INNOVATIONS IN BOUNDARY MAPPING: NAMIBIA, CUSTOMARY LAND AND UAV'S

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February, 2015

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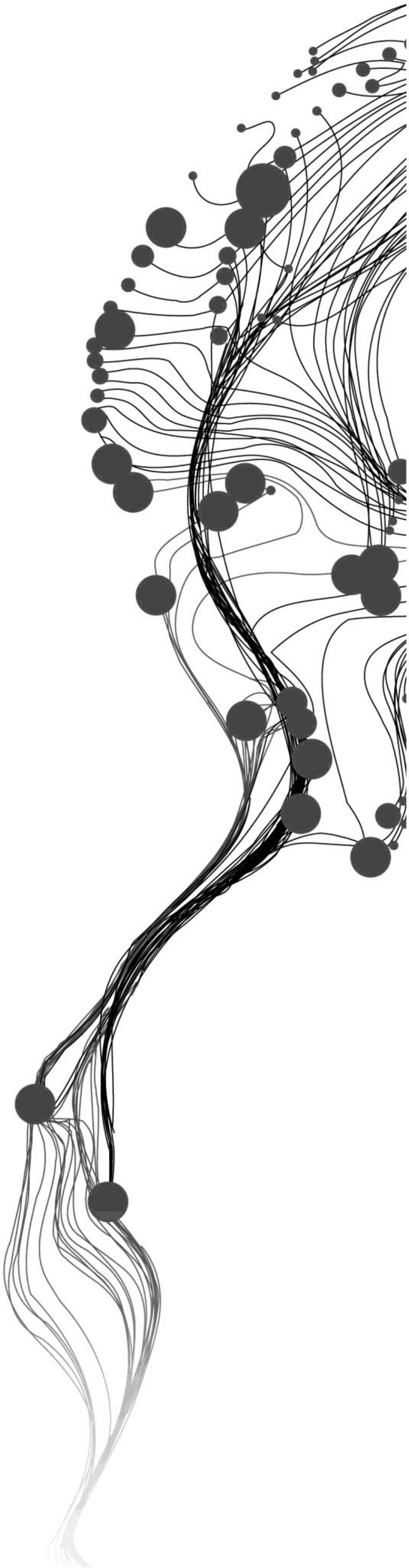

Innovations in Boundary Mapping: Namibia, Customary Land and UAV's

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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Land Administration

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ABSTRACT

Unmanned Aerial Vehicle (UAVs technology provides the opportunity to improve the speed, cost, and accuracy of cadastral surveying and mapping in various contexts. Research focus has turned to investigating the use of UAV-captured images in the adjudication, mapping and registration of rural land areas. By applying UAV to mapping customary parcel boundaries in Namibia, this thesis seeks to understand whether the prevailing challenges associated with conventional mapping techniques can be overcome. One of the objectives of the study was to develop a procedure for mapping customary land parcels using a UAV. Accordingly, one was developed and tested in Namibia: aerial photographs were captured at 150m flight height, 70% lateral overlap, and 80% forward overlap in 20 minutes fly time over an area of 160ha. Ground control points were accurately measured using differential GPS techniques and were used in geo-referencing during image processing. The generated orthophoto was then used to survey the parcel boundaries. Further tests were carried out to evaluate the spatial accuracy of the survey, and root mean square error (RMSE) was used to compute the standard deviation which was 4-5cm. Based on the findings of this study, it is concluded that the UAV mapping approach enables the production of highly accurate orthophoto maps that can easily be applied in the domain of customary land parcel boundary mapping. The procedure developed is functional, further work could explore the social-technical aspects of the approach, for example overcoming resistance from the existing cadastral surveying profession.

Key Words: Customary Land, Boundaries, Mapping, Namibia, Parcels, Surveying, UAVs

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I am inspired by these words by Robert Brault; "There is no such thing as gratitude unexpressed. If it is unexpressed, it is plain, old-fashioned ingratitude" followed by George Coleman who says "praise the bridge that carried you over". In light of these inspiring words;

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Mukendwa Don Mumbone
February 2015

DEDICATION

This work is dedicated to the following people:

To my mother, Christina Mulemwa Liomba MPH, P.G.D, through her hard work, selflessness, and perseverance has been my role-model. She instilled in me the inspiration that any goals set can be achieved through hard work. I hope this achievement will realize the dream she had for me when she first left me in a class room.

To the memory of my father, Albius Simwanza Mumbone, who throughout his life emphasized the importance of education to his children. I am proud to say that I am well underway on the path he set me on.

To the memory of my brother, Luther Sikosi Mumbone, not only was he a brother, but a friend who acted as an emotional anchor during my time of need. He may be gone, but will never be forgotten.

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CLB	: Communal Land Board
GCP	: Ground Control Point
GNSS	: Global Navigation Satellite System
GPS	: Global Positioning System
GSD	: Ground Sampling Distance
Ha	: Hectare
ID	: Identification
MLR	: Ministry of Lands and Resettlement
NCLAS	: Namibia Communal Land Administration System
RMSE	: Root Mean Square Error
RTK	: Real Time Kinetic
UAV	: Unmanned Aerial Vehicle
UML	: Unified Modelling Language
UPI	: Unique Parcel Identifier

1. INTRODUCTION

1.1. Background

Over two thirds of Namibia's population still live on unregistered customary land (Kasita, 2011). On these lands, laws demand the boundaries of the individual and collective land holdings to be adjudicated, mapped and recorded. Thus, it has been the obligation of government to develop initiatives aimed at satisfying these demands. One such initiative was the enactment of the Communal Land Reform Act, Act 5 of 2002, which aimed to eliminate tenure insecurity in the communal land areas through the registration of customary land rights.

Thus far, the rights are registered through an innovative land administration system (Williamson et. al., 2010). Formal land surveying and mapping practices, such as physical demarcation and placing of monuments at boundaries, are not required. However, a 2D graphical footprint of the land parcel is required for decision making purposes. For these reasons, the Ministry of Lands and Resettlement sought the use of conventional mapping techniques in the form of aerial photographs and simple GPS devices. These practices have been carried out by land registration staff with basic surveying and GIS training.

Adjudication of land rights requires a suitable means for surveying and mapping parcel boundaries. The choice of a survey method is dependent on the accuracy needs of the specific application and intended future use of the data. As highlighted by previous research, conventional ground-based surveying methods, including high-precision GNSS, can have negative implications in land administration: the methods can be slow, expensive, labour intensive, complicated and cause delays in project completion. It is believed that the advancement in emerging technologies such as small and affordable UAV systems and geo-information techniques, offer an alternative, if not innovative, means for capturing and producing cheaper and faster spatial data for use in land administration projects (Kelm, 2014). Such advancement in technology can help land administration agencies and governments secure land rights for their people, both in Namibia and more broadly.

UAVs use a combination of GPS navigation technology and model airplane technologies to offer a mapping method that is fast and affordable (Barnes et al., 2014;Barnes et al., 2013). The use of UAVs in mapping customary lands may produce a high resolution cadastral map within a limited time of flying. The method is speedy and user-friendly; and produces understandable 2D representation of parcels, as opposed to polygons with no graphical backdrop. The high resolution orthophotos enable the user to identify features that guide in the identification and mapping of parcel boundaries. These features include fences, hedges, footpaths, crop fields, houses, or whatever visible features the local context utilizes.

Proven benefits with regards to costs, efficiency, accuracy and flexibility have been revealed, especially in urban areas where the majority of tests have occurred. However, the argument is yet to be empirically proven in more rural contexts, particularly those with customary lands, such as those found in rural Namibia. This study, therefore seeks to address this gap by testing the applicability of UAV technology in capturing images for surveying and mapping customary land parcels. By applying UAV to mapping customary land parcel boundaries in Namibia, this study seeks to understand whether the prevailing challenges associated with conventional mapping techniques can be overcome.

1.2. Research Problem

Studies in Namibia have revealed that aerial photos are the most efficient means to map customary land boundaries (see Meijs et al., 2009). However, since the beginning of the land registration program in 2005, aerial photos have not been available country wide. Until early 2014, the use of orthophotos has been limited to the northern part of the country. This is due to high acquisition costs and prioritization issues. In addition, due to the amount of time it takes for the suppliers to prepare the images, they are out-dated at the time of delivery; meaning that the images do not represent the current situation on the ground. Additionally, there has been resistance from the land surveying community about the accuracy of customary land surveys that utilize imagery. The argument has been that the surveys carried out of customary land are not within the bounds of the surveying laws in the country, in terms of accuracy. This situation apparently threatens the envisaged merger of the Namibia Communal Land Administration System (NCLAS) with the national deeds system in the future.

Therefore, it is of great importance to explore a method that is able to deliver up-to-date geo-referenced images, at low cost whenever needed. A method that can deliver spatial accuracy as close as possible to the standards prescribed in the survey regulations is needed. However, at the same time, the progressive mentality embedded into the communal land reform activities, that aligns with fir-for-purpose land administration designs (FIG & WORLD BANK, 2014), needs to be maintained.

The problem therefore is that:

> *It is unknown whether or not UAV technology can be used to survey and map customary land parcel boundaries to required legal and technical requirements.*

1.3. Aim of The Study

Responding to the research problem, the overarching aim of this study is:

> *To assess the use of UAV surveying methods in mapping customary land parcel boundaries in terms of spatial accuracy and legal compliance.*

Where:

UAV surveying refers to the process of capturing digital aerial photographs with unmanned aerial vehicles and processing such photographs into an orthophoto on which demarcations can be done.

Customary land refers to a land right allocated in terms of the communal land reform act for residential and farming purposes.

Spatial Accuracy is the degree to which spatial data collected matches true to accepted values, based on accepted survey standards.

Mapping refers to the act of creating a graphic representation of a piece of land using spatial data collected from the field.

1.4. Objectives and Questions

In order to achieve the overarching objective, the following sub-objectives, and related questions, are defined:

Objective 1: To understand the current context regarding customary land mapping and UAVS

Question 1: What are the policies, laws, tenures, administrative approaches, and technologies that inform customary land mapping in Namibia Currently?

Question 2: What are the policies and laws regarding UAV usage in Namibia?

Objective 2: To design a new customary land mapping approach around UAVs

Question 1: What approach can be used to design the new approach?

Question 2: What does the new approach look like – and what steps are involved?

Objective 3: To validate the new approach to customary land mapping

Question 1: What is the best way to assess the designed approach?

Question 2: What do the assessments reveal?

1.5. Conceptual Framework

Miles & Huberman, (1994) define a conceptual framework as a graphical or written product that narrates the main points under study. These are concepts, key aspects and variables, as well as the supposed relationships between them. For this research, the conceptual framework is summarised in an intersection diagram (Figure 1). The diagram is composed of three main elements; customary land tenure, cadastral surveying & registration, and Geo-Information Science Technology. It shows the relationships between each term, and each term's relation with UAV technology.

The advancement in Geo-Information technology has introduced a method in which UAV technology can be used in cadastral surveying and registration. This study focuses on how UAV surveying technology can be used to survey customary land parcel boundaries. This would aid in maintaining spatial records of customary boundaries. In the end, the ultimate aim is for securing customary land tenure for the citizens in communal land areas.

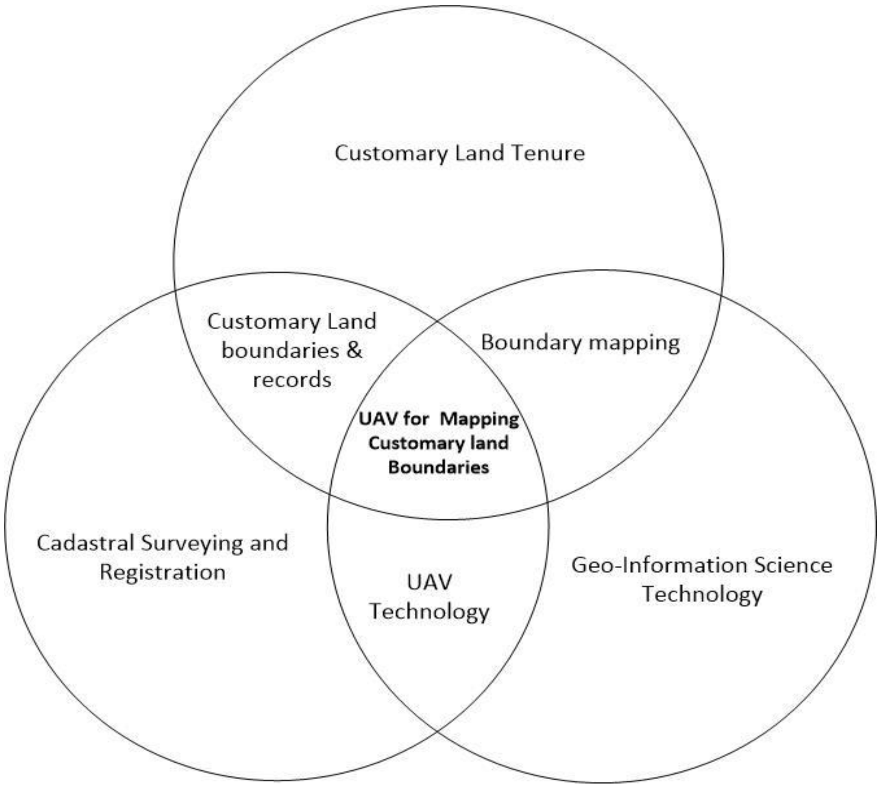

Figure 1 Conceptual Framework

1.6. Research Matrix

The research matrix shows the objectives of the study and the methods to follow in answering the research questions. The data and materials needed for the study are also shown, as well as the anticipated results of each objective.

Table 1: Research Matrix

Objectives	**Questions**	**Methods**	**Materials**	**Anticipated Result**
Objective 1**:** To understand the current context regarding customary land mapping and UAVS	Question 1: What are the policies, laws, tenures, administrative approaches, and technologies that inform customary land mapping in Namibia Currently? Question 2: What are the policies and laws regarding UAV usage in Namibia?	Literature review	Surveying Laws Surveying manuals Government Reports Land Acts Aviation Laws/Acts	Determine what the laws say regarding communal land surveying in terms of techniques to be used, how surveys are to be done and accuracy standards. To determine whether or not UAVs are recognised in Namibia
Objective 2: To design a new customary land mapping approach around UAVs	Question 1: What approach can be used to design the new process? Question 2: What does the new processes look like – and what steps are involved?	Design & Develop Workflows UAV survey methods-literature	UML software Arcmap Google Earth Fixed wing UAV Laptop Flight planning software Pix4D DGPS	A process depicted in a flow chart Photogrammetric output (orthophoto) GIS generated parcel map of boundaries
Objective 3: Validate the new approach to customary land mapping	Question 1: What is the best way to assess the designed approach? Question 2: What do the assessments reveal?	Accuracy assessment (RMSE) Photogrammetric operations	Microsoft Excel Pix4DMapper	Accuracy Results Legal compliance results

1.7. Thesis Structure

Chapter 1: Introduction

This chapter offers the introduction of the study in form of the background and justification. The chapter further discusses the research problem, research aim and objectives. The research questions to the objectives are also presented.

Chapter 2: Literature Review and Concepts

This chapter discusses theoretical and empirical concepts that the research is based on. Customary land tenure, land registration, adjudication, cadastre and boundary surveying as well as unmanned aerial vehicle technology are discussed

Chapter 3: Research Methods

Chapter 3 presents the methods used in answering the research questions. The study area is also present in this chapter. The chapter is presented in three stages; pre-field work, field-work and post-field work stages, which are aligned to the order of the objectives.

Chapter 4: Results and Discussion

This chapter presents the results of the study. The results are presented according to the objectives. The first section presents the current context regarding customary land mapping and UAVs (the policies and technical background). The design results are presented in the second section, where the developed workflow for mapping customary land parcel boundaries is discussed. The third section presents the results of the pilot test of the developed procedure

Chapter 5: Conclusion and Recommendations

This chapter concludes the study by visiting and discussing how the specific objectives were met and answered, this is followed by recommendations for further research.

2. LITERATURE REVIEW & CONCEPTS

This chapter reviews conceptual and empirical literature pertaining to the concepts of customary land tenure, land registration and adjudication, boundary surveying and unmanned aerial vehicle technology. The study will discuss these concepts in relation to customary land adjudication, identifying current surveying and mapping techniques with an emphasis of discussing UAV as a potential alternative. Firstly, a general description of the concept will be given, which will include the relevance of the concept in this study, and then some case studies on UAV-use in mapping will be presented.

2.1. Customary Land Tenure

Land tenure can be defined as the mode in which land is owned or held (Zevenbergen, 2002). According to the United Nations Habitat (UN-Habitat, 2008), Land Tenure is the manner in which land is occupied or owned by groups and individuals. It can also be said to refer to the set of legal or customary relationships defined between people with regard to land. Therefore, tenure describes the relationships that people have with their land. There are different forms of land tenure. According to (Dale & McLaughlin, 1999), land can either be held under private (ownership or freehold), state, communal (customary) and open access. These may also include different sets, or bundles of rights to land, property and natural resources. In this study, we focus on customary land tenure.

Dale & McLaughlin, (1999) defines customary or communal tenure as a right which may exist within a community where each member has the right to independently use the holdings of the community. Customary tenure naturally arises as a result of customs, norms and traditions of a society; it includes communal rights to use grasslands, as well as exclusive private rights to agricultural and residential parcels (FAO, 2002). The United Nations Habitat (UN-Habitat, 2008) mention further that ownership in customary tenure is vested in the tribe, group, community or family. Customary leaders such as chiefs administer the land on behalf of the community and allocate land to those in need for cultivation of crops or residential purposes. However, in recent times, particularly in developing countries, the pressure on land and resources has increased drastically, instilling immense insecurity among the people as access to land becomes more tenuous over time (IFAD, 2012). This phenomenon has resulted in an increased demand for the improvement of tenure security through land registration. The following terms are often used in relation to customary tenure:

1. **Customary land:** Land which is collectively owned by indigenous people and administered in accordance to the local customs of a particular rural area.
2. **Communal land:** A designated area of land held by an indigenous community and administered based on local customs and norms
3. **Traditional land:** In this case we refer to land that is held by native people of a community through customary usage.
4. **Group land:** Group ownership may refer to a situation in which rights to land are held by more than one person, this may be a family or an organisation.
5. **Conservancy:** This refers to an area or an organisation designated to protect/conserve natural recourses including wild life.
6. **Native Title:** This is common in Australia (Aboriginal and Torres Strait Islander people). This type of title recognises tenure over land and water for people who have been living and practicing traditional norms and laws prior to independence.

For purposes of this study we refer to customary land as a type of communal land that is allocated for residential and farming purposes. While communal land is the collectively owned land by indigenous people, which is administered in accordance with local customs. The words communal and customary may have been used interchangeably in this study as they are believed to be synonymous.

2.2. Boundary Concepts

Dale & McLaughlin, (1999) define a boundary in legal and common language. Legally, a boundary can refer to an imaginary line dividing neighbouring estates, while in common language, the term represents the physical objects representing this line of division. Kaufmann & Daniel, (1998) define it as a dividing line between physical or abstract spheres. They separate areas belonging to different behaviours, territories, societies, jurisdictions, clans and natural and legal persons. More specific on real property, we consider a definition by (Jing et. al., 2011) who define a boundary as a line (imaginary) marking the bounds of two adjoining parcels of land. Therefore, based on these definitions, it can be concluded that a boundary can either be a physical object that marks the extent and limits of a property or it can be an imaginary line that divides two properties.

The description of parcel boundaries, in whatever form, is an essential prerequisite for land administration (Lemmens, 2011). This is because in many legal systems ownership of land is said to extend to the centre of the earth and extend to the infinite skies, which would include all natural and man-made features attached to the land in question. Therefore, means of determining such boundaries should be such that reduce disputes between neighbours or help solve such disputes when they arise. The determination of boundaries depends on the type of boundary in question; fixed, general or numeric.

2.2.1. Fixed Boundaries

Fixed boundaries are those that are determined accurately by a professional land surveyor, boundary corners can as well be traced accurately once lost because boundary corners are monumented and coordinated accurately (Tuladhar, 1996). In addition, fixed boundaries are legally binding when an agreement is reached between two neighbours and as such monuments cannot be moved without a transfer document(Dale & McLaughlin, 1988). Dale & McLaughlin, (1999) distinguish three categories of fixed boundaries:

1. Defined on the ground prior to development and identified - for example, in documents of sale;
2. Identified after development - for example when the line of the boundary is agreed on between neighbours at the time of adjudication;
3. Defined by surveys to specified standards

2.2.2. General Boundaries

General Boundaries on the other hand are not surveyed accurately and boundary lines are demarcated by existing physical features such as walls fences and hedges. Dale & McLaughlin, (1999) defined general boundaries as the approximate line(s) of the boundary, whereby the precise details can only be established through further investigation. The vagueness of such a boundary system allows for the land register to ignore shifts in the agreed position of the parcel corner (Tuladhar, 1996). This method is appropriate in rural areas of developing countries where accuracy is of little concern. The establishment of general boundaries in these areas can be done through photogrammetric means which is generally more cost effective and efficient than fixed boundary system (Lemmens, 2011). Likewise with fixed boundaries, Dale & McLaughlin, (1999) distinguish three categories as follows:

1. The ownership of the boundary feature is not established, so that the boundary may be on one side of a hedge or the other or down the middle;
2. The boundary is the indeterminate edge of a natural feature such as a forest; and
3. The position of any boundary is regarded as approximate so that the register may be kept free from boundary disputes.

Namibia uses a fixed boundary system using beacons as permanent land marks. Werner & Dahl, (1999) states that; the Land Survey Act is the guiding legal framework for land surveying in the country. This Act compels all land in Namibia to be surveyed by a professional land surveyor before it can be registered with the deeds office. The accuracy standards make the system very reliable and secure but however very expensive. Land Surveying is carried out by private land surveyors; as a result it becomes very costly and is only affordable to a few.

In communal land areas however, accuracy is not highly considered because parcel corners are not demarcated. A general boundary approach is used; therefore no permanent beacons are installed. For that reason less accurate fit-for purpose methods have been applied. This is however argued to be in conflict with provisions of the survey act because it does not conform to minimum accuracy standards. As a result communal land (unless surveyed professionally) is not registered in the deeds office of Namibia. This is one of the issues which would be potentially solved by the UAV method.

2.3. Land Registration

In the following section we discuss land registration. It is important for this study to understand land registration and its underlying aspects. Land registration makes the back bone of cadastral surveying of parcel boundaries which is the main focus of this research. Knowledge of land registration gives the researcher an insight of why registration is done; how it's done (adjudication) and where this "registration" takes place (cadastre). Land registration is a key aspect in land administration. Dale & McLaughlin, (1988) define land registration as "the process of recording officially recognised interests in land". Zevenbergen, (2002) describes it as a process of officially recording rights in land through deeds or title. In (Zevenbergen, 2004), land registration is discussed in a systems approach.

For this study, land registration is considered as the aggregated processes of land adjudication, demarcation, surveying, and recording (Henssen, 2010) . This means there is an official record (land register) of rights pertaining to the legal situation of a particular land parcel. The paper further notes that land registration gives an answer to "who" owns the land and "how" it is owned.

2.4. Adjudication

Dale & McLaughlin, (1999) defined adjudication as the practice in which existing rights pertaining to a land parcel are authoritatively established. Adjudication is a prerequisite to registration of title and to land consolidation arid redistribution, the process does not alter existing rights or create new ones. Meanwhile; Zevenbergen, (2004) discusses adjudication in a systems approach, noting that adjudication is the first of three functions that a system of land administration should fulfil. Dale & McLaughlin, (1999) further describe Adjudication as the first step in the registration of title to land which encompasses procedures for determining what rights exist on the ground.

Adjudication may also be said to be part of the land registration system. Lemmens, (2011) defines adjudication as the process of acknowledging existing rights by an authoritative institute. It is the first stage in the registration of land rights in areas where these rights are not yet officially known. The same author further notes that adjudication is merely concerned with formalising land rights which already exist. It is made up of two aspects, legal and technical. The legal aspect is concerned with the identification of rights and resolving disputes that may arise in the process Dale & McLaughlin, (1999). The technical aspect of adjudication is concerned with the identification of parcel boundaries through cadastral surveying and mapping. Such parcel boundaries are mapped and given a unique parcel identifier (Williamson et al., 2010) As such; this study focuses on the technical aspects of adjudication.

2.5. Cadastre

To give an answer to "where" and "how much" we consider the cadastre. A Cadastre is an official record of information about land parcels, including details of their boundaries, tenure, use, and value (Dale & McLaughlin, 1988). Zevenbergen, (2002) on the other hand describes a cadastre as a systematically arranged public register of property data, which is based on the survey of the property boundaries. Lemmens, (2011) elaborates further emphasizing on the importance of having a method that traces boundaries unambiguously on land parcels as they are key entities of the cadastre. This is in order to solve or prevent disputes. In terms of this study, the definition from Zevenbergen, (2002) will be used because it has a spatial focus.

It is important to note that land registration and cadastre complement each other. Terms like land recording or land records are used to refer to the two components as a unit (Henssen, 2010). In this study, the researcher will discuss the Namibian communal land administration system (NCLAS) which is a cadastral database that is the official repository of information collected during the adjudication and mapping procedure. Thus, knowledge about the "Cadastre" is vital. Furthermore, knowledge on cadastral surveying gives the researcher an understanding on the basic principles of surveying land, why the need for surveying in relation to land registration and adjudication, and different methods that are used in the practice of surveying.

2.6. Cadastral Surveying and Mapping

Surveying can be defined as the art and science of making measurements of the relative positions of natural and manmade features on the earth's surface, and the presentation of this information either graphically or numerically (Bannister et. al., 1998). Land surveying involves determining the spatial location of points on or near the surface of the earth and displaying them on a map (Cole, 2003). Whereas, according to Louw, (2004) mapping is the construction of a real world model on paper from measurements taken in the field.

As noted by (Holmberg, 2006) there are different types of surveys; ranging from geodetic, control, plane, topographic, hydrographical and most importantly for this research cadastral survey. Holmberg, (2006) defined cadastral survey as a survey that creates, restores, marks, and defines property lines of parcels of land to describe individual ownership. Cadastral surveying can further be defined as the determination, demarcation, surveying and mapping of property boundaries (Louw, 2004).

These definitions conclude that surveying and mapping is concerned with determining the legal and physical extent to which land is owned. Cadastral maps are maps that show graphical information about surveyed parcels of land within a specified area. They show all the surveyed land parcels in a given area in relation to one another. (Louw, 2004) further describe a cadastral map as a plan showing the relative position and boundaries of surveyed parcels of land. Cadastral surveying forms the basis of land administration, it serves as a pivotal tool to collect and analyse spatial data in support of a country's land administration system.

2.6.1. Surveying Techniques

The last 30 years have seen a dramatic increase in the development of new survey techniques, from traditional optical instruments to newer sensor platforms (Scaioni et. al., 2014). According to Dale & McLaughlin, (1999) there are two broad categories of surveying techniques or methods, namely the field survey technique (ground survey method) and the photogrammetric survey technique (aerial photography method).

Field or ground surveying is the most common method used in land surveying. Over the years, cheap and simple methods such as tapes and optical squares to more sophisticated total stations have been used (Larsson, 1991). However, advancement in technology has seen the increase in use of more sophisticated Real Time Kinetic GPS/GNSS systems as they offer more efficiency and accuracy.

Photogrammetry can be defined as the art science and technology of obtaining reliable spatial information by the interpretation of photographs. As a method of measurement, the disadvantage of photogrammetry lies in that the measured object has to be reduced in size to fit the scale of a photograph, while the advantage lays in that photogrammetry offers the only solution to measuring in instances whereby direct measurement is impractical, impossible or uneconomical(Bannister et al., 1998). Photogrammetry uses various remote sensing techniques for the acquisition of photographs. It can be argued that photogrammetry is a subset of remote sensing in which all measurements are done within the visible part of the electromagnetic spectrum (Awange & Kyalo Kiema, 2013). The main outputs of photogrammetric operations are Digital Surface Models and Orthophotos.

Aerial photogrammetry and close-range photogrammetry are the main categories, the latter being a method in which the camera is close to the object, i.e. hand held or mounted on a pole. According to (Bannister et al., 1998) Aerial photogrammetry involves the use of photographs taken in a systematic manner from the air. Hence, the photographic sensor is mounted on an aerial platform such as aeroplane, UAV, kite or balloon. It is important to note that when aerial photos are being taken, there should be no gaps between the series of photographs, also for stereoscopic analysis, every point on the ground must feature in at least two images, hence images are taken at minimum 60 % overlap, creating stereo pairs(Bannister et al., 1998).

Siriba, (2009) identified five ways in which photogrammetry can be used in for parcel boundary mapping; The use of digital or analytical stereo plotters or comparators, the preparation of base maps by photogrammetric stereo compilation, the use of orthorectified photographs, the use of simply enlarged but rectified photographs to identify land parcel boundaries, and the identification and plotting of land parcel boundaries using simply enlarged and unrectified photographs. This study examines the use of orthorectified photographs in mapping customary land parcel boundaries. This has been widely applied in mapping customary land parcel boundaries in some African countries; Ethiopia (Lemmen, 2009), Kenya (Ondulo & Kalande, 2006), Rwanda (Akinyemi & Nkubito, 2013) and Namibia (Meijs et al. 2009).

This study will discuss UAV technology that is growing popularity in cadastral surveying and mapping. Together with photogrammetric operations, this technology has the potential to be an effective means to capture image data for adjudication and mapping purposes.

2.7. Unmanned Aerial Vehicles (UAV)

Unmanned Aerial vehicles were initially designed for military operations, however recent advancement in technology have seen smaller, more lightweight platforms being used in civilian applications such as Forestry and Agriculture(Engel & Teichert, 2008), Mapping and Surveying (Nex & Remondino, 2013). The term UAV photogrammetry has emerged (Eisenbeiss, 2009), which in simple terms is the use of UAV platforms for photogrammetric measurements. When used as mapping platforms, the platforms are equipped with photogrammetric measurement systems such as still or video cameras (Eisenbeiss, 2011)

Bailey, (2012) defined UAV as a motorised aircraft system controlled remotely by remote control devices, or completely autonomous with the aid of an on-board system of navigation and a control station. Apart from the name UAV, various other names such as; Drone, UVS (Unmanned Vehicle System) and UAS (Unmanned Aircraft System) are commonly used. As argued by (Eisenbeiss, 2009), UAS is commonly understood to refer to the whole system; the UA(Unmanned Aircraft) and the ground control station(GCs).

There are two distinct categories of UAVs, Rotary-wing and fixed-wing UAV systems. Rotary-wing is based on rotors and blades, and is said to be well suited for surveying small areas(figure 2), whereas the fixed-wing's design is based on that of an actual aircraft (Figure 3) and is suited for surveying larger areas (Tahar & Anuar, 2012). Furthermore, the multiple rotor design of the rotary-wing gives it the ability to fly steadily, hover over an area and capture images (Eisenbeiss & Sauerbier, 2011). According to Tahar & Ahmad, (2013), this gives the rotary-wing the ability to be more stable and thus capture images easily.

Figure 2: Aibot X6 Hexacopter Rotary Wing

Figure 3: Mavinci Sirius Pro Fixed-Wing (Mavinci, 2015)

Both types may be used in land administration projects, depending on the scope of the project and extent of the area to be mapped. For example, mapping an entire village of up to 100ha would require a fixed wing, whereas mapping selected homesteads in that village would require the use of a rotary-wing UAV. In a UAV test in Switzerland, Manyoky et al. (2011) used the Octocopter Falcon 8 rotary wing UAV to capture images and demonstrated that UAV could reach the required accuracy for cadastral surveying. Many other UAV tests have been undertaken recently. A study by Jing (2011) investigated the application of UAVs in adjudicating land rights in a city in China and concluded that UAV technology can benefit adjudication in rural areas where accuracy standards are not high. Meanwhile Barnes et al. (2013) developed a methodology that outlines the steps involved in using UAV for cadastral surveying and mapping projects, emphasising on community participation. This was done on a case study basis in

Northern Ghana. A similar methodology can be seen in (Eisenbeiss, 2011). In Albania (Kelm et.al., 2014), UAVs were tested in three major areas; rural mapping applications, urban mapping applications and peri-urban applications. In the rural area, it was tested whether the technology can deliver high resolution orthophotos for administering compensation related to expropriations for infrastructure projects as well as for cadastral surveying. An orthophoto with 2cm accuracy was produced. The Albanian tests concluded that UAV technology is indeed fit-for purpose because it includes elements of flexibility, participation, inclusivity, affordability, reliability and upgradeability.

3. RESEARCH METHODS

The previous chapter discussed in detail, theories and concepts necessary in guiding this research; this chapter will give a description of the methods and techniques used in answering the research questions.

3.1. Research Approach

This study employs the scientific research process of conducting research. The scientific process is described in Kothari (2011) as a process consisting of series of actions necessary to carry out research, and the desired sequencing of the steps. Furthermore, the study is based on applied research, according to (Kothari, 2011), applied research aims at finding a solution for an immediate problem facing society or an industrial or business organisation. Two kinds of literature were examined for the researcher to be well acquainted with the problem. Firstly, conceptual literature was gathered and reviewed. This type of literature is made up of concepts and theories concerning the field of study. In this case, concepts such as surveying, land tenure, boundaries, mapping, photogrammetry, customary land and adjudication were reviewed. Secondly, empirical literature comprising of previous studies were reviewed. Case studies of UAV use in cadastral applications, as well as studies on land tenure regularisation. This helps the researcher objectively validate the background facts concerning the problem, hence addressing the research problem meaningfully. This research was designed taking into consideration the order in which the research objectives are outlined. It took three main stages; Pre-fieldwork, field-work and post-field work, as can be seen in figure 4.

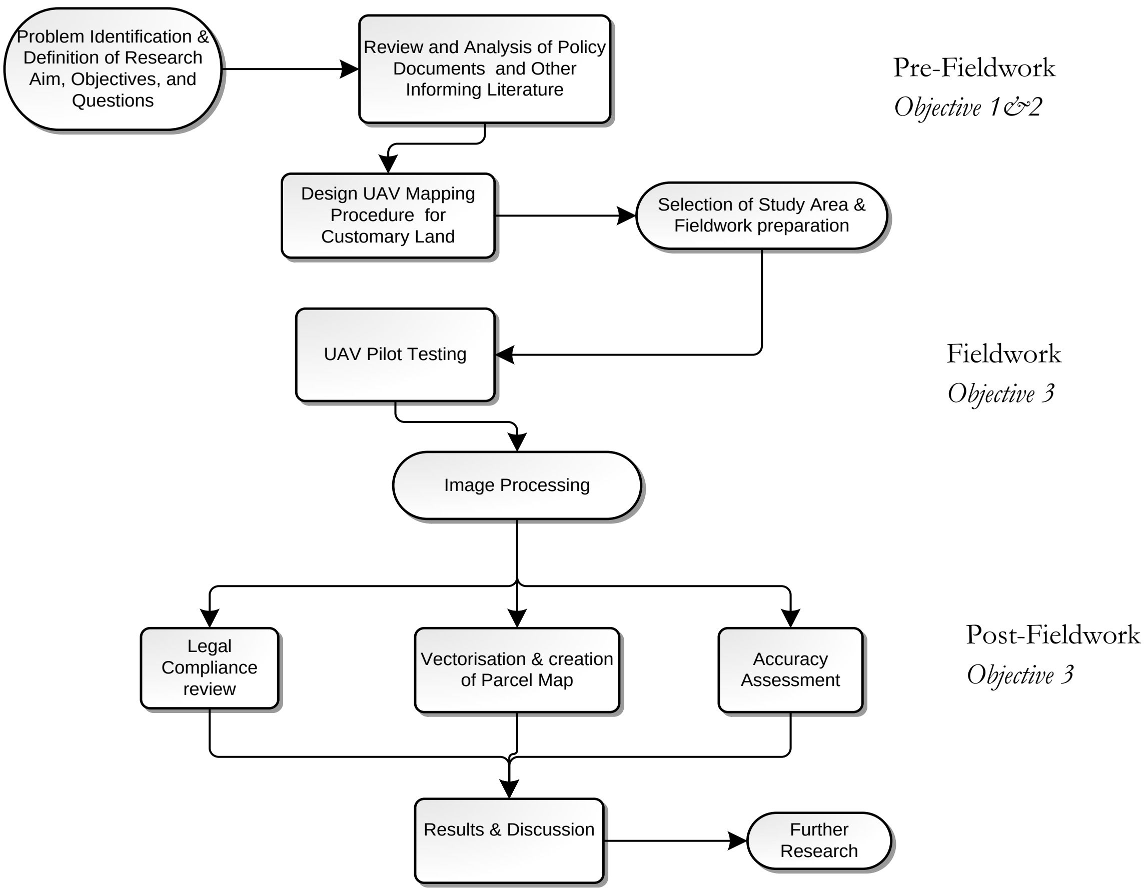

Figure 4: Research Workflow

3.1.1. Pre-Field Work

During the pre-fieldwork stage, questions to objectives 1 and 2 were answered. *Objective 1* aimed to understand the current context regarding customary land mapping and UAVs, which was intended at determining the laws, policies, tenures approaches, and technologies that inform customary land mapping. To answer this objective a comprehensive analysis of legal documents, policies, reports, manuals and some published articles concerning land in Namibia were reviewed. These are summarised as follows:

Policy (Legal compliance)

Document Reviewed & Source	Type	Relevance
The Constitution of The republic of Namibia	Law	Article 16 of the constitution provides for the right of acquisition, disposal, and ownership of land by Namibians in any part of the country. In order to understand any laws governing land, it is important to make reference to the constitution, it being the supreme law of the country.
National Land Policy of 1998	Policy	This Policy was enacted in spirit of national reconciliation constitutionality and nation building, the problem of dispossession, discrimination, and inequitable distribution of land that was characterized by the pre-independence era. The Policy provides for a unitary land system where Namibians have equal rights, opportunities, and security across a range of land tenure irrespective of whether the land is in communal or commercial area. Important for this research, the policy informs about the different land tenure approaches in the country.
Communal Land Reform Act, Act No 5 of 2002	Act	The act was promulgated for the allocation of communal land rights; as well as to establish Communal Land Boards, and give allocating powers to Chiefs and Traditional Authorities (LAC, 2005). It is important in this study to consider this act as it is the guiding legislation for communal land.
Land Survey Act 33 of 1993	Act	The land Survey Act, Act 33 of 1993, was promulgated to regulate the survey of land in Namibia and to provide for all matters incidental thereto (Government Gazette No 770, dated 22 December 1993). It is important in this research to consider this act as it informs the researcher about the land surveying procedures in different parts of the country.
The Aviation Act 74 of 1962	Act	This act was enacted to make provisions for the control, reinforcement and regulation of flying within Namibia's airspace. Since this research is based on UAV surveying, it is important to understand what this law regulates regarding UAV use in the country.

Document Reviewed & Source	Type	Relevance
Olukonda Project Report 2008 (MLR)	Report	This document provides an insight of the activities that took place during the pilot testing of aerial photography use in mapping Namibia's northern communal areas. The document gives technical information regarding the process of customary land registration
NCLAS Manual (MLR)	Government Publication	This document is relevant in this research because it is the reference manual on how activities of customary land mapping are currently being undertaken.
Namibia: Country Report 2003 (Owolabi, 2003)	Report	This report highlights the land surveying system and cadastral approaches in the. It also highlights different land tenure systems, which are vital in this research.
Land Registration using aerial photography in Namibia : Costs and lessons (Meijs et al., 2009)	Published Article	This article presents the findings of the initial pilot project of mapping customary land parcels with aerial photographs. It gives vital background information needed in this research.
Establishing Communal Land Registration in Namibia : The Process , Benefits and Challenges (Kasita,2011)	Published Article	This article discusses the customary land registration system in the country, how it was established, benefits and the challenges. Such information is vital in this research.
Communal Land Support Sub-activity Registration Strategy & Implementation Plan (MCA, 2010)	Report	This report gives an improved procedure for mapping customary land parcels which was trialled (using DGPS) but not implemented. The document also reports on an improved general methodology for registration of land rights as a whole.
The Potential of Unmanned Aerial Vehicles for Mapping (Eisenbeiss, 2011)	Published article	This paper gives an introduction of UAVs in survey and mapping. It is relevant in that this research is based on the same concept.

Technical information from the above literature was also vital in the development of the UAV mapping procedure for customary land.

Objective 2 was aimed at designing a new customary mapping process around UAVs. To arrive at this objective, further review of literature regarding UAV mapping processes was carried out. A generic process was adopted and modified to best fit customary land mapping. To model the new procedure, various process modelling techniques were used. Many other articles were read, and are evident in this research. However, the listed articles were essential in the design of the UAV mapping process for mapping customary land.

Document Reviewed & Source	Type	Relevance
Drones for Peace : Part 1 of 2 Design and Testing of a UAV-based Cadastral Surveying and Mapping Methodology in Albania (Barnes et al., 2014)	Published article	This article presents a generic methodology for using UAVs in surveying and Mapping. The methodology presented in here was adopted and modified to fit the purposes of this research.
Unmanned Aerial Vehicle In Cadastral Applications (Manyoky et al., 2011)	Published Article	This article presents another methodology for mapping land with the use of UAV. This methodology was also considered in the design of the customary land mapping procedure in this research.
A simulation study on the capabilities of rotor wing unmanned aerial vehicle in aerial terrain mapping (Tahar & Anuar, 2012)	Published Article	An important methodology is also found in this article. The methodology is for using UAV in aerial terrain mapping, which is similar to the objective of this research. This methodology is presented by means of a flow chart. In addition, this article presents accuracy assessment procedures for assessing UAV output.
Assessment of Photogrammetric Mapping Accuracy Based on Variation Flying Altitude Using Unmanned Aerial Vehicle (Udin & Ahmad, 2014)	Published Article	In this article an accuracy assessment procedure is presented, as well as a methodology for adoption. Since this research is also aimed at finding out accuracy of the mapping output, this is an important article to consider.

After adopting the UAV mapping procedure from various works, the new procedure for mapping customary land parcels was modelled. This was done by considering the existing procedure for registration of land rights (which encompasses mapping of parcels) and combining it with the UAV mapping procedure adopted and modified for customary land purposes. It should be noted here that the author of the thesis brings extensive knowledge of the existing process of mapping customary land parcels in Namibia, through working in this area for a period of 4 years. The following inputs were necessary in the completion of this task:

(i) *UML modelling software* – The Software is used to design and model workflows and flow charts in the order of UML activity diagrams. An activity diagram depicts activities that must be realized to execute a business process and the relationships among them (Bastos et al., 2002). This software is mainly used for software systems design. It was chosen in this this thesis for its ease of use in modelling workflows.

(ii) *Existing Procedures for mapping customary land parcels in Namibia*- Since UAV mapping will be fused in mapping customary land parcels (registering land rights) the current procedure is important to take into account.

(iii) *General methodology for surveying and mapping with UAV*- These methods are the backbone of designing the new procedure.

Having these inputs into consideration, four main activities were chosen as swim lanes. Each main activity was given suitable sub-activities that completed the flow chart. A swim-lane is a method of grouping activities executed by one actor in a single lane; this is useful in identifying the steps, and the actor (employee) responsible for each step. Swim-lanes may also aid in identifying obstacles in the process(Damelio, 2011). Swim-lane diagrams are useful for presenting how each activity in a business process crosses roles(Alter, 2007). This is useful in this research because the activities being modelled consists of sub-activities that interconnect. That interconnection of sub-activities should be displayed without losing track of the main activity.

3.1.1.1. Selection of Study Area

The study took place in the "Freedom Square" informal settlement situated on the outskirts of Gobabis. Gobabis is the regional capital of the Omaheke region, located 200km east of the capital Windhoek, along the Trans Kalahari highway towards Botswana (22°00'S 19°30'E). Freedom Square is situated to the north of the Epako settlement. It has approximately 3188 inhabitants in 808 households, the housing structures are made of corrugated iron sheets, plastic, grass and wood. The area was chosen because it gives a broad overview of the diverse spatial and social structures in different communal parts of the country. It was understood that the close proximity of the area to the town of Gobabis, would accord the researcher more time to sensitize communities prior to the flight, to process the data and return to communities within 24 to 48 hours with the finished product to complete the mapping exercise. In the end it took less time and effort to get much higher yield in terms of number of households and variety in development status and density, although the mapping test only took place at a later stage. The figure 5 shows the location of the study area.

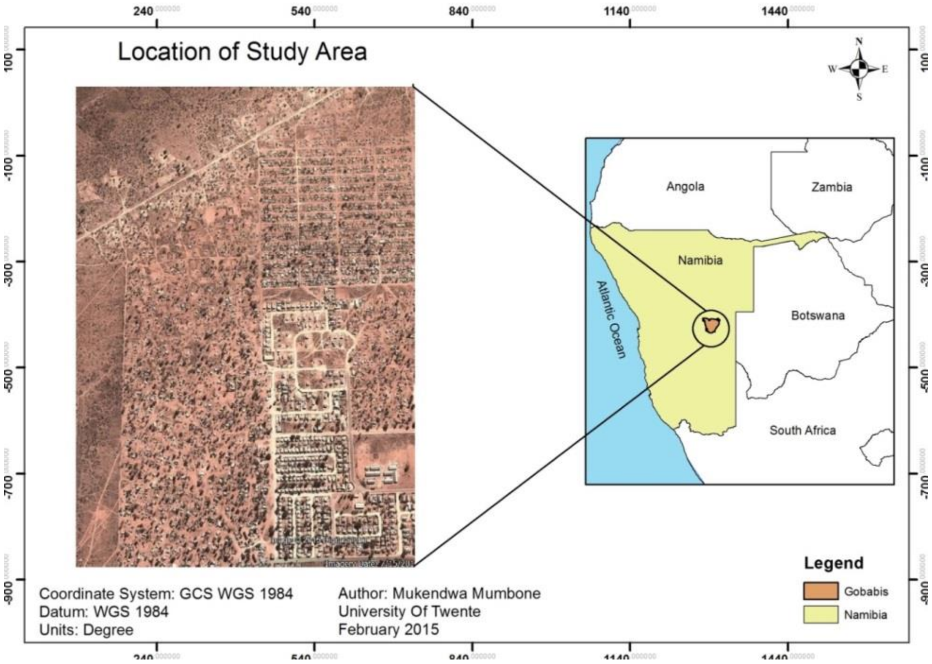

Figure 5: Location of Study Area

3.1.2. Field Work

During the fieldwork stage, questions to Objective 3 were answered. *Objective 3* was aimed at validating the newly designed procedure for mapping customary land parcels. Only one aspect was validated here, which is the execution of the UAV mapping procedure. It should be noted here that the focus of this exercise was only to validate the mapping procedure and its outputs. Whether or not the complete land registration procedure enabled with UAV mapping can be implemented in reality is subject to further research.

The validation of the mapping procedure was carried out as a pilot study in the selected study area. For this research "pilot study" is defined as a small scale trial aimed at evaluating the feasibility of a newly designed product or equipment (procedure) with the aim of finding out whether the procedure works for the intended purpose or not. During the pilot test, the activities in the designed procedure were executed systematically as they are modelled. This is narrated in the following text, including procedures, tools and inputs that were employed.

A locally manufactured fixed-wing drone was used to capture the Imagery in the study area "Freedom Square" which covers an area of 160 ha/1.6 square kilometres. It was fitted with a 16mp camera from Sony, and had a payload of 650g (Annex 3). A total of 23 ground control points where placed systematically across the area, using V-maps differential GPS system (Annex 3). The V-Map system is a pair of light weight (130g) dual frequency receivers, small and light enough to be carried by small drones. The units are configured for event marking and are primarily designed to determine camera exposure positions by means of post-processing L1 and L2 phase observations. To locate a known reference point, coordinates were sourced from a land surveyor who had previously surveyed the area. These coordinates were loaded into a GPS navigating device, with the aim of locating at least one of the reference points.

This activity however proved futile as the markers had either been removed or buried deep in the sand. To remedy this situation, a local reference point was established and a local reference station was installed and positioned through GPS (WGS 84 Datum). It is important to note that because of the remaining, unknown offset with the mapping frame, the coordinates of the GCPs also have this unknown bias. Locally, however, this is acceptable. The residuals observed in pix4d are in XY are still in cm range. Manholes, tires and white paper plates stuck in the ground were used as markers. The excess amount of ground control points were a guarantee that in the end of the flight, some GCPS would still be visible besides being removed by children or blown away by the wind. Otherwise, only 17 of them were used; 12 control points for geo-referencing and 5 check points for validation. The coordinates where established using post–processing techniques because the GPS system was not in Real Time Kinetic (RTK). Whether in practice such a large number of ground control points is necessary is subject to further research. In this research, the researcher wanted to ensure highest available accuracy.

In order to be able to later assign the right coordinates to the correct ground control point, each time a ground control point was established, its positions was fixed by placing and levelling the rover over it for 60 seconds, during which a photograph was taken at 30 seconds on each point with a camera whose time is synchronised with that of the GPS. Using the open source planning software called "Mission Planner" a flight plan was designed to cover the study area with an average ground sampling distance (GSD) of 45mm. The flight plan was uploaded to the UAV system, which was then launched to capture 16MP images with the following specifications: 150m flight height and an average air speed of 14m/s, a lateral overlap of 70%, and forward overlap of 80%. This was the end of the field work exercise.

3.1.3. Post-Field Work

The post-fieldwork stage was the data analysis and presentation phase. The image data collected in the field was processed and evaluated. This was followed by thesis writing, in which the processing and discussing of results were presented in logical order as per the objectives. Finally, recommendations for further work were given. The entire process was then validated against the prescribed laws, and the assessment of the mapping output (orthophoto) in terms of accuracy.

After the field work was completed, Image processing and analyses took place. The image processing was carried out using professional software called "Pix4DMapper" from Pix4D. The interior orientation parameters of the camera (focal length, position of the principal point, and lens distortion parameters) were estimated through a self-calibration process, i.e. during bundle block adjustment. An alternative pre-calibration was not possible in the field, and experience shows that self-calibration delivers sufficient accuracy for most applications. After bundle block adjustment, photogrammetric results such as a Digital Surface Model (DSM) and an Ortho-mosaic were generated. For this research only the Orthomosaic was used for further analyses. It was used in the vectorisation of delineated parcel boundaries.

The next stage in the methodology is the quality check. This was the assessment of the photogrammetric result in terms of accuracy. During initial processing by pix4dmapper, an accuracy assessment report for the bundle adjustment was generated (Annex 2). To evaluate the quality of the orthophoto, further analyses were done. GCPs were uploaded into Arcmap, where the base layer was the generated orthophoto. A manual approach was applied where the researcher visually checked if the uploaded coordinates of the ground control points fits with their marker on the orthophoto. In cases where there were significant differences (mostly in cm), the researcher then manually retrieved the coordinates from the centre of the mark which is visually represented in the orthophoto. An assumption was made to use the GCPs collected in the field by GPS as the reference value to use in comparison with the coordinates retrieved from the orthophoto in arcmap. The Root Mean Square Error (RMSE) of the coordinates was then computed in Microsoft Excel. See (Tahar & Anuar, 2012) for further accuracy assessment procedures.

As per the workflow, vectorisation is the final stage in the process. In this study, this activity took place after the image processing and quality checks were completed. Since the researcher could not return to the field personally to conduct a test on parcel delineation, research support was sought from colleagues in Namibia. A colleague with experience in mapping procedures in customary became the research support. The research support made the necessary arrangements with a community representative to gather a sample of around 15 random residents who were available and willing to participate in the exercise. A small gathering was then held with the people. During the gathering, a laptop was used to view the orthophoto digitally in Arc Map. Each of the people took turns to identify their parcel boundaries on the digital image, allowing the support researcher to delineate the 2D footprint of the parcel. The parcels information was immediately entered in the attribute table. Each parcel was given a unique parcel identifier (UPI) for identification purposes, since no sufficient permissions were sought to use the participant's names in the research. The researcher then used this data to create a sample cadastral map (figure 12) of a defined area for display purposes only.

3.2. Research Limitations

There were no major obstacles faced in the execution of the set activities. However, during the planning and preparation stage, the project was delayed by the sourcing of GPS equipment; fortunately the V-Maps were available. The survey of ground control points was found to be a lengthy exercise because more ground control points than needed were surveyed. The paper plates used for target markings were not easy to locate on the images during processing. The paper plates are similar to many other features in the surrounding, such as plastic bags and other kinds of rubble. Some paper plates had to be replaced numerous times because of the wind, demanding for some points to be resurveyed. This would have been avoided had we used more distinct features like white concrete slabs. This method would work in a more permanent situation, but since this was done only for research purposes, paper plates were adequate. Due to time and distance constraints, the researcher was unable to return to the field to personally conduct the vectorisation process. However, an appropriate solution was reached.

4. RESULTS AND DISCUSSION

4.1. Current Context Regarding Customary Land Mapping and UAVs

4.1.1. Policy

Various types of legal documents were reviewed to uncover the legal and technical details surrounding customary land mapping and use of UAV.

The Namibian Land Policy of 1998

A review into the policy revealed that survey and mapping is only discussed with relation to urban land. There is no relation made to rural (communal) land surveying. Hence, there are no requirements for mapping stipulated in the land policy.

Communal Land reform Act no 5 of 2002.

It was vital to for this thesis to study this act as it is the guiding legislation for communal land. Despite this piece of legislation demanding for customary land parcels to be mapped and adjudicated in Namibia, surveying methods are not prescribed. This study uncovered that this act does not specify the type of survey instruments or the minimum accuracy standards that should be considered in mapping customary land parcels.

The Land Survey Act, Act 33 of 1993

The land survey act 33 of 1993 specifies classes of surveys, and accuracy standards, but nothing specific is said about communal land. Class A for urban areas, Class B for surveys in townships, and Class C for all others not contained within class A and B. It is also stipulated under the same regulation that the Surveyor General may determine the standard of accuracy of any survey operation that is not specified in the regulations. There is however no documentary evidence that the Surveyor General has ever determined any surveying standards for communal lands. There researcher found this to be vague and ambiguous as there is no reference of communal land contained under any of the mentioned classes.

The Aviation act 74 of 1962

The Namibia Civil Aviation Authority compels any person who would like operate a "remotely piloted aircraft", which in this study is understood as a UAV, to seek prior approval from the relevant authorities. According to the aviation authority, UAVs may not be operated within a published controlled zone, air traffic zone or air traffic area. The maximum flight height cited is 45.7m/ 150 feet, and this should not be closer than 9.26 km to an airport. Research has shown that UAV use is heavily regulated in most developed countries for security reasons. In the case of Namibia, this study reveals that there are regulations put in place for using the UAVs, but the aviation authority (Aviation act 74 of 1962) does not restrict the use of the technology. However the researcher observed that these provisions are rarely enforced because UAV technology is still new in Namibia, and only a few people use it. Therefore, the authorities are yet to be alarmed about UAV use in the country.

Land in Namibia, like other sub Saharan countries is vast. However, land is not equally distributed and its utilization is controlled by factors such as climatic conditions, limited water resources and physical geomorphology. The current distribution of land is also influenced by the countries' colonial past and current land prices, and as such, thousands of hectors are held in private hands or the few who can afford it. The colonial regime brought about a situation in which less than 10% of the population own close to half the land, while 65% of the population live off the rest (41%), this can be seen in (Table 2). It can be seen in the same table that communal land covers an area of 326293 km², which is the total communal land area in the country. Whilst the area is this large, the smaller customary land rights (parcels) of around 20ha are what this thesis is aimed at mapping, not the entire area.

Table 2 Distribution of land in Namibia

Land Tenure	**Land Category**	**Total Area km²**	**Percentage of total area %**
Freehold, Leasehold	Rural Private land / Commercial	35907	43.2
Communal, Leasehold	Communal Land	326293	39.5
State	National Parks	114500	13.9
State	Registered Diamond areas	21600	2.7
Leasehold, Freehold	Urban Private land	5900	0.7
	Total	824 200	100

(UN-Habitat, 2005)

According to (Odendaal, 2014), The German colonial rule from 1885 to 1915 created two land use zones. The Police Zone was a "whites only" settlement that was held under freehold title. Outside the Police Zone were the northern and north-eastern parts of the country which were created for the indigenous black Namibian people. Movements by the indigenous people outside these areas were restricted by legislation. Today, all land outside the police zone is referred to as communal land. Although linkages to Namibia's political past has influenced the land distribution subject, the national government has initiated through line ministries, programmes that a geared to tackle land distribution. 25 years after independence, the task has proved to be a slowly progressive process. Recommendations of the UN-FIG Agenda 21 is that countries should set-up land tenure types ensure security of tenure for all land users; Particularly women, people with low income in urban areas, indigenous people and those in rural areas. Based on these recommendations, after independence the Namibian government implemented a land policy that was aimed at introducing land tenure forms that will ensure its citizens access to land. Namibia thus recognizes the following land tenure forms:

4.1.1.1. Freehold land tenure

Freehold land refers to land that can be bought, sold and owned by private individuals. This type of land is registered in the deeds office, hence giving security of tenure to the owner. Registration of the title deed in the deeds office means the ownership of that piece of land is protected by law. Freehold land can either be a residential plot in a city or town or a commercial farm in the rural areas. During the apartheid regime, freehold ownership of land was restricted to white settlers only. By independence, all commercial farmland was owned privately by only a fraction of the country's population (42% of the land owned by 4500 individuals) while the majority find themselves in the former reserves. After independence, the Agricultural commercial land reform act 6 of 1995 was enacted with the aim of redressing some of these past injustices related to commercial land distribution.

The government of Namibia practices a willing buyer willing seller system of land reform, which gives the state the right of first refusal to purchase all commercial farms. It is through this program that the government waits for a farm to be offered and then exercise its rights to purchase the land for purposes of land reform and redistribution. This system has however received scrutiny from the landless public for its slow delivery of land. Despite government having the right to expropriate land as per the constitution, this mode of land acquisition is yet to be used in the country.

4.1.1.2. Leasehold Land Tenure

According to Amoo, (2014) The Common law and the Communal Land Reform Act allow for land leases. Leases of communal and commercial land can be granted by Communal Land Boards and the government for a period of 99 years and may be transferred, inherited, renewed, and mortgaged.

4.1.1.3. Occupancy in Informal Settlements/Flexible Land Tenure

Flexible land tenure is an incremental system of land tenure in which informal tenure is gradually upgraded to freehold status(Christensen, 2004). Christensen and Hojgaard (1997) identify three tenure types for the Flexible Land Tenure System in Namibia; Starter title, Land hold title and Freehold title. The above tenure types are designed to provide security of tenure and different land rights for different land-users with the basic two being able to be upgraded to freehold title. These rights are all to be registered at a local property office.

4.1.1.4. State land

The constitution of the Republic of Namibia (Article 16(2)) states that all land belongs to the state, unless lawfully owned by an individual or any other legal person. Most state land is made up of proclaimed diamond areas and national parks. The government has the discretion to utilise state land in a manner it sees fit. The state may lease the land to private individuals or proclaim some of it as either communal or town lands, as long as it is of benefit to the people.

4.1.1.5. Communal Land Tenure

Communal land is land that is held and managed under customary law. According to the constitution, communal land or any other land not otherwise owned by anyone vests in the state. The state gives powers to traditional authorities to allocate and cancel land rights. This is done through the Communal Land reform Act no 5 of 2002. The act also establishes Communal Land Boards to exercise control over land allocations done by traditional authorities (Meijs et al. 2009). Both these stakeholders work hand in hand in the administration of communal land across the country.

Communal land may either be held individually, as a family or in a group. Based on customary norms, customary land rights are held for the natural life of the right holder. In case of death, the right reverts back to the traditional authority to facilitate smooth succession measures among the hairs. The act further stipulates two categories of rights that can be allocated under communal land; customary land rights, which can be used for residential and subsistence farming, and leasehold land rights that may be allocated for business purposes (LAC & NNFU, 2003). Unlike commercial land, communal land is not surveyed or registered in the deeds office. As a result communal land may not be bought or sold, but can only be transferred according to provisions of the communal land reform act. Although some traditional authorities have kept personal land registers along the years, such registers only serve as evidence of land allocation and do not necessarily confer the same security as deeds registration.

Grazing land is reserved as commonage in which all residents of a particular communal area have equal access to graze their animals freely. However, due to the increase in population , socio economic changes, and increasing commercialisation of production on communal land, customary tenure systems have begun to wear off (Owolabi, 2003). This has exerted immense pressure on communal land, leading to various unlawful conducts such as self-allocation, land grabbing, boundary disputes and poor land management (Kasita, 2011).One response to this phenomenon was the introduction of land registration and mapping of customary land rights through the communal land reform act. According to (Meijs et al., 2009) the act was passed with the aim to facilitate a uniform land administration system, a system which is believed to secure land tenure and minimise land disputes in communal areas. It was believed that by having all land rights on communal land registered, land administration methods would improve.

All persons who held customary rights on communal land prior to the enactment of the act in 2003 was compelled to apply for the recognition and registration of such a land right by the end of February 2014, this deadline was extended three times by the Minister of Lands and Resettlement to allow for more applications to be processed. Parallel to recognition of existing rights, the act also calls for new customary land rights to be registered. New customary land rights are those rights that were acquired after the enactment of the act (1 march 2003 and beyond).

Registration of such land rights is an on-going activity and has no deadline. The typical use of customary land is subsistence farming and residential purposes, and seldom leasehold. Today a total number of 65559 land rights have been mapped and registered, and 188375 are estimated to be pending mapping and registration, see Annex 1. It should be pointed out that Namibia has 13 regions with communal land, but in the Kavango regions, no registration of rights is taking place due to resistance from tradition authorities.

4.1.2. Technical Situation

The Ministry of Lands and Resettlement maintains a communal cadastre system called the Namibian Communal Land Administration System (NCLAS) for administering communal land information. The NCLAS has two parts; the Communal Deeds and the Communal Cadastre. The Communal Deeds is a Microsoft office database in which non-spatial information is stored. The second part of the NCLAS is the Communal Cadastre. This is an ArcGIS based geo-database built in ArcSDE comprising of tabular and spatial data. The two parts are linked through a Unique Parcel Identifier system (UPI), which is a coding system designed to ensure that every land parcel has a unique name for identification purposes.

The UPI will also enable the consolidation of the NCLAS into the country's main Deeds system. Together with Personal IDs, the UPI makes it possible to register individual persons and individual parcels in separate tables, a separate rights table is used to join the two. The rights table consists of rights held by persons on the parcel. It's through the NCLAS system that land rights certificates are produced and other statistical information can be generated including parcel diagrams and village maps. (Annex 7) shows the position of the NCLAS in the land registration process, as well as the components.

Current Process for Mapping Customary Land Parcels

The process of mapping land parcels is part of the main process of customary land rights registration, which has 5 major steps. The first step in the process is the application lodgement. The current land registration system is generally carried out using a sporadic adjudication system. Hence, the process only starts when an application for registration of a land right is lodged with the traditional authority or the land board. Different application forms are available at offices of the Ministry of lands and resettlement and at traditional authority offices country wide. Application forms are submitted to either the communal land board (existing land rights) or the traditional authority (new land rights).

For purposes of determining the size of land parcels, and to support the graphical part of the Namibia Communal Land Administration System (NCLAS), parcel boundaries need to be established. The most convenient and affordable means is the use of Orthophoto. As pointed out in a report by the Millennium Challenge Account (MCA, 2010), orthophotos were acquired in 2008, and are available digitally. They are geo-referenced 10x10 km tiles with a ground resolution of 1 meter and an accuracy of 2-3 meters.

This process begins with the retrieval of tiles that cover the area to be mapped. Tiles are printed and stored as hard copy. The tiles are carried along in the field where parcel owners identify their parcel boundaries and mark them with a fine pointed marker pen. Sometimes this is done house to house, or in cases where a prior arrangement had been done, a community meeting is arranged. Back in the office, the tiles are scanned and the parcels vectorised. The problem with this approach is that the orthophtos are out-dated. The orthophotos are over 8 years old, and do not depict developments that have taken place over the eight years. In addition, the printing and scanning of orthophotos causes them to lose accuracy.

Alternatively, the use of GPS is employed. This system includes simple hand-held GPS devices with an accuracy of about 5-10 meters, and cost between N$ 500 – N$ 2000(€50-200) per unit. A GPS survey can map up to an average of 10 land parcels a day depending on the size. The process begins with the preparation of the GPS equipment. The GPS receivers are set up to WGS84 datum, and further set up to collect waypoints in Decimal Degrees. Parcels are marked by walking to each parcel corner and marking the way point at that specific corner. The way point numbers for each parcel are recorded on a paper (data collection sheet) as back up. Back at the office, the way points are downloaded into ArcMap as shapefile. Guided by waypoint numbers, the waypoints are connected to each other creating polygons (vectorisation), this information is entered into the communal cadastre (NCLAS) where a land right certificate is generated (figure3). Knowing the size of the land helps the land board decide on the allocation as they may only decide on allocations smaller than 20ha without the involvement of the Minister (LAC, 2005).

Prior to final approval, the application is placed on the notice board for public display for 7 days. This public display is an important legal step in which objections are invited by aggrieved parties. This is a display of transparency. Should there be objections to the land right allocation; a hearing is held by the land board with all concerned parties. During a land board meeting, applications are presented and decided upon. It is during this meeting that the land board either approves and ratifies the application or rejects the application. After approval, the right is registered in the communal cadastre (NCLAS). In case of rejection, the land board may hold further investigations or refer the application back to the allocating authority for correction. Once all the processes are complete, the applicant is issued with the land right certificate. See annex 5.

4.2. Design Results

In the reviewed literature, a generic model of UAV mapping was discovered. The literature reviewed revealed similar workflows; these workflows were examined and used as the pillar in designing the new process. Notably, the workflow by Udin & Ahmad, (2014), seen in figure 6 and that of Barnes et al., (2014) were considered. The adopted workflow was then modified to fit the needs of customary land mapping. The following main activities were developed; (1) Planning & Preparation (2) Image Acquisition (3) Image Processing (4) Vectorisation. These are displayed in the form of a swim-lane diagram (figure 7); each main activity (swim-lane) is discussed.

Planning and Preparation

This stage entails the planning and preparation of the project. The area to be mapped is studied, and the equipment and facilities are prepared. According to (Barnes et al., 2014), various technical aspects are to be considered before using UAV for mapping. These range from ground sampling distance, the terrain type and proximity of area being mapped to airports, as well as legal issues.

Image acquisition

Image acquisition involves the acquisition of ground control points, mission planning and the launching of the flight. The acquisition of ground control points is dependent on whether or not geo-referencing of the end product (orthophoto) is required. In case there is a need to fulfil specific accuracy standards, geo-referencing is required, and hence ground control points need to be collected. Ground control points are usually surveyed by the use of high accuracy differential GNSS equipment, and placing markers systematically across the area. The markers are usually bright coloured features that are easily visible in an image. Once the ground control points have been surveyed, a flight mission is developed. This can be done using open source flight planning software which is freely available on the web. In mission planning, the desired area is marked on an image from Google Earth; together with other parameters, this guides the UAV in its mission. Mission planning is an important undertaking as it also allows for real time control of the drone during a mission(Colomina & Molina, 2014).

Image Processing

This stage involves the orthophoto generation and quality check. The generation of the orthophoto is achieved through various photogrammetric operations. Firstly, camera calibration is performed, which is followed by the processing of the images to create 3D point clouds. The point cloud is then geo-located using ground control points that have been identified in the image. The point cloud is used to generate a Digital Surface Model (DSM). The geo-referenced images are combined to form an Orthomosaic. There is a number of image processing software available. Once this is done, it is good practice to perform a quality check of the orthophoto in terms of accuracy, depending on the accuracy needs of the intended use.

Vectorisation

Given that UAV mapping is based on aerial photography, the best and most efficient way to use aerial photos/ orthophoto is to conduct mapping in one workshop (Jing et al., 2011). This method is developed with the aim of citizen participation in which the mapping activities will be conducted in one gathering. The stage includes vectorisation, computing of the parcel size and the generation of the parcel diagram. Vectorisation refers to the process of converting raster data into vector data. In this case, land parcel boundaries are delineated on the image (raster) and stored into a geo-database as vector polygons. The parcel size is computed in Arcmap and displayed on the parcel diagram. The parcel diagram is the final output of this exercise.

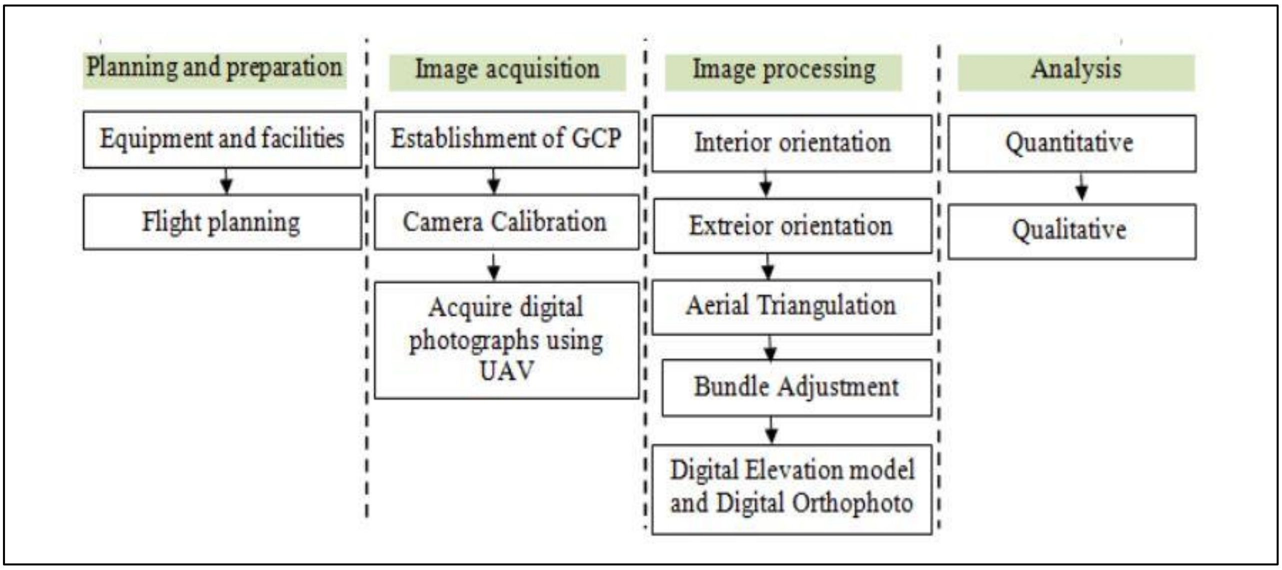

Figure 6: Adopted UAV Mapping Workflow (Udin & Ahmad, 2014)

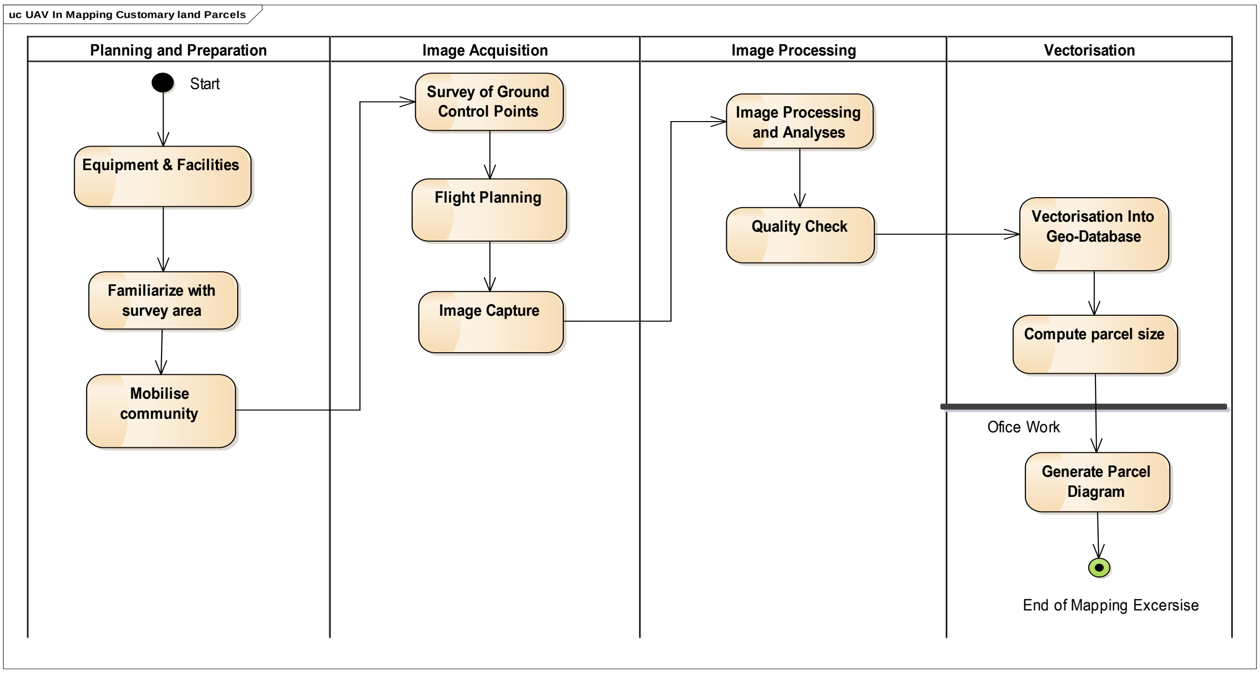

Figure 7: Developed UAV Mapping Process for Customary Land Mapping

What is apparent when visually comparing the original diagram to the new diagram is that, the analysis stage was removed and fused together with image processing. Vectorisation was then added to the workflow as the last stage of the process replacing analysis. Other significant differences are in the planning stage where community mobilisation was added as a sub-activity, as well as familiarisation with study area. This is because these sub-activities are important aspects in mapping customary land parcels. This workflow was tested during a pilot test and the results from each main activity are presented in section 4.3. Whether or not this designed process will fit in to the main customary land registration process is subject to further research.

4.3. Pilot Test Results

4.3.1. Image Acquisition

High resolution images were captured in the field during the image acquisition stage. An example is displayed in figure 8. A fixed wing UAV, mounted with a 16mp camera was used in this exercise. The quality of the image is proven by the clear visibility of features such as tree crowns, fences, houses and hedges.

Figure 8: Sample Image Captured with UAV

4.3.2. Image Processing

During image processing in Px4dMapper, an Orthophoto was produced (Figure 9). This is a geo-referenced mosaic of all the captured images fused together. The green points displayed on the orthophoto are positions of ground control points. An orthophoto in digital format can be zoomed to different scales, as per the user's discretion.

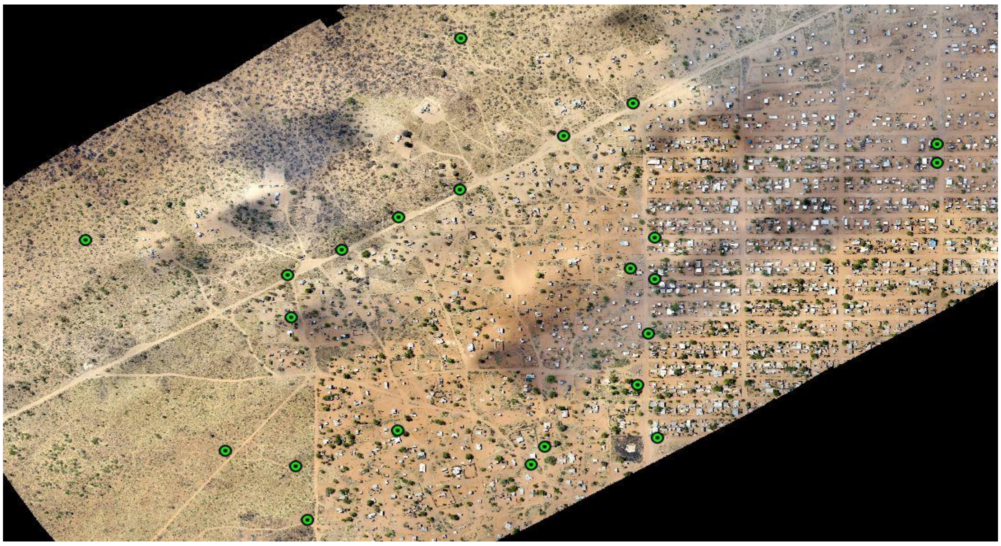

Figure 9: Orthophoto

4.3.3. Accuracy Assessment

Pix4D generated Accuracy

During initial processing by pix4dmapper, an accuracy assessment report for the bundle adjustment was generated. The summary result shows an average ground sampling distance (GSD) of 4.81cm. This can be seen in Annex 2. Regarding the accuracy assessment, Figure 10 shows the results of the accuracy assessment using object coordinate residuals at both ground control and check points based on Root Mean Square error (RMSE). It should be noted that the accuracy considered is that of the check points (bottom), because check points are independent from bundle adjustment. The error in X (east) is 5 cm whereas in Y (north) is 8 cm.

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
2356 (3D)	0.020/ 0.020	0.021	0.016	-0.003	0.164	9 / 9
2381 (3D)	0.020/ 0.020	0.088	-0.059	-0.137	1.707	6 / 6
2382 (3D)	0.020/ 0.020	0.039	-0.010	-0.027	0.220	13 / 13
2384 (3D)	0.020/ 0.020	-0.003	0.006	-0.072	0.049	3 / 3
2404 (3D)	0.020/ 0.020	0.034	-0.038	0.004	0.685	10 / 10
2408 (3D)	0.020/ 0.020	0.008	0.033	0.071	1.799	14 / 14
2409 (3D)	0.020/ 0.020	-0.003	0.017	-0.032	0.732	11 / 11
2410 (3D)	0.020/ 0.020	-0.019	0.009	0.023	0.480	13 / 13
2411 (3D)	0.020/ 0.020	-0.017	-0.029	-0.103	0.425	3 / 3
2414 (3D)	0.020/ 0.020	-0.041	0.003	-0.025	0.578	8 / 8
2416 (3D)	0.020/ 0.020	-0.016	0.013	0.049	0.504	3 / 3
2418 (3D)	0.020/ 0.020	-0.018	-0.031	-0.003	1.126	15 / 15
Mean		0.006123	-0.005900	-0.021293		
Sigma		0.033471	0.026253	0.057343		
RMS Error		0.034026	0.026908	0.061168		

0 out of 5 check pointss 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
2405	0.0200/0.0200	0.0941	0.0354	0.2332	0.8530	12 / 12
2406	0.0200/0.0200	0.0340	0.0771	0.2951	0.5718	12 / 12
2407	0.0200/0.0200	0.0450	0.0457	0.2231	0.9761	12 / 12
2412	0.0200/0.0200	-0.0121	-0.0169	0.1624	0.5234	13 / 13
2415	0.0200/0.0200	-0.0545	0.1517	-0.0759	0.5443	14 / 14
Mean		0.021302	0.058591	0.167582		
Sigma		0.050772	0.055533	0.128803		
RMS Error		0.055060	0.080727	0.211362		

Figure 10: Accuracy assessment in Pix4D

Arcmap generated Accuracy Assessment

It can be seen in figure 11 that the accuracy of the orthophoto is 4cm in X and 5 cm in Y, which is not significantly different from the Pix4d generated accuracy (Table 2). We can also observe that the residual delta Y in point 2413 is significantly different to other points. This error could have been caused by a wrong measurement or it is an outlier.

	Ground Truth			Measured			Residuals	
NO	X	Y		X	Y		ΔX	ΔY
2356	292074.017	7517955.636		292073.987	7517955.658		0.030	-0.022
2381	292381.075	7518073.440		292381.072	7518073.467		0.003	-0.027
2382	292188.984	7518096.376		292188.963	7518096.382		0.021	-0.006
2384	291779.120	7518387.443		291779.133	7518387.419		-0.013	0.024
2404	292514.386	7518250.864		292514.332	7518250.935		0.054	-0.071
2408	292048.232	7518270.925		292048.207	7518270.954		0.025	-0.029
2409	292042.929	7518335.936		292042.947	7518335.923		-0.018	0.013
2410	292112.304	7518376.290		292112.322	7518376.273		-0.018	0.017
2411	292186.200	7518428.156		292186.233	7518428.171		-0.033	-0.015
2414	292263.293	7518707.092		292263.379	7518707.038		-0.086	0.054
2416	292717.935	7518945.086		292717.955	7518945.003		-0.020	0.083
2418	292886.743	7518522.505		292886.644	7518522.466		0.099	0.039
					RMSE		0.045	0.040

	Ground Truth			Measured			Residuals	
NO	X	Y		X	Y		ΔX	ΔY
2405	292521.693	7518336.259		292521.697	7518336.245		-0.004	0.014
2406	292489.554	7518352.497		292489.486	7518352.436		0.068	0.061
2407	292520.834	7518400.965		292520.829	7518400.885		0.005	0.080
2412	292265.044	7518471.970		292265.055	7518471.967		-0.011	0.003
2413	292399.022	7518557.041		292399.053	7518555.928		-0.031	1.113
2415	292489.894	7518609.267		292489.970	7518609.121		-0.076	0.146
					RMSE		0.044	0.460

Figure 11: Accuracy assessment result

A conclusion can therefore be drawn that the intermediate steps (image matching, terrain modelling, and orthophoto projection) did not significantly reduce the accuracy of the final orthophoto; hence we can assume that point on ground, measured within this orthophoto will have a positional accuracy with a standard deviation of 4 to 5 cm. From these results, it can be concluded that UAV techniques that are used in this study gives very high accuracy on 2D mapping. In figure 10, there is an apparent 21cm error in height, however, considering the fact that the maps used for cadastral purposes require just X and Y coordinates, the Z coordinates and their accuracy do not play a significant role on mapping and on 2D cadastre in general. Thus, for this research height was not considered.

4.3.4. Legal Compliance

Legal compliance refers to whether or not the procedure falls within the provisions set out in the relevant laws that apply to methods of mapping customary land rights. The policy review revealed that both laws on customary land and UAVs are vague. This leads to the argument that there are no prescribed surveying and mapping requirements for customary land mapping as per the law. This vagueness in the law leaves land administrators with the task of being proactive and constantly research and employ new methods and techniques that are fit for the purpose. It is clear however that UAV use is not prohibited, and that mapping of parcel boundaries is an important step in the registration of customary land rights. These findings brought the researcher to the conclusion that, since there are no tools and techniques prescribed by law, any survey and mapping method can be employed, given it has been proven to work. Therefore, these findings warrant for the testing of UAVs in mapping customary land parcels in Namibia. Future policy amendments and changes by government may affect UAV usage or customary land procedures, whether these will be negative or positive effects is subject of further research.

4.3.5. Vectorisation

During the vectorisation process a cadastral map was generated in Arcmap, showing delineated parcel boundaries. This is shown in figure 12. Barnes et.al, (2013) advocate for the use of unmanned aerial vehicle in the "In-situ" delivery of high resolution aerial photos, as well as promotion of citizen participation in adjudication. This exercise saw a number of people participate in the mapping process. Participation by all land owners and their neighbours prevents or minimizes boundary disputes because all concerned parties are involved in the mapping process. This affirms that UAV-mapping encourages participation. Without the need for placing monuments, a line is drawn around the holder's land parcel, guided by natural features such rows of trees, hedges and rocks, or man-made features such as fences, foot paths and roads. Since the guiding features were clearly visible on the images, it can be concluded that in addition to good spatial accuracy, the orthophoto also delivers good visual quality. Thus, it can be argued that UAV generated orthophoto is well suited for mapping customary land parcels.

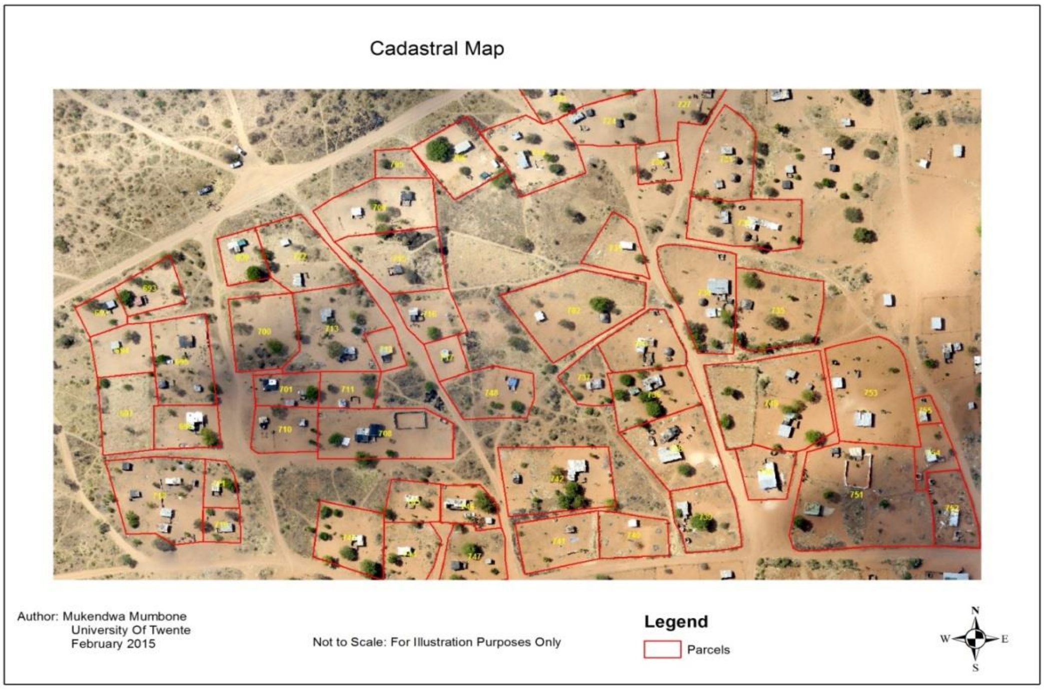

Figure 12: Sample Parcel Map

4.4. Concluding Remarks

It was discovered that UAV is ideal for adjudication purposes and first registration. Should there be a need to update the cadastre in terms of subdivision or new rights registered in the same area, no flying would be required as the images are already available. Many studies justify the use of UAV in that the method reduces the need of surveying with High precision GNSS, which is often a lengthy and tiresome process. This study discovered that the process is an important aspect in maintaining high accuracy of the orthophoto. If the purpose of the survey requires high accuracy, then ground control points need to be surveyed and used to geo-reference the images. Otherwise, in a situation whereby accuracy is not important, UAV generated images can still be used differently. This can either be as enlarged but rectified photographs to identify land parcel boundaries, or by identifying and plotting of land parcel boundaries using simply enlarged and unrectified photographs, see (Siriba, 2009). These approaches would not require the use of high precision GNSS. However, recent advancements in technology have seen researchers develop a means to automatically geo-reference images as they are being captured by the UAV. Whether this approach will completely eliminate the need for high precision GNSS is subject of further research.

5. CONCLUSION & RECOMMENDATIONS

The aim of this research was to assess the use of UAV surveying methods in mapping customary land parcel boundaries in terms of spatial accuracy and legal compliance. The aim was reached by setting three objectives, which will be summarised in this chapter. The research was presented in four chapters; the first chapter gave a background of the research problem, aim, objectives and questions. While the second chapter discussed literature and concepts, the third chapter presented the methods and techniques used in answering the research questions. Finally, chapter 4 presented and discussed the research results. The research results were presented in three stages according to how the research was designed and conducted; (1) Pre-fieldwork (2) Fieldwork and (3) Post-fieldwork. This chapter therefore concludes this research by discussing what was achieved in each objective.

5.1. Conclusion

Objective 1: To understand the current context regarding customary land mapping and UAVS

This objective was aimed at gaining information about the policies, laws, tenures, administrative approaches, and technologies that inform customary land mapping in Namibia Currently, as well as on the policies and laws in Namibia. This objective was fulfilled through a mix of examining acts and policies relating to land and UAVs in Namibia. This research revealed that all the laws relevant to customary land do not specify any technical requirements for mapping customary land. Important aspects such as minimum accuracy standards and survey tools and techniques are not prescribed. Further review revealed that the use of UAV technology is permitted by law. This is however subject to certain restrictions such as flight height, proximity to airports and built up areas. Based on these findings, it was concluded that any proven surveying method may be used to map customary land parcels. Therefore, these findings warranted for the testing of UAVs in mapping customary land parcels in Namibia.

Objective 2: To design a new customary land mapping approach around UAVs

This objective was aimed at designing a procedure for mapping customary land parcels with the aid of UAV. In this respect, a method was developed using UML modelling software, and the trial was carried out in an informal settlement area in Gobabis, Namibia. A locally manufactured UAV, as well as high accuracy GPS equipment where used in the exercise. In designing the procedure, existing methodologies were adopted from various UAV related studies. The activities were modified to fit the needs of mapping customary land mapping. The researcher's expert knowledge regarding current procedures for registering customary land rights and mapping land parcels in Namibia was vital in the design procedure. The designed procedure is presented in section 4.2 (figure 7).

Objective 3: To validate the new approach to customary land mapping

This objective was aimed at assessing the newly designed approach for mapping customary land parcels. All the steps in the developed procedure were successfully trailed; the testing procedure can be seen in the methods chapter section 3.2.1. The research revealed that the UAV enabled mapping approach supports capture of high resolution images out of which good quality orthophotos can easily be generated. See section 4.3 figure 8. Results also revealed that the survey of ground control points is a long and physically demanding process. However, the step is vital for maintaining high accuracy of the orthophoto. Aerial photography has been seen to be the most preferred method of mapping land parcels in Africa and other developing countries. This is seen in (Akinyemi & Nkubito, 2013; Lemmen, 2009; Meijs et al., 2009 and

Ondulo & Kalande, 2006). Therefore, due to the high resolution nature and timeliness of aerial images generated by UAVs, such images can easily be used for mapping customary land parcel boundaries. This can be done in a fast and relatively cheap fashion of vectorising parcels digitally without the need of having to print the orthophoto. This exercise also proved that the visual quality of the images is adequate for boundary mapping as the guiding features such as fences and hedges were clearly visible. Mapping customary land parcels with the aid of UAV technology gives the land administration institution the flexibility of producing their own aerial images at will. This eliminates the need of purchasing aerial photographs from usually very expensive suppliers. Further validation was carried out to uncover the positional accuracy achieved by the UAV survey approach. The research revealed that the accuracy derived from photogrammetric operations is good enough to fit the purpose of mapping customary land parcels. It was revealed that accuracy derived from this method surpasses those derived from hand held GPS receivers and the current orthophoto techniques. The results show an accuracy of 4-5centimeters, which is by far higher than that of current methods, said to range between 5-10meters. Whether or not these accuracies and the method in general are acceptable by the land surveying authorities is subject to further research. There are many other ways to verify the accuracy of an orthophoto. However, due to time limitations such avenues were not explored in this study. Should there be a need to verify these results, this study recommends that other evaluations methods be used; for example, to perform a ground survey using RTK GNSS, and then compare with the accuracy of the vectorised features. This however depends on the quality needs of the survey, as it is time consuming and may lead to extra costs.

5.2. Recommendations for Further Research

Given that this study aimed to ensure highest possible accuracy, many ground control points were collected, which was time-consuming. Further studies are encouraged to find out whether in practice such a large number of ground control points are necessary. There are already UAVs on the market with a dual frequency RTK receiver, see e.g. the system Sirius Pro by Mavinci (figure 2), which means that the location of the camera for each single image can be theoretically computed by 2-4 cm accuracy. This could potentially eliminate the need for GCPs and significantly improve the efficiency of UAV surveys. Study into the potential of these improvements is subject of further research. An example of a similar product can be seen in (Eling, 2014; Rieke & Foerster, 2011). With these accuracy results derived in this study, it is recommended that further studies into the potential merger of the communal cadastre into the country's main deeds system be carried out. It is further recommended that the use of UAV be considered in other similar applications in Namibia i.e.; farm assessments and monitoring activities, building of 3D cadastre in urban areas, and informal settlement planning and upgrading. It is also important to study whether these approaches can be transferred to other countries with specific land administration needs. Other important factors that were not covered in this research, such as the efficiency, a comprehensive cost benefit analysis, and social acceptance of the developed method are subject of further research.

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ANNEX 1 STATISTICS OF MAPPED AND REGISTERED LAND RIGHTS

Table 3: Statistics of Mapped and Registered Land Rights

Region	Existing CLR registered	New CLR Registered	Leasehold Registered	Male	Female	Estimated Land rights pending registration
Zambezi	3716	599	58	2409	1933	25000
Erongo	1675	1187	2	1759	1104	1875
Hardap	692	643	0	950	385	1125
!Karas	1443	530	9	1269	711	1375
2*Kavango	0	0	44	36	6	0
Kunene	2442	499	97	1737	1241	6000
Ohangwena	10444	842	77	6468	4876	37000
Omaheke	1192	176	24	952	431	7000
Omusati	13997	3069	75	9946	7133	49000
Oshana	11656	1881	28	7598	5924	23000
Oshikoto	5942	528	62	3807	2723	32000
Otjozondjupa	1868	54	8	1379	547	5000
TOTAL	**55067**	**10008**	**484**	**38310**	**27014**	**188 375**

(Own compilation with information from the MLR)

ANNEX 2 QUALITY REPORT GENERATED FROM PIX4D

Quality Report

Generated with version 1.2.98

Important: Click on the different icons for:
- Help to analyze the results in the Quality Report
- Additional information about the feature

For additional tips to analyze the Quality Report, click here.

Summary

Project	firstproject
Processed	2015-Jan-14 11:05:16
Camera Model Name	NEX-5N_E16mmF2.8_16.0_4912x3264 (RGB)
Average Ground Sampling Distance (GSD)	4.81 cm / 1.89 in
Area Covered	1.6068 km^2 / 160.684 ha / 0.6207 sq. mi. / 397.264 acres
Image Coordinate System	WGS84
Ground Control Point (GCP) Coordinate System	WGS84
Output Coordinate System	WGS84 / UTM zone 34S
Processing Type	full aerial nadir
Feature Extraction Image Scale	0.5
Camera Model Parameter Optimization	optimize externals and all internals

Quality Check

Images	median of 10697 keypoints per image
Dataset	329 out of 330 images calibrated (99%), all images enabled
Camera Optimization	1.52% relative difference between initial and final focal length
Matching	median of 6217.37 matches per calibrated image
Georeferencing	12 GCPs (12 3D), mean error = 0.039 m

Preview

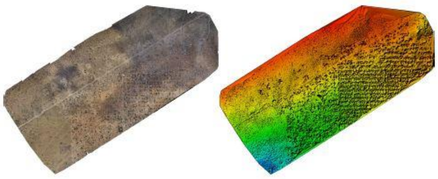


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	329 out of 330
Number of Geolocated Images	0 out of 330

Initial Image Positions

The preview is not generated for images without geolocation.

Computed Image/GCPs/Manual Tie Points Positions

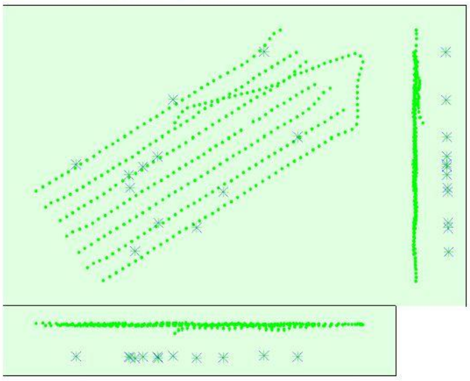


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images.

Overlap

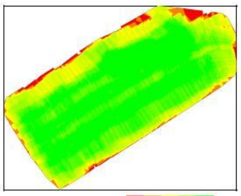


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.
Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint 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	2327827
Number of 3D Points for Bundle Block Adjustment	710858
Mean Reprojection Error [pixels]	0.142398

Internal Camera Parameters

NEX-5N_E16mmF2.8_16.0_4912x3264 (RGB). Sensor Dimensions: 23.5 [mm] x 15.6 [mm]

EXIF ID: NEX-5N_E16mmF2.8_16.0_4912x3264

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	3374.859 [pixel] 16.146 [mm]	2443.669 [pixel] 11.691 [mm]	1588.980 [pixel] 7.602 [mm]	0.001	-0.008	0.011	-0.002	0.001
Optimized Values	3323.363 [pixel] 15.900 [mm]	2444.429 [pixel] 11.695 [mm]	1614.905 [pixel] 7.726 [mm]	-0.063	0.094	0.001	-0.003	-0.002

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	10697	6217
Min	727	93
Max	20905	13672
Mean	11668	7075

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	379037
In 3 Images	135248
In 4 Images	75438
In 5 Images	37902
In 6 Images	23220
In 7 Images	17450
In 8 Images	14443
In 9 Images	10208
In 10 Images	6594
In 11 Images	4622
In 12 Images	3104
In 13 Images	1821
In 14 Images	979
In 15 Images	427
In 16 Images	226
In 17 Images	86
In 18 Images	42
In 19 Images	7
In 20 Images	4

3D Points from 2D Keypoint Matches

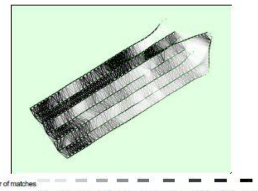


Figure 5: Top view of the image computed positions with a link between matching images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images.

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
2356 (3D)	0.020/ 0.020	0.021	0.016	-0.003	0.164	9 / 9
2381 (3D)	0.020/ 0.020	0.088	-0.059	-0.137	1.707	6 / 6
2382 (3D)	0.020/ 0.020	0.039	-0.010	-0.027	0.220	13 / 13
2384 (3D)	0.020/ 0.020	-0.003	0.006	-0.072	0.049	3 / 3
2404 (3D)	0.020/ 0.020	0.034	-0.038	0.004	0.685	10 / 10
2408 (3D)	0.020/ 0.020	0.008	0.033	0.071	1.799	14 / 14
2409 (3D)	0.020/ 0.020	-0.003	0.017	-0.032	0.732	11 / 11
2410 (3D)	0.020/ 0.020	-0.019	0.009	0.023	0.480	13 / 13
2411 (3D)	0.020/ 0.020	-0.017	-0.029	-0.103	0.425	3 / 3
2414 (3D)	0.020/ 0.020	-0.041	0.003	-0.025	0.578	8 / 8
2416 (3D)	0.020/ 0.020	-0.016	0.013	0.049	0.504	3 / 3
2418 (3D)	0.020/ 0.020	-0.018	-0.031	-0.003	1.126	15 / 15
Mean		0.006123	-0.005900	-0.021293		
Sigma		0.033471	0.026253	0.057343		
RMS Error		0.034026	0.026908	0.061168		

0 out of 5 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
2405	0.0200/0.0200	0.0941	0.0354	0.2332	0.8530	12 / 12
2406	0.0200/0.0200	0.0340	0.0771	0.2951	0.5718	12 / 12
2407	0.0200/0.0200	0.0450	0.0457	0.2231	0.9761	12 / 12
2412	0.0200/0.0200	-0.0121	-0.0169	0.1624	0.5234	13 / 13
2415	0.0200/0.0200	-0.0545	0.1517	-0.0759	0.5443	14 / 14
Mean		0.021302	0.058591	0.167582		
Sigma		0.050772	0.055533	0.128803		
RMS Error		0.055060	0.080727	0.211362		

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

Georeference Verification

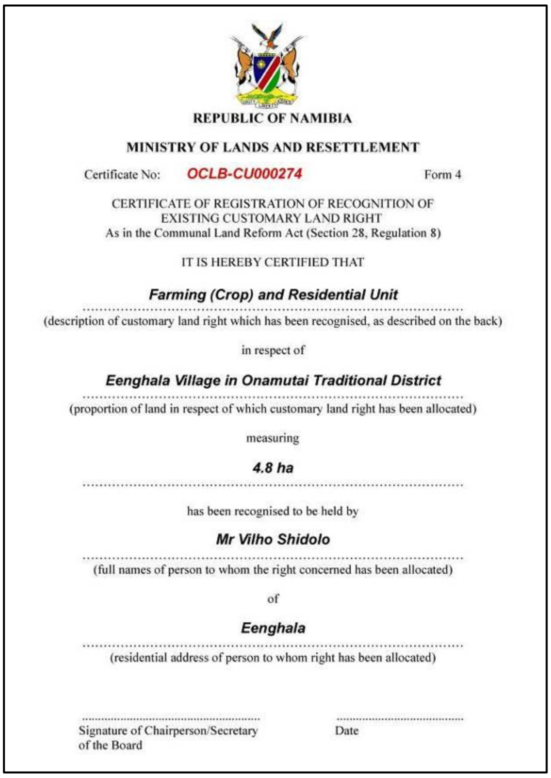
ANNEX 3 FIXED-WING UAV & V-MAP DUAL FREQUENCY GPS

1. Fixed-Wing UAV

2. V-Maps GPS

ANNEX 4 UAV MAPPING IN ACTION WITH THE COMMUNITY

ANNEX 5 CUSTOMARY LAND RIGHT REGISTRATION CERTIFICATE



REPUBLIC OF NAMIBIA

MINISTRY OF LANDS AND RESETTLEMENT

Certificate No: **OCLB-CU000274** Form 4

CERTIFICATE OF REGISTRATION OF RECOGNITION OF
EXISTING CUSTOMARY LAND RIGHT
As in the Communal Land Reform Act (Section 28, Regulation 8)

IT IS HEREBY CERTIFIED THAT

Farming (Crop) and Residential Unit
....
(description of customary land right which has been recognised, as described on the back)

in respect of

Eenghala Village in Onamutai Traditional District
....
(proportion of land in respect of which customary land right has been allocated)

measuring

4.8 ha
....

has been recognised to be held by

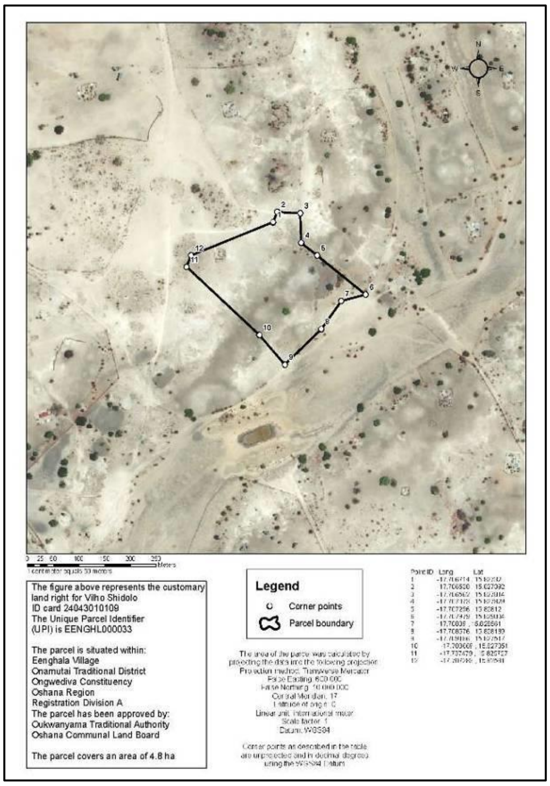
Mr Vilho Shidolo
....
(full names of person to whom the right concerned has been allocated)

of

Eenghala
....
(residential address of person to whom right has been allocated)

....
Signature of Chairperson/Secretary of the Board   Date

1. Front of Certificate



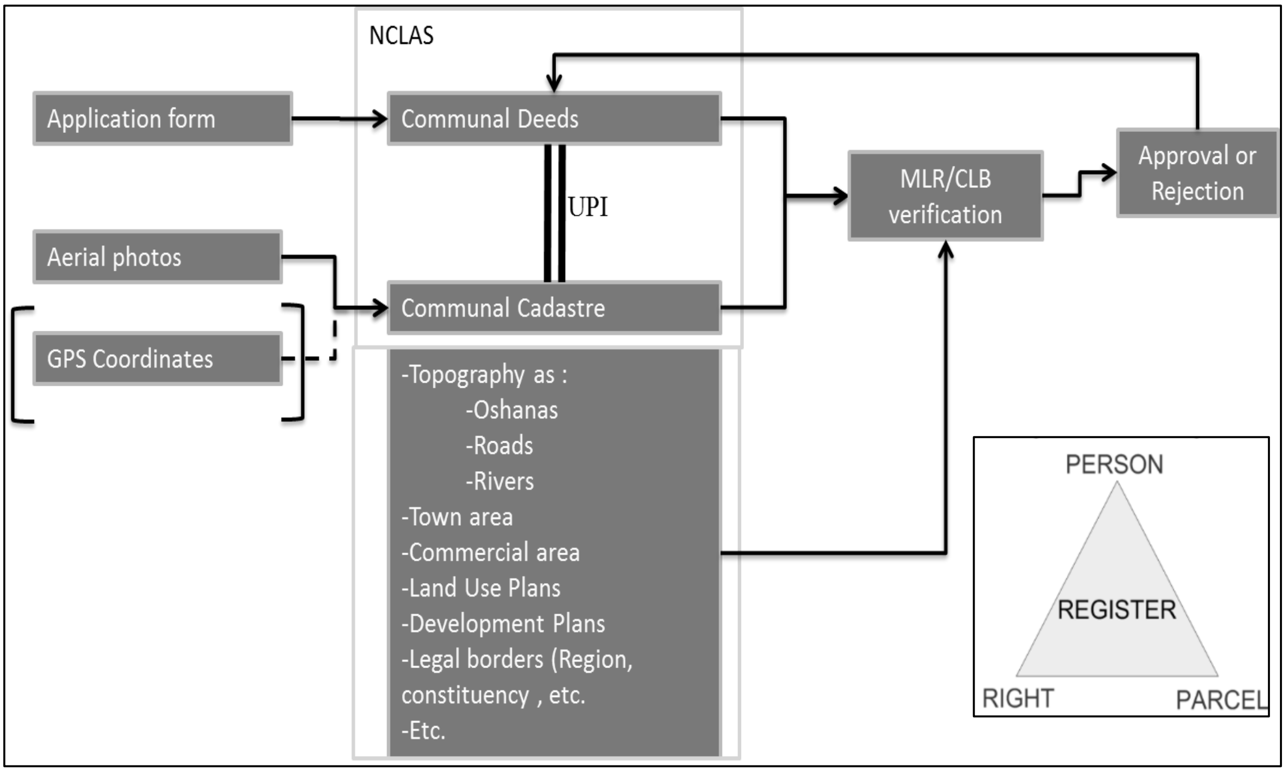
2. Back of Certificate with backdrop of aerial photo

ANNEX 6 CURRENT MAPPING TOOLS

1. Aerial Photo

2. Handheld GPS Receiver

ANNEX 7 NCLAS SYSTEM



(Meijs et al., 2009)