for approval. The valuation process of improvements is currently being done for all former commercial farms. Technically, A1 farms are not explicitly being valued but the parent farm from which they were derived through subdivision process.

Research Question 1.2*: What are the policies and regulations regarding UAVs usage?*

In order to determine the usage of UAVs in Zimbabwe, a review of the regulations regarding their use was done. Findings from the existing legislation revealed that UAVs can be used in Zimbabwe only after registration and obtaining flight permission from the aviation authority (CAAZ). Based on the findings from the obtained DRAFT regulations, and discussions with CAAZ authorities, the use of UAVs is permitted only upon registration of the UAV and issuance of Operators Licence. However, official regulations governing usage of UAVs are yet to be published and the procedure to be followed in their usage is still unclear at the moment.

Sub-objective 2*: To develop a UAV-image based approach for boundary mapping and valuation of agricultural land particularly A1 farms in Zimbabwe*

Research Question 2.1*: What does the new UAV based approach contain and what steps are involved in applying it?*
The UAV-based approach for boundary and mapping was designed through adapting generic workflows from previous studies. Expectations from the existing approaches in boundary mapping and valuation were also included in the design. The workflow was demonstrated in two study areas. The demonstration involved participatory mapping of landholders and image acquisition. Generated orthophos were used to digitize three land parcels for the case study in Marondera (Annex 11) and for measuring areas of improvements (Figure 19). In identifying and ascertaining technical conditions of the improvements for valuation purposes raw images were also utilised. The designed UAV-image based approach for boundary mapping and valuation of agricultural land is presented in section 4.2.

Research Question 2.2*: Can UAVs be imbedded in the existing approach for boundary mapping and valuation?*
In order to assess the possibility of embedding the new UAV-based approach, perceptions of the authorities involved in boundary mapping and valuation activities of agricultural land were gathered through semi-structured interviews. Findings from the conducted interviews revealed that the possibility of imbedding UAVs in the existing approaches is moderate. Given that the UAV technology is still new, mixed reactions were obtained from officials involved. Further researches are required where perceptions of other institutions such as the DSG are incorporated in the analysis.

Sub-objective 3*: To evaluate the developed new approach in Zimbabwe*

Research Question 3.1*: What are the benefits offered by the new UAV-image based approach in terms of up-to-datedness, completeness and accuracy?*
The newly developed approach produces accurate results as evidenced by the accuracy of the orthophotos generated in this study. When compared with the current approach (use of handheld GPS), the proposed UAV-imaged based approach gives results in the range of centimetres. Such high accurate results enables relocation of boundaries should need arise. Furthermore, the study revealed that UAV-image based approach gives a complete and up-to-date results representation of a targeted agricultural land parcel and associated improvements.

Given high information contained in images acquired using UAVs, the study revealed that physical characteristics of improvements can be obtained from the images. In addition, the generated orthophoto can be used to identify and determine these improvements on land. Subsequently measurements such as area can be done for improvements using orthophoto and technical conditions assessed using raw images. However, this research revealed that images are limited when interior technical conditions of improvements are required. In such instances an inspection of the improvement is imperative and this might mean duplication of effort.

Research Question 3.2*.: What are the recommendations for future use of the proposed approach in Zimbabwe?*
The developed UAV-based approach was applied to few land parcels and further investigations are required to determine how the approach works when more land parcels (e.g. several farms) are considered. Given that the acquired images and generated orthophotos have high information content useful in both boundary valuation processes as evidenced by results obtained in this study, further investigations are required to ascertain how the approach can be applied to more than single farm in a systematic or semi-systematic approach.

5.2. Recommendations for further research

This study explored the feasibility of applying a UAV-based boundary mapping and valuation approach for agricultural land, primarily focusing on A1 farms. Using the developed approach, three A1 land parcels were mapped and improvements on a single A2 farm were identified. Based on the findings from this research, further investigations are required in the following areas:

Approach improvement

The main rationale behind adopting innovative land tools is to enable registration of land at a minimum cost, in the shortest time possible whilst maintaining the requirements of accuracy. Therefore there is need for further investigation on the use of the developed UAV-based approach to map more than a single farm in a single flight and conduct a cost comparison of boundary mapping with conventional photogrammetry and satellite imagery.

Regulatory issues

The use of UAVs in Zimbabwe is still in its infancy and it falls outside the existing Survey Regulations. Therefore, further investigation is required on how the UAV technology can be incorporated into the existing suite of acquisition tools regulated by the Land Survey Regulations.

Institutional issues

There is need to conduct a thorough user needs assessment of the institutions involved in the entire processes of mapping and valuation. Therefore guidelines on the use of a UAV-based approach for boundary mapping and valuation of agricultural land should be developed in order to have reliable and homogenous results.

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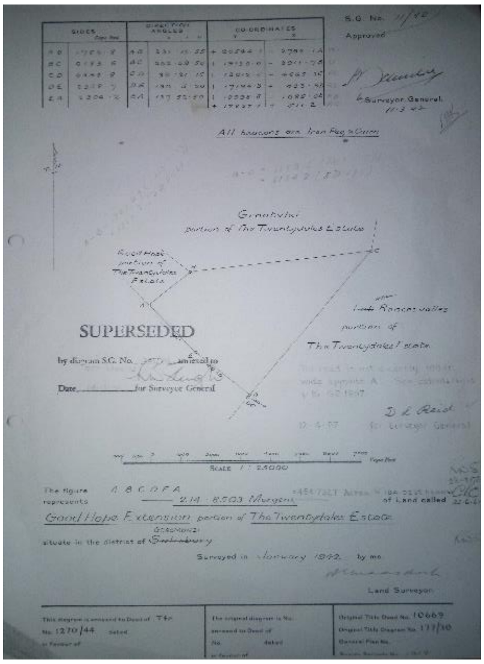
ANNEX 1

Approval letters and Survey diagrams for study areas



All correspondences should be addressed to: The Secretary
TELEPHONE: 797325 and 706286

FAX: 708315

Ministry of Lands and Rural Resettlement
Private Bag 7779
Causeway, Harare

Ref: P/ALI F.
E. C. No. STUDENT

13 October 2016

Mr. Freeman Ali
4 Bayswater Road
Highlands
Harare

REQUEST TO CARRYOUT A RESEARCH IN THE MINISTRY OF LANDS AND RURAL RESETTLEMENT: MR. FREEMAN ALI: STUDENT: MASTER OF SCIENCE DEGREE IN LAND ADMINISTRATION: FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION: UNIVERSITY OF TWENTE

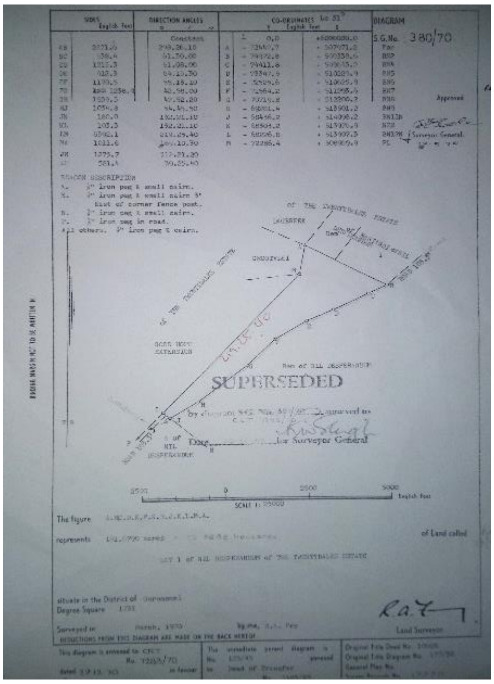
Reference is made to the above subject matter.

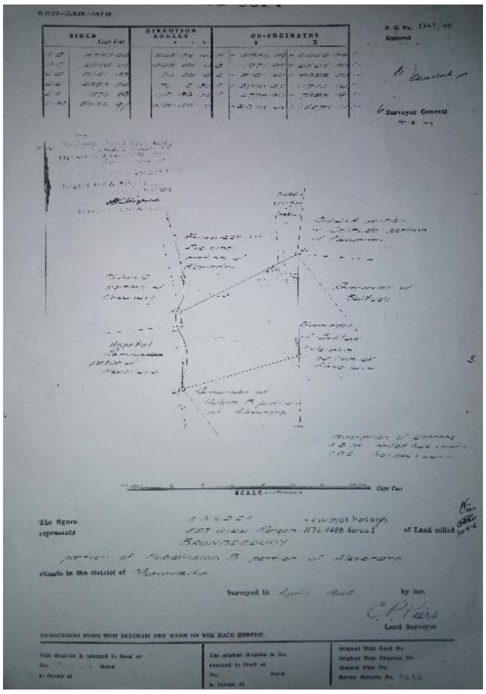
This letter serves to inform you that the Secretary for Lands and Rural Resettlement has approved your application to carry out a research in the Ministry of Lands and Rural Resettlement.

Furthermore you are advised to use the information that you obtain for the research project only and avail a copy of the project research to the Ministry upon completion.

PROVINCIAL ADMINISTRATOR
MASH-EAST PROVINCE
19 OCT 2016
P.O. BOX 445, MARONDERA
ZIMBABWE. TEL 24332/4

E. Nguwi
FOR SECRETARY FOR LANDS AND RURAL RESETTLEMENT
cc. Permanent Secretary
Director Finance, Admin and HR
Surveyor General
Deputy Director Human Resource
P/f
R/f





MINISTRY OF LANDS AND RURAL RESETTLEMENT

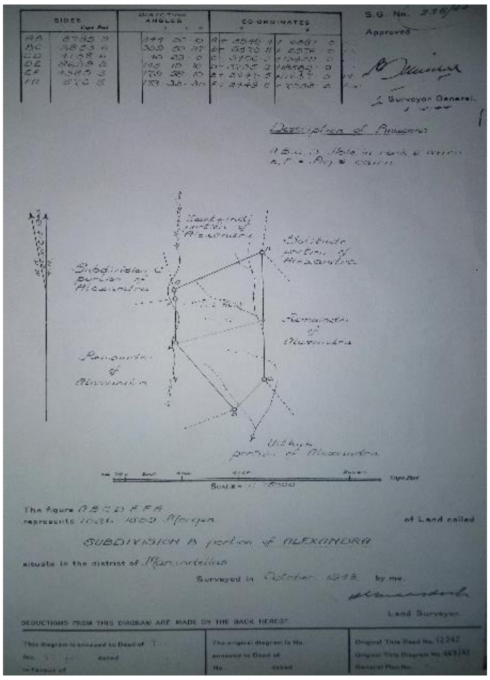
ROUTING SLIP

TO: Mr. Muzube DATE: 14/10/2016

FROM: A/DEPUTY DIRECTOR RESETTLEMENT

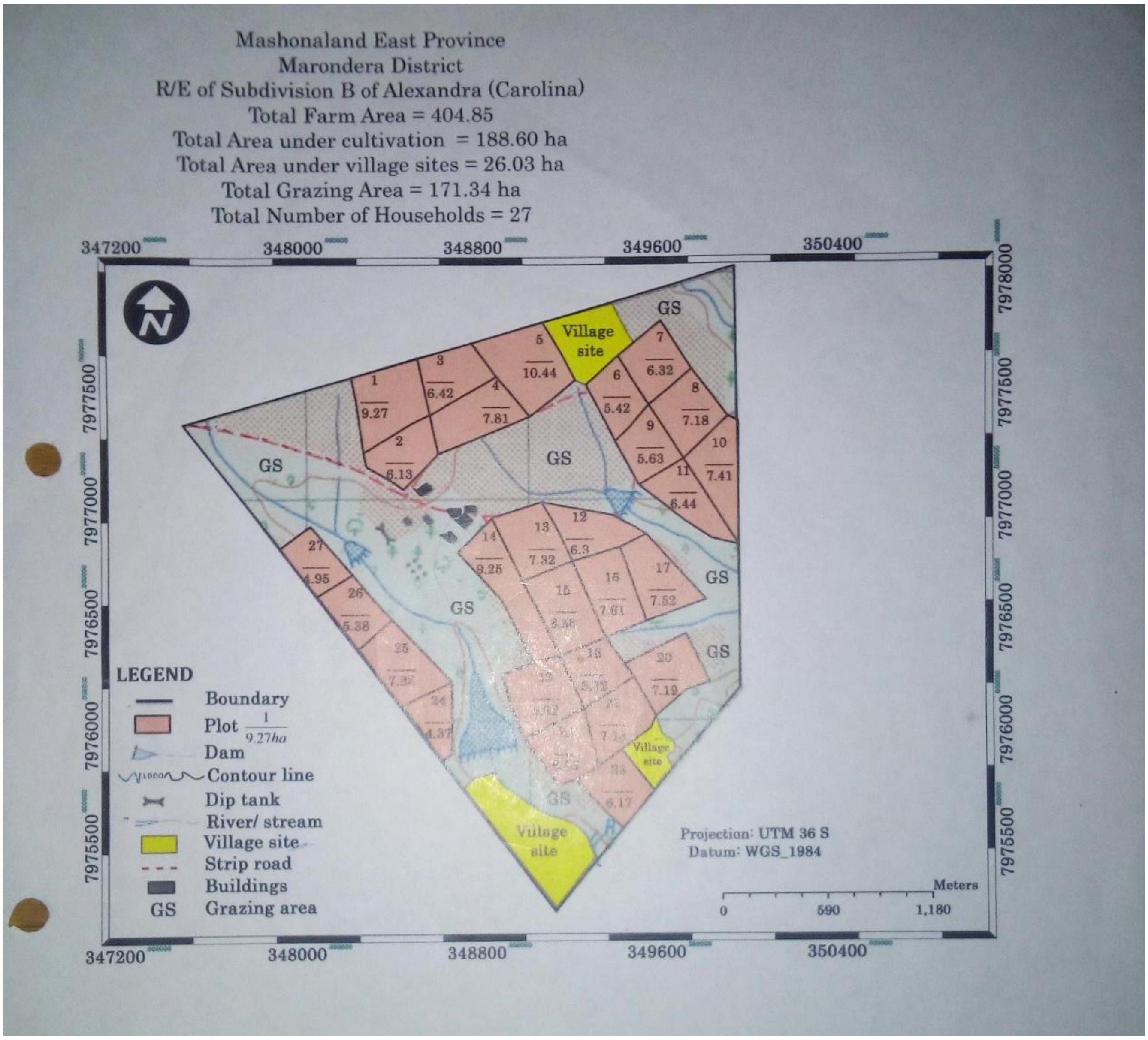
FOR ACTIONING	✓	FOR INFORMATION	
FOR APPROVAL		FOR DISCUSSION	
FOR CIRCULATION		FOR YOUR SIGNATURE	
FOR COMMENTS		FOR YOUR FILE	
FOR CORRECTION		NOTE AND RETURN	
FOR CONSIDERATION		AS DISCUSSED	
FOR ADVISE		FOR YOUR ATTENTION	
FOR GUIDANCE		YOUR COPY	

REF Assist Mr. Ali with required information since his research was approved by the P.S.



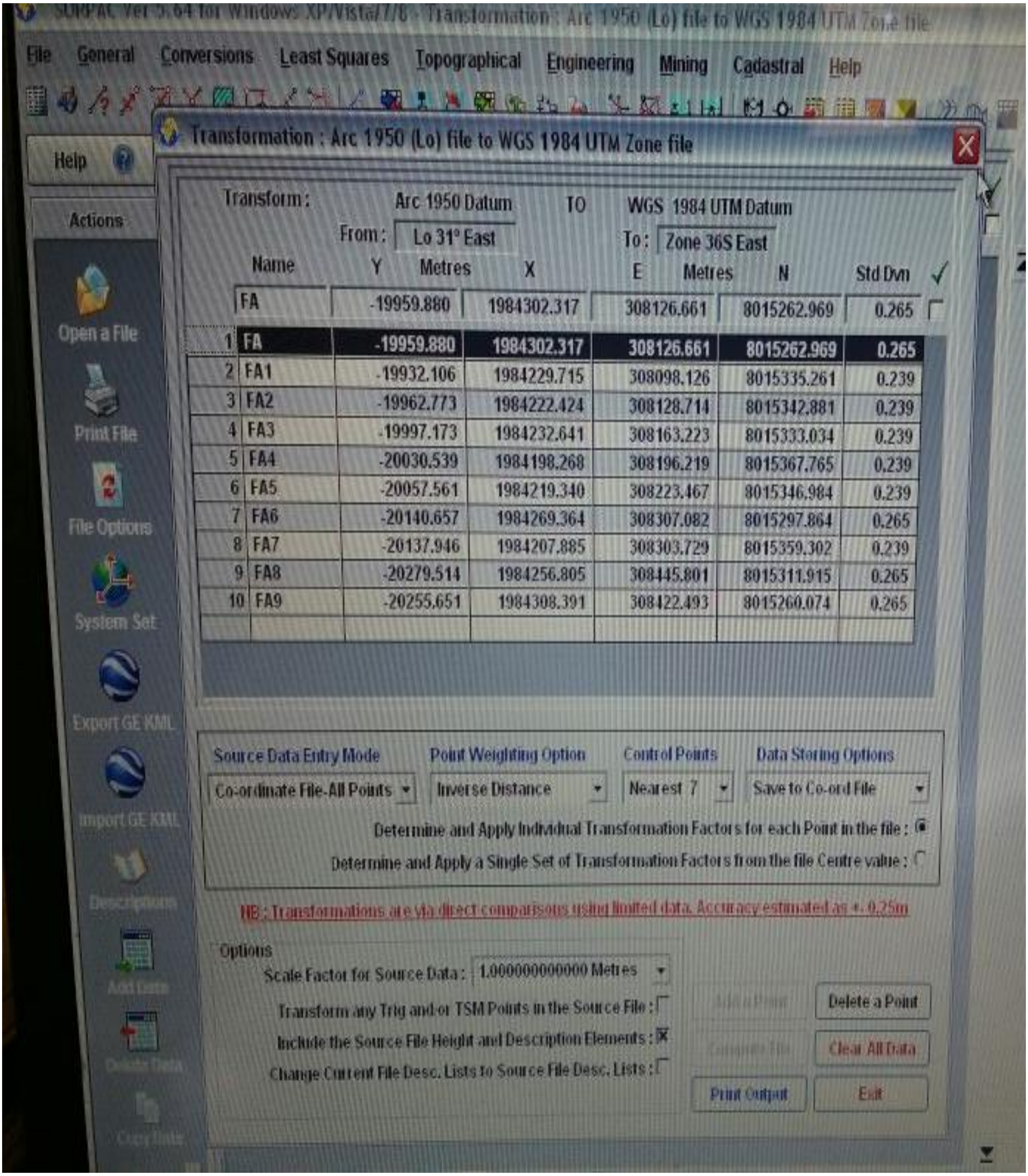
ANNEX 2

Parcel boundary map from existing approach (Source: MLRR)



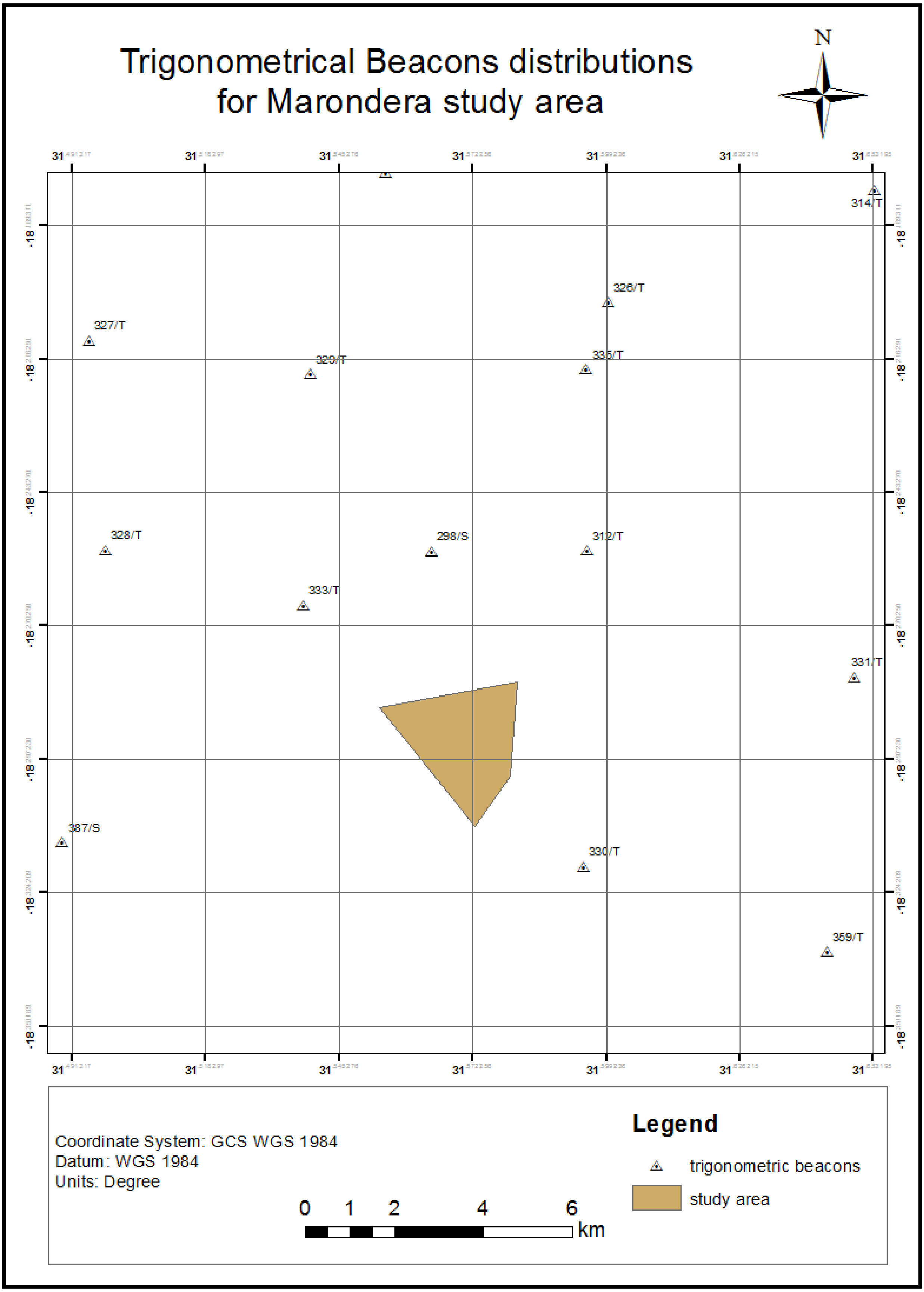
<u>**ANNEX 3**</u>

Coordinate transformation from local system to WGS84 UTM using Surpac software



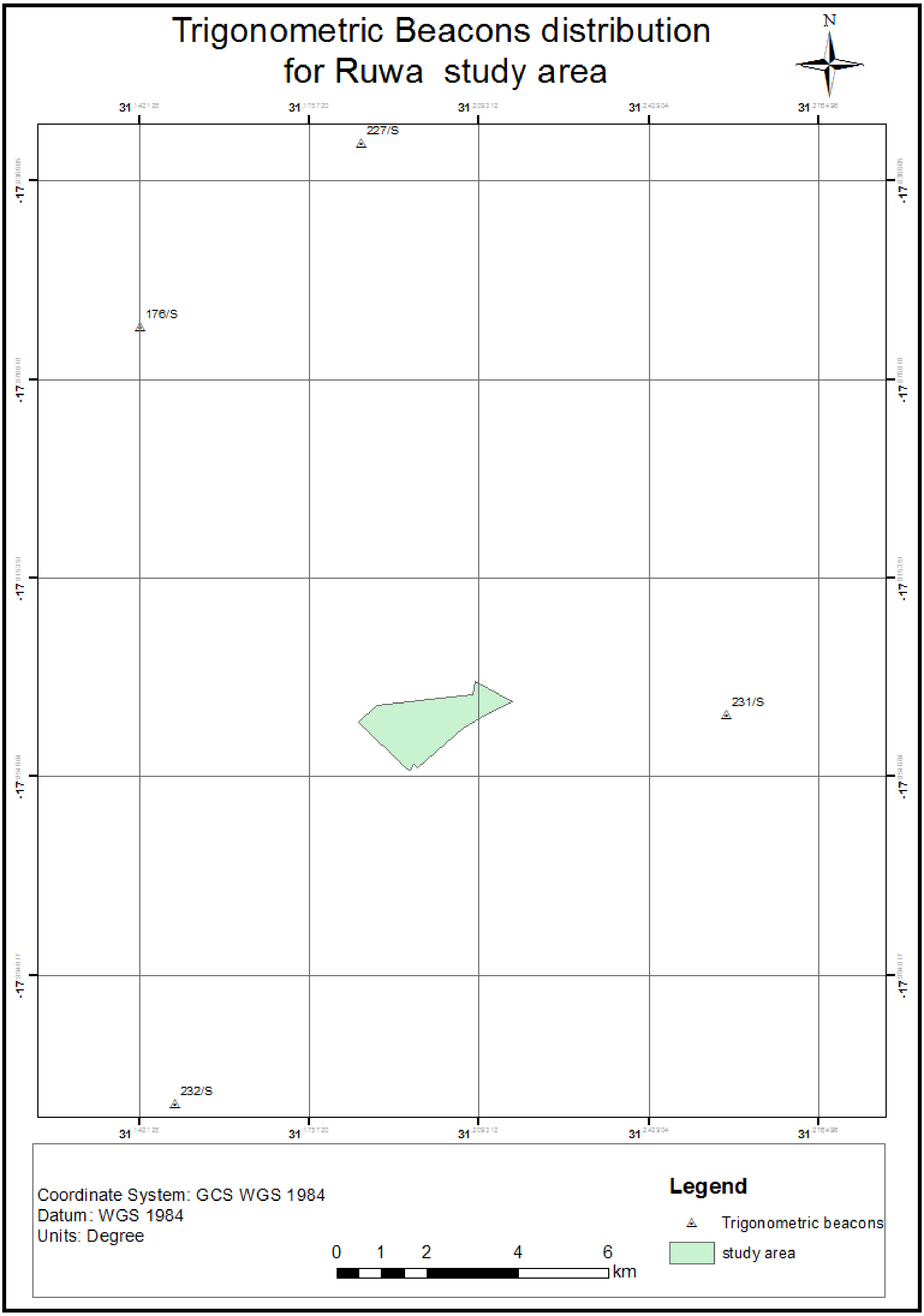
ANNEX 4

Distribution of trigonometrical beacons used in Marondera case study



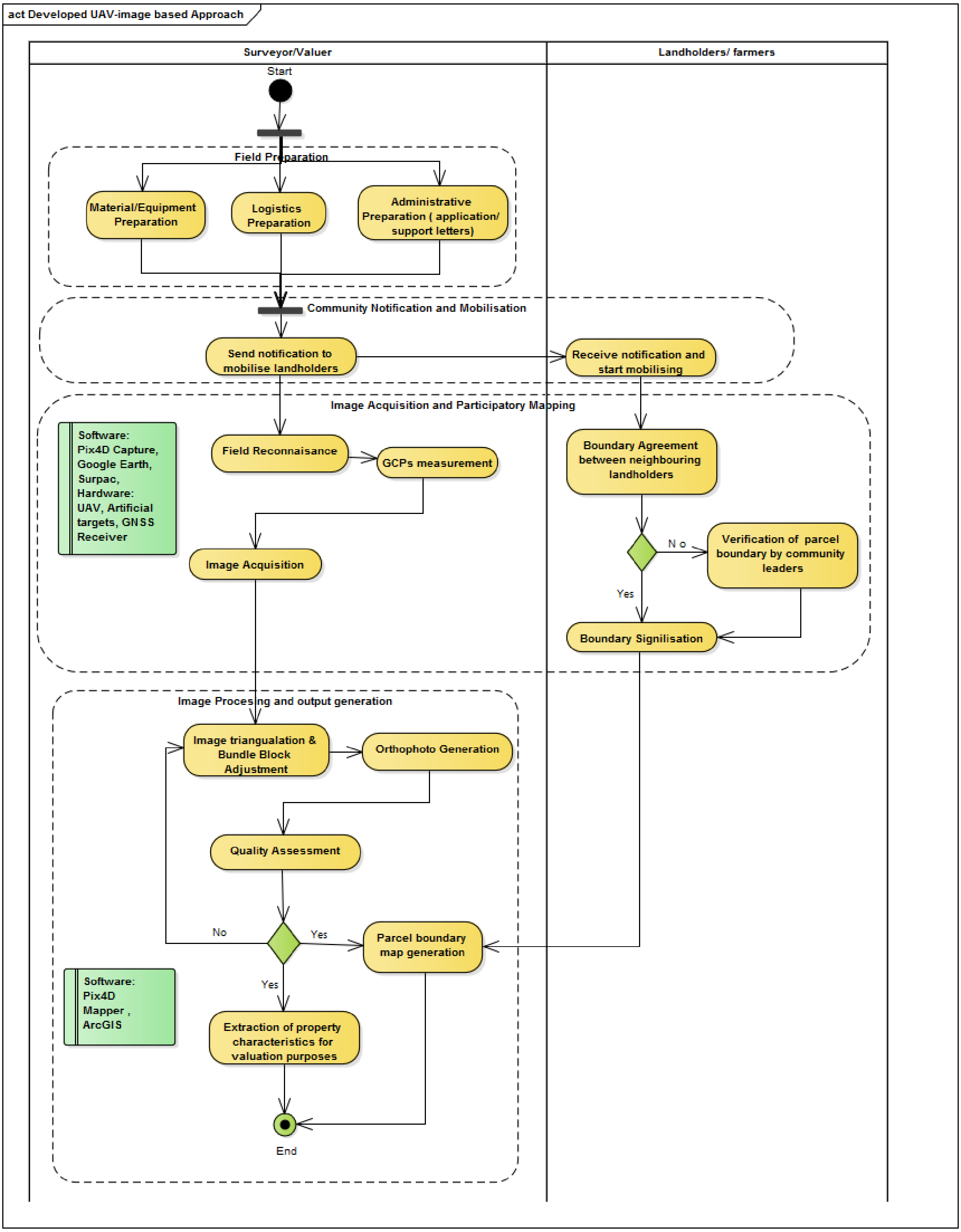
ANNEX 5

Distribution of trigonometrical beacons used in Ruwa case study



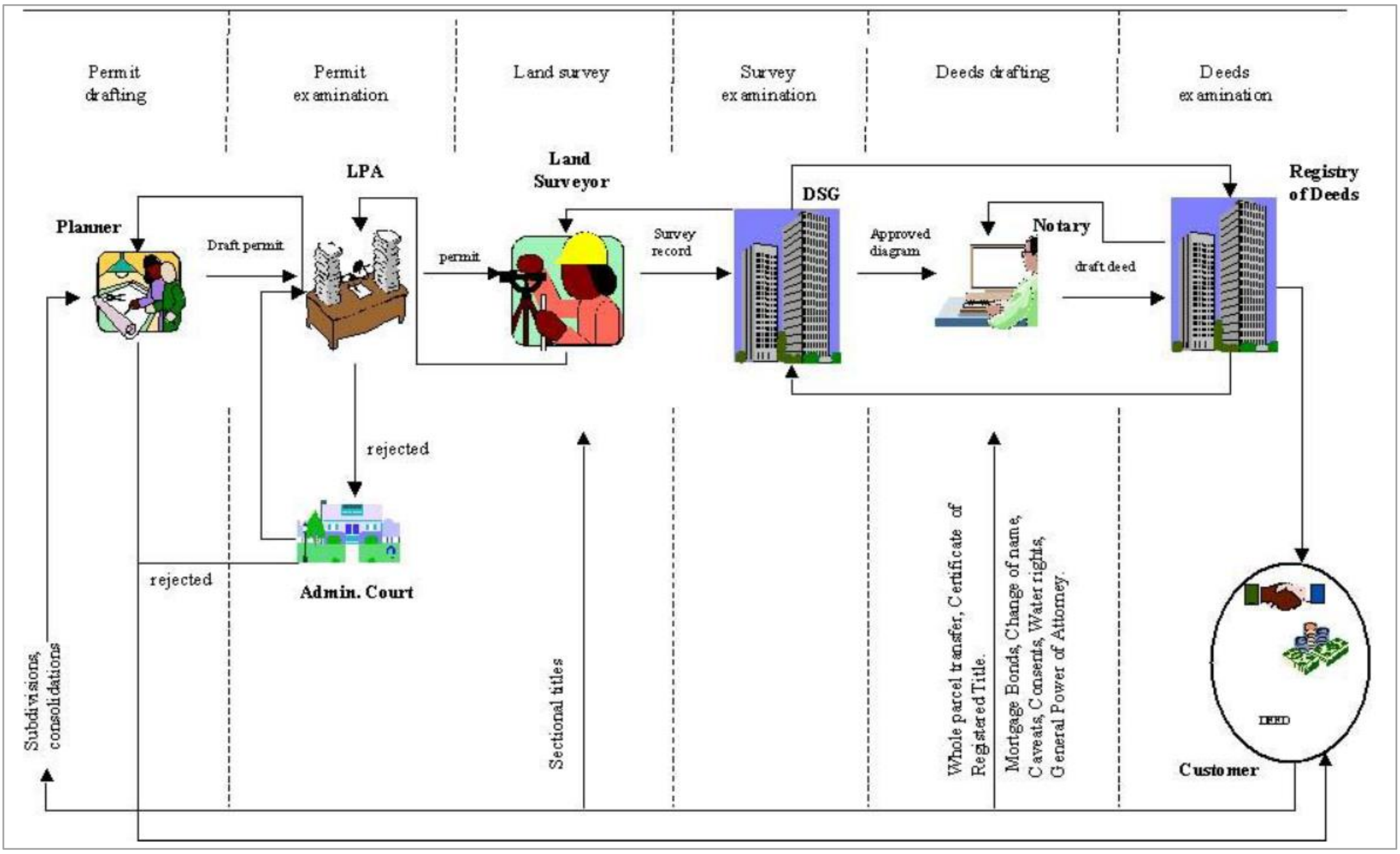
ANNEX 6

Developed UAV-image based approach for boundary mapping and valuation



ANNEX 7

Existing cadastral system in Zimbabwe



(Chimhamhiwa, 2002)

ANNEX 8

Quality Reports generated from Pix4D Mapper (Carolina Farm case study)

Quality Report

Generated with Pix4Dmapper Pro version 3.1.18

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	marondera_proj
Processed	2016-12-27 20:22:48
Camera Model Name(s)	FC330_3.6_4000x3000_new (RGB)
Average Ground Sampling Distance (GSD)	2.02 cm / 0.79 in
Area Covered	0.2874 km^2 / 28.7446 ha / 0.111 sq. mi. / 71.0663 acres

Quality Check

Images	median of 63263 keypoints per image
Dataset	773 out of 773 images calibrated (100%), 67 images disabled
Camera Optimization	1.04% relative difference between initial and optimized internal camera parameters
Matching	median of 29198.4 matches per calibrated image
Georeferencing	yes, 6 GCPs (6 3D), mean RMS error = 0.028 m

Preview

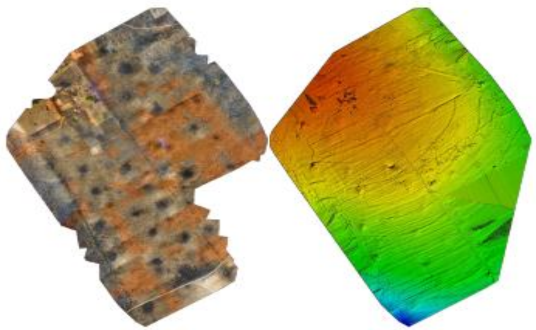


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	773 out of 840
Number of Geolocated Images	840 out of 840

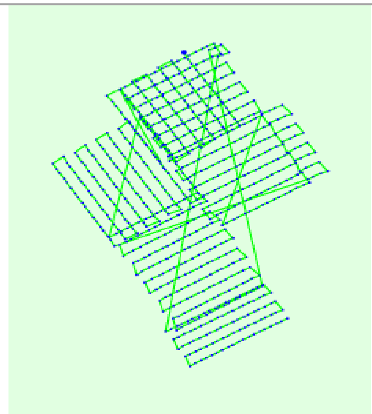
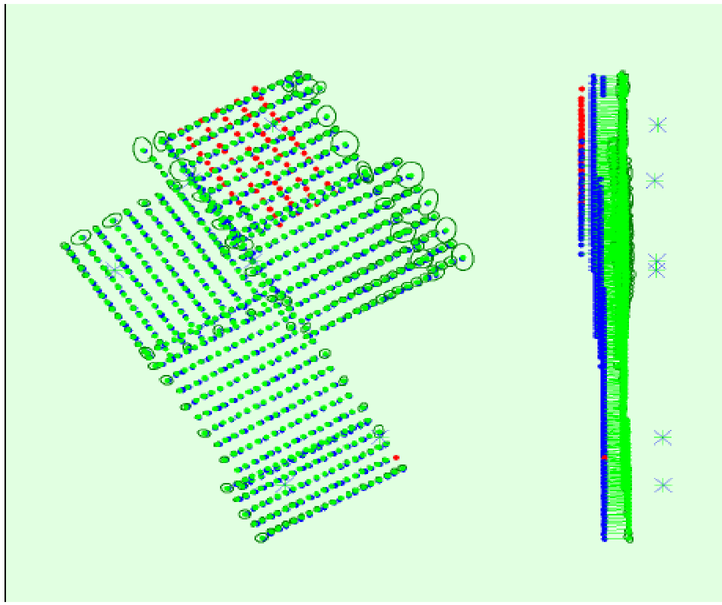
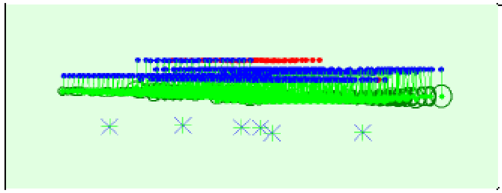


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions





Uncertainty ellipses 100x magnified

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). Red dots indicate disabled or uncalibrated images. 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	0.044	0.043	0.039	0.040	0.039	0.014
Sigma	0.021	0.023	0.023	0.025	0.022	0.007

Overlap

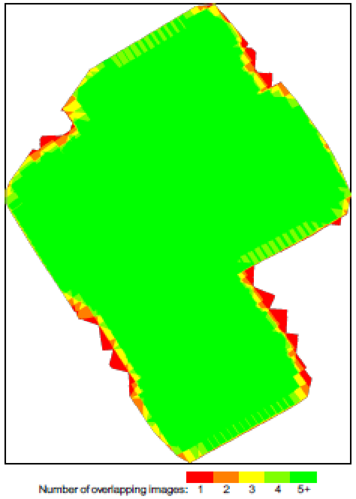


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.
Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	21741404
Number of 3D Points for Bundle Block Adjustment	5432935
Mean Reprojection Error [pixels]	0.179

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
CP2 (3D)	0.020/ 0.020	-0.009	-0.035	0.027	0.504	14 / 14
CP5 (3D)	0.020/ 0.020	-0.004	-0.044	-0.008	0.470	8 / 8
CP6 (3D)	0.020/ 0.020	0.027	-0.000	0.003	0.717	19 / 19
CP8 (3D)	0.020/ 0.020	-0.036	0.051	0.020	2.240	14 / 14
CP9 (3D)	0.020/ 0.020	0.013	0.016	0.017	0.588	17 / 17
CP11 (3D)	0.020/ 0.020	-0.001	0.011	-0.071	0.155	16 / 16
Mean [m]		-0.001703	-0.000021	-0.002083		
Sigma [m]		0.019484	0.031986	0.032846		
RMS Error [m]		0.019558	0.031986	0.032912		

0 out of 3 check points have been labeled as inaccurate.

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
CP3	0.0200/0.0200	-0.0313	0.0048	0.0447	0.5126	7 / 7
CP7	0.0200/0.0200	-0.0062	0.1133	0.1159	0.5098	12 / 12
CP10	0.0200/0.0200	0.0009	0.0411	-0.0257	0.5499	16 / 16
Mean [m]		-0.012199	0.053042	0.044968		
Sigma [m]		0.013822	0.045098	0.057847		
RMS Error [m]		0.018436	0.069623	0.073269		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has 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	2.46
-9.00	-6.00	0.00	0.00	36.87
-6.00	-3.00	4.79	0.52	5.17
-3.00	0.00	44.11	51.75	8.80
0.00	3.00	46.83	44.50	3.36
3.00	6.00	4.27	3.23	2.98
6.00	9.00	0.00	0.00	37.13
9.00	12.00	0.00	0.00	3.23
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.955265	-1.013696	33.223626
Sigma [m]		1.768597	1.407565	6.887766
RMS Error [m]		2.010091	1.734595	33.930084

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Geolocation Bias	X	Y	Z

ANNEX 9

Quality Reports generated from Pix4d Mapper (Lot 1A Nil Desperandum)

Quality Report

Generated with Pix4Dmapper Pro version 3.0.17

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	ruwa_proj
Processed	2016-12-12 19:18:37
Camera Model Name(s)	FC330_3.6_4000x3000_new (RGB)
Average Ground Sampling Distance (GSD)	1.6 cm / 0.63 in
Area Covered	0.116 km^2 / 11.5987 ha / 0.0448 sq. mi. / 28.6758 acres

Quality Check

Images	median of 38183 keypoints per image
Dataset	945 out of 945 images calibrated (100%), all images enabled
Camera Optimization	2.61% relative difference between initial and optimized internal camera parameters
Matching	median of 5201.25 matches per calibrated image
Georeferencing	yes, 5 GCPs (5 3D), mean RMS error = 0.017 m

Preview

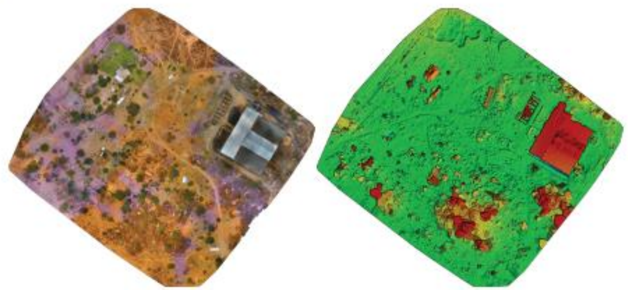


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	945 out of 945
Number of Geolocated Images	945 out of 945

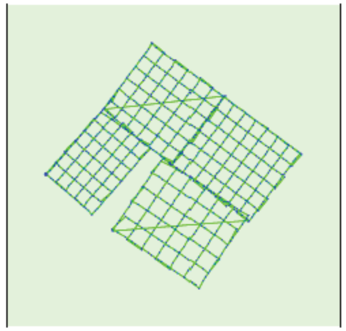
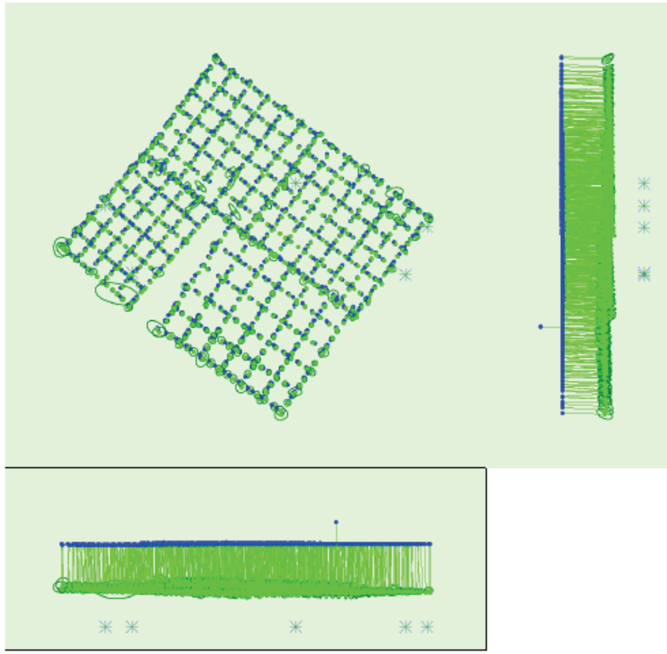


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 50x magnified

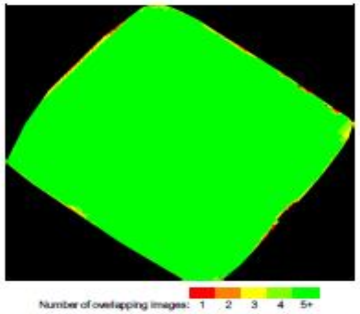


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.
Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	5399022
Number of 3D Points for Bundle Block Adjustment	1843432
Mean Reprojection Error [pixels]	0.154

Internal Camera Parameters

FC330_3.6_4000x3000_new (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2441.100 [pixel] 3.855 [mm]	2006.794 [pixel] 3.169 [mm]	1504.302 [pixel] 2.376 [mm]	-0.012	0.017	0.003	0.000	0.000
Optimized Values	2504.936 [pixel] 3.956 [mm]	2009.597 [pixel] 3.174 [mm]	1420.878 [pixel] 2.244 [mm]	-0.013	0.018	0.003	0.001	0.001
Uncertainties (Sigma)	2.522 [pixel] 0.004 [mm]	0.247 [pixel] 0.000 [mm]	0.598 [pixel] 0.001 [mm]	0.000	0.001	0.001	0.000	0.000

The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model is color coded between black and white. White indicates that, in average, more than 16 ATPs are extracted at this pixel location. Black indicates that, in average, 0 ATP has been extracted at this pixel location. Click on the image to the see the average direction and magnitude of the reprojection error for each pixel. Note that the vectors are scaled for better visualization.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	38183	5201
Min	20784	176
Max	61885	28287
Mean	38335	5714

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	1211832
In 3 Images	313195
In 4 Images	126097
In 5 Images	63863
In 6 Images	37078
In 7 Images	23573
In 8 Images	15545
In 9 Images	10927
In 10 Images	7891

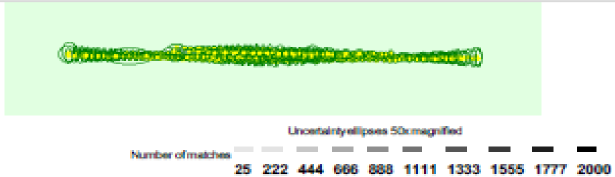


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.040	0.040	0.061	0.082	0.076	0.025
Sigma	0.025	0.023	0.032	0.039	0.039	0.013

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
CP1 (3D)	0.020/ 0.020	-0.028	0.010	0.021	0.420	11 / 11
CP2 (3D)	0.020/ 0.020	0.014	-0.013	-0.057	0.342	3 / 3
CP8 (3D)	0.020/ 0.020	0.000	-0.008	0.014	0.380	16 / 16
CP9 (3D)	0.020/ 0.020	0.004	-0.001	0.004	0.332	7 / 7
CP10 (3D)	0.020/ 0.020	0.004	0.010	-0.016	0.464	8 / 8
Mean [m]		-0.001181	-0.000511	-0.006641		
Sigma [m]		0.014118	0.009404	0.028224		
RMS Error [m]		0.014168	0.009418	0.028994		

0 out of 3 check points have been labeled as inaccurate.

Check Point Name	Accuracy XY/Z [m]	Error X[m]	Error Y[m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
CP4	0.0200/0.0200	0.0187	-0.0221	0.5841	0.3555	15 / 15
CP6	0.0200/0.0200	0.0086	-0.0212	0.4891	0.1724	8 / 8
CP7	0.0200/0.0200	0.0030	-0.0206	0.4650	0.3803	15 / 15
Mean [m]		0.010090	-0.021310	0.512728		
Sigma [m]		0.006501	0.000598	0.051423		
RMS Error [m]		0.012003	0.021318	0.515300		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has been automatically verified vs. manually marked.

Absolute Geolocation Variance

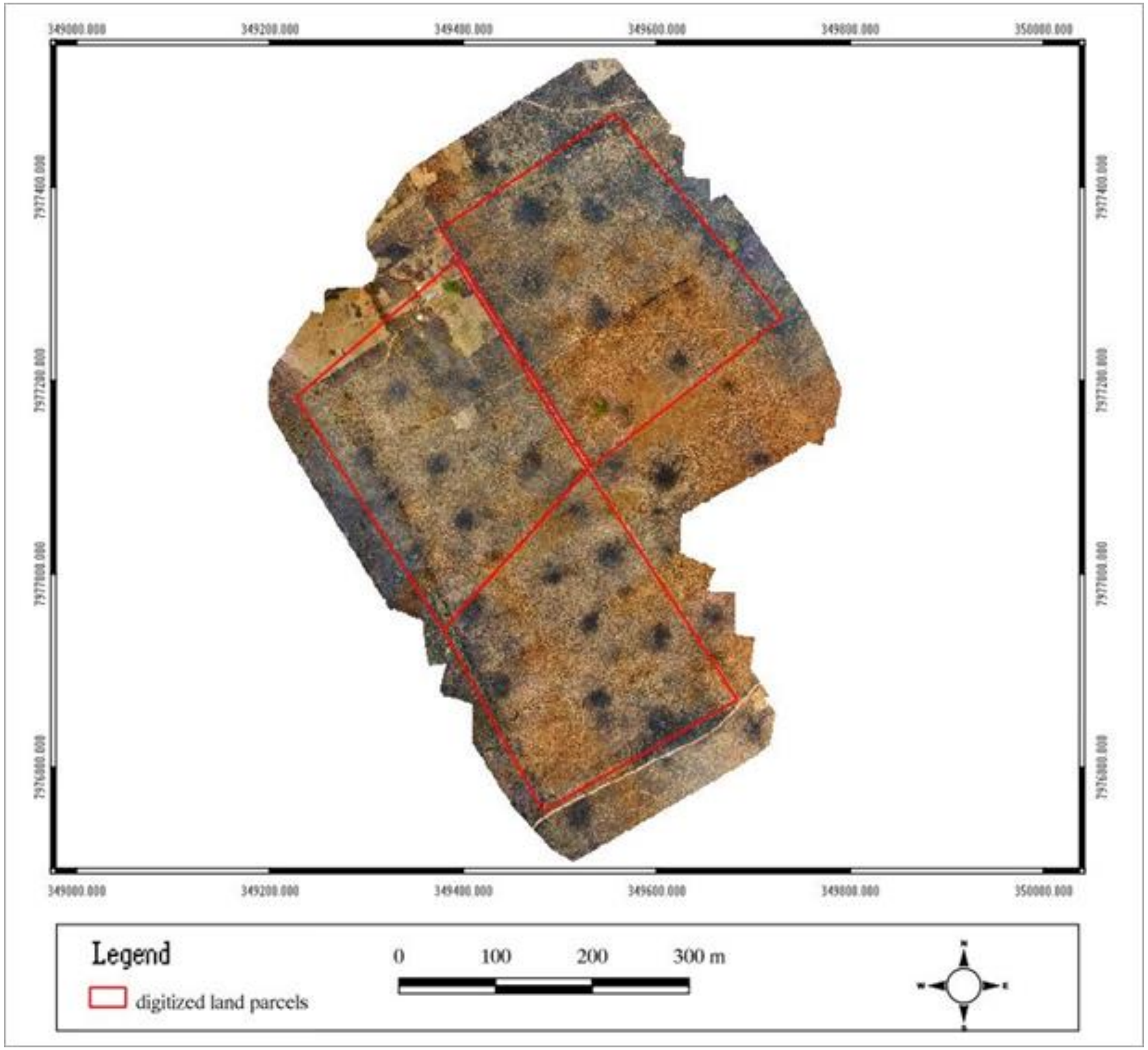
Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.32
-9.00	-6.00	0.00	0.00	3.60
-6.00	-3.00	3.70	4.34	15.98
-3.00	0.00	47.20	46.98	26.77
0.00	3.00	44.02	45.61	32.80
3.00	6.00	5.08	3.07	18.73
6.00	9.00	0.00	0.00	1.69
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	0.11
Mean [m]		-0.550999	1.074041	48.658219
Sigma [m]		1.762135	1.713613	3.369182
RMS Error [m]		1.846272	2.022383	48.774724

ANNEX 10

Ground Control Points Distribution

ANNEX 11

Digitized parcel boundaries from UAV based boundary mapping



ANNEX 12

UAV-image Based Approach preparation and implementation with participation of landholders

ANNEX 13

Existing Survey Classes in Zimbabwe (Second Schedule of Land Survey Regulations)

Survey Class	Allowable Misclosure (metres)	Class Description
Class A	$0.005\sqrt{(0.0075f+0.000\,15f^2)}$	Refers to surveys to determine the position of town survey-marks;
Class B	$0.02\sqrt{(0.0075f+0.000\,15f^2)}$	Surveys in townships, other than surveys of high-density developed townships; and Survey operations in high density developed townships
Class C	$0.03\sqrt{(0.0075f+0.000\,15f^2)}$	All surveys on rural land
Class D	$0.25+0.03\sqrt{(0.0075f+0.000\,15f^2)}$	Refers to surveys carried out by photogrammetric methods.
*Where "**f**" is the sum of the traverse distances, expressed in metres.*		

(Kurwakumire & Chaminama, 2012)

ANNEX 14

Structure of landholdings from 1980-2010

Farm categories	Farms/households (000's)						Area held (000 ha)						Average Farm size (ha)		
	1980		2000		2010		1980*		2000*		2010*		1980	2000	2010
	No	%	No	%	No	%	ha	%	ha	%	ha	%			
Peasantry															
Communal	700	98	1,050	92	1,100	81.3	16,400	49.2	16,400	50.1	16,400	49.9	23	16	15
Old resettlement	-		75	7	75	5.5	-		3,667	11.2	3,667	11.2		49	49
A1	-				145.8	10.8	-		-		5,759	17.5			40
Sub-total	***700***	***98***	***1,125***	***99***	***1,321***	***97.6***	***16,400***	***49.2***	***20,067***	***61.3***	***25,826***	***78.6***	***23***	***18***	***20***
Middle farms															
Old SSCF	8.5	1.2	8.5	0.8	8.5	0.6	1,400	4.2	1,400	4.3	1,400	4.3	165	165	165
Small A2	-				22.7	1.7					3,000	9.1			133.9
Sub-total	***8.5***	***1.2***	***8.5***	***0.8***	***31.2***	***2.3***	***1,400***	***4.2***	***1,400***	***4.3***	***4,400***	***13.4***	***165***	***165***	***142***
Large farms															
Large A2	-		-		0.217	0.02					508.9	1.6			2,345
Black LSCF			0.956	0.08	0.956	0.07			530.6	1.6	530.6	1.6		555.0	555
White LSCF	5.4	0.8	4	0.4	0.198	0.01	13,000	39	8,161	24.9	117.4	0.4	2407	2,040	593
Sub-total	***5.4***	***0.8***	***4.956***	***0.4***	***1.371***	***0.1***	***13,000***	***39***	***8,691.6***	***26.6***	***1,156.9***	***3.5***	***2,407***	***1,754***	***844***
Agro-Estates															
Corporate	0.049	0.01	0.049	0.004	0.02	0.001	1,084	3.3	1,084	3.3	806.4	2.5	22,122	22,122	40,320
Parastatal	0.126	0.02	.126	0.01	0.106	0.01	379.2	1.1	379.2	1.2	295.5	0.9	3,010	3,010	2,788
Conservancy	0.008	0.001	0.008	0.001	0.008	0.001	958	2.9	958	2.9	247	0.8	119,750	119,750	30,875
Institution	0.113	0.02	0.113	0.01	0.113	0.01	145.7	0.4	145.7	0.5	145.7	0.4	1,289	1,289	1,289
Sub-total	***0.296***	***0.05***	***0.296***	***0.02***	***0.247***	***0.02***	***2,567***	***7.7***	***2,567***	***7.9***	***1,494.6***	***4.5***	***8,672***	***8,672***	***6,051***
Total	***714.2***	***100***	***1,138.8***	***100***	***1,354***	***100***	***33,367***	***100***	***32,726***	***100***	***32,878***	***100***	***46,7***	***28,7***	***24,3***

(Moyo, 2013)