Testing the use and accuracy of satellite imagery for land registration in Angot Yedegera, Ethiopia

Master thesis - Geography

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Abstract

Aim: The aim of this thesis was to study the suitability of using satellite imagery for land registration in Ethiopia. The primary focus was to investigate whether the accuracy of the derived coordinates from a WorldView-1 satellite image met the 1m requirement for rual cadastral mapping in Ethiopia. Another aim was to examine whether different border types could affect the accuracy. A final aim was to investigate the relationship between slope and the accuracy of the derived coordinates, to examine whether there was a correlation between the two.

Methods: A number of 42 Ground Control Points (GCPs) were surveyed for the orthorectification of the satellite image. Static surveying of second order points was conducted prior to the Real-Time Kinematic Global Positioning System (RTK GPS) surveying. A number of 210 parcel corners in Angot Yedegera, Ethiopia, were surveyed, using RTK GPS. These RTK GPS data served as the basis for comparison with the coordinates derived from the satellite image. Statistical analysis of the discrepancies was performed by analyzing values of central tendency and dispersion. In addition, outlier tests were conducted using boxplot and percentile values, as well as a Moran I autocorrelation test. A Pearson r correlation test was performed, between slope and the accuracy of the derived coordinates.

Results: 46.4 % of the coordinate values derived from the satellite image had discrepancies below the 1m requirement. The median of the discrepancies was 1.088m. Further, the 75th percentile was 2.386m, and the maximum deviation was 10.103m. It was found that the deviations varied according to different border types, both concerning central tendency and dispersion. The median for the border types ‘fence’, ‘pasture land’ and ‘parcel’ was below the 1m requirement, whereas the other border types had medians varying from 1.777m to 2.367m. The correlation test indicated that slope was not related to the accuracy achieved (Pearson r = 0.029).

Conclusion: It was found that the coordinates derived from the WorldView-1 satellite image do not meet the requirement of 1m accuracy. It was also found that different border types have a large influence on the accuracy achieved. The border types ‘fence’, ‘pasture land’ and ‘parcel’ achieved the highest accuracy, while the border types ‘path’, ‘forest’ and ‘diffuse’ achieved the lowest accuracy. Slope was not proved to affect the accuracy of the coordinates in either positive or negative extent.

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Explanation of terms

Land tenure	Land tenure is the relationship, whether legally or customarily defined, among people, as individuals or groups, with respect to land. Land tenure is often categorized as private, state, communal or as open access (Tenaw et al. 2009).
Tenure security	Tenure security is a matter of trust among members of a community with their local and national governance (Bekure 2006). A set of juridical rights should give legal protection against actions which can create fear of losing land or that discourage land investments and production.
Usufruct rights	The limited right to use another party's property without owning the property itself. In the Ethiopian case the government owns all the land, and people have usufruct rights to their land. The usufruct rights exclude the right to sell or mortgage the land (Tenaw et al. 2009).
Holder	The legal owner of one or multiple parcels, which can be an individual holder (e.g. head of family) or a group of holders (e.g. husband and wife). All parcels are registered in the Book of Holding, which is issued to the holder of the parcels as a proof of their rights and obligations.
Book of Holding	The official certificate which shows that those named within are the rightful users of the land described in the book. Contains e.g. parcel description, photo and land use. Also called the Green Book because of its green color (SARDP 2010).
Parcel	A unique portion of land defined by physical demarcation, a mathematical description often based on a coordinate system or an area with a particular type of land use. A parcel can be controlled by an individual, a group or the state (Marquardt 2006).
Woreda	A woreda (e.g. Dembecha) is a third-level administrative division which is managed by a local government. Amhara consists of 128 administrative woredas (REILA 2012).
Kebele	Each woreda is made up by a number of small kebeles (e.g. Angot Yedegera). It is the smallest administrative level in Ethiopia. Amhara consists of 3146 kebeles, with an average of 25 kebeles per woreda (REILA 2012).

Abbreviations

Amsl.	Above mean sea level
BoEPLAU	Bureau of Environmental Protection, Land Administration and Use
C/A	Coarse Acquisition
DOP	Dilution of Precision
GCPs	Ground Control Points
GDOP	Geometric Dilution of Precision
GIS	Geographic Information System
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
LAC	Land Administration Committee
PPM	Parts Per Million
QGIS	Quantum Geographic Information System
REILA	Responsible and Innovative Land Administration
RTK GPS	Real-Time Kinematic Global Positioning System
Sida	Swedish International Development Cooperation Agency
SNNP	Southern Nations, Nationalities, and Peoples
TIN	Triangulated Irregular Network
UNECA	United Nations Economic Commission for Africa
UTM	Universal Transverse Mercator

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1. Introduction

1.1 Background

This master thesis is part of a bilateral cooperation between the governments of Finland and Ethiopia. In 2011, Finland committed to a long-term cooperation with Ethiopia on sustainable land management called Responsible and Innovative Land Administration (REILA). One of the main objectives of the cooperation is to establish an improved land administration system in Ethiopia, which aims to enhance land tenure security for smallholder farmers (Orgut 2011). In this process I took part in the technical assistance of REILA, particularly I investigated whether new methods could be used for cadastral surveying, i.e. use of satellite images. The Swedish consultant company Orgut assists REILA in the technical part of the cooperation. I have joined this project by contact with Thomas Dubois, a consultant for Orgut in Ethiopia.

1.1.1 Structure of the thesis

In the first chapter the research questions is presented. Then I present some theory on using satellite images and orthophotos for cadastral purposes. Further, a brief introduction is given about Ethiopia and its land management system and history. Then the research area is presented, explaining the areas topography and most important components. At the end of the chapter information about the REILA project and the Imagery Trials is given. In the second chapter I present the theory relevant as background information for understanding GNSS, satellite images and the statistics used in this thesis. The third chapter deals with the methodological framework of the thesis. I first present the preparatory work that had to be done before field work, before I proceed to a detailed presentation of how the second order points were established and how the static and RTK GPS surveying was conducted. I also explain how the different border types were categorized. In the end of the chapter a presentation of the methods used for post processing of the surveyed data is given, with focus on Geographic Information System (GIS) and statistical analysis. In the fourth chapter the statistical results are presented. A major focus is directed towards descriptive statistics concerning values of central tendency and dispersion, in addition to outlier analysis and a correlation analysis. In the fifth chapter I discuss the validity and reliability of the thesis. Furthermore I discuss the statistical results and link the discussion to the research questions. The sixth chapter contains the final remarks and answers to the research questions. Finally, I also present some recommendations for future research.

1.2 Research questions

Does the coordinates derived from a WorldView-1 satellite image meet the demands of accurate rural cadastral mapping in Ethiopia, which is one meter accuracy?

How do different border types and terrain affect the accuracy of the derived coordinates from a WorldView-1 satellite image?

The coordinates of the parcel points, in the setting of small scale farmland, should meet the requirement of an accuracy of less than one meter (Dubois 2011). In relation to this, I am required to do surveying on the ground to compare coordinates from the satellite images with the coordinates from RTK GPS. More specifically, I will analyze values of central tendency and dispersion derived from the difference in coordinate values from the two methods.

To investigate how border types and different terrain might affect accuracy based on satellite imagery, I will study different border types in rural areas in Ethiopia, and how accurate these can be expected to be measured using satellite images. I will also correlate measurements deviations with slope to assess whether or not terrain influence measurement accuracy. Ethiopia is a mountainous country, and Wang & Ellis (2005) has found that landscapes with complex terrain relief can exacerbate the accuracy of the final orthorectified satellite image. I will rely on primary sources of data which will be gathered during field work.

Little research has been performed on the use of satellite images for cadastral purposes. The interest is, however, increasing since the method has potential of making the surveying process more efficient (Siriba 2009). It is important to investigate whether this method meets the accuracy requirements, as it may be a good, efficient and cheap method in areas which have not previously been mapped (Corlazzoli & Fernandez 2004; Amorim et al. 2008; Konecny 2009; Ahn & Song 2011).

Improved land tenure and certificates with precise descriptions of parcels, by the implementation of technical equipment, have proved to give stronger incentives to invest in land, reduced land related disputes and has given farmers a more predictable future (Gebreselassie 2006; Deininger et al. 2007; Deininger et al. 2011). Holding a title of registered land rights may be used as a physical proof against potential counterparties in a land dispute. According to Hernando de Soto, formal property is the key to create active capital because a formal property system allows people to use their land as for example collateral for a loan (De Soto 2000).

Prior to my field research and data analysis I read several articles and reports regarding the land certification project in Ethiopia, especially from the Swedish International Development Cooperation Agency (Sida) project in Amhara (SARDP 2010; Palm 2012; SARDP 2012). These papers constituted my background information about the land registration project and the methods which were being used. Most of the papers I read had a positive angle on how land registration in Ethiopia was conducted, and also advocated strong arguments for satellite images as a suitable method for mapping land parcels. This influenced my preconception before I went to the field. My expectation was that the accuracy of satellite images was sufficient for mapping land parcels.

1.3 Using satellite images and orthophotos for cadastral purposes

Since the launch of the first earth orbiting satellites some 50 years ago, satellite images have been used for scientific and monitoring purposes by recording the earth's surface and atmosphere (Robinson et al. 1995; Whalen 2009). High resolution satellite images have been used for, e.g. mapping of refugee camps during war and conflict (Bjørgo 2000), for mapping of disasters and humanitarian crisis (Moran & Lorenzo 2008), and in recent years there has also been an increasing interest in using satellite images for cadastral purposes (Siriba 2009). Corlazzoli and Fernandez (2004) did research with a SPOT-5 satellite image (resolution 2.5m) and found that one advantage of high resolution satellite imagery is the ability to survey large areas in a short time, which makes the method cost effective.

Surveying methods like GPS and total station are often referred to as the conventional methods for cadastral surveying. These methods can often be time consuming, involve high cost and labor. Quicker and more economical alternative methods for cadastral surveying have been requested from the cartographic community (Amorim et al. 2008; Jayalakshmi et al. 2011). Ahn and Song (2011) found from their land registration study in Azerbaijan that images from digital photogrammetry could be as accurate as, and significantly cheaper than, ground surveying. In Norway, the cadaster for rural areas is based upon mapping from orthophotos. This was performed in a twenty year period starting in 1960. The method was highly inaccurate, but many of these maps are still part of the cadaster covering rural Norway. These maps are now causing several property disputes (Mjøs & Sevatdal 2011).

There are however several challenges concerning the use of satellite images. Especially, shadows from e.g. trees, houses and clouds which can make it difficult to see details in the image. If a large tree covers the border of a land parcel it will be difficult to see the exact border corner. Corlazzoli and Fernandez (2004) found that the accuracy of a satellite image depends directly on the type and amount of vegetation cover in the study area, the size and shape of the property and the topography of the area. Another challenges is that landscapes with complex terrain relief can influence the accuracy of the orthorectification of satellite images in a negative direction, while landscapes with less terrain relief are more easy to handle This is due to terrain distortions of the uncorrected satellite image (Wang & Ellis 2005). Another challenge concerning the use of satellite images for land registration is that legal boundaries cannot be determined without extensive ground truthing. In situations where parcel boundaries have been surveyed directly from the satellite image in the office, a follow-up is needed to confirm with the holders and neighbors whether the boundaries are correct (Ahn & Song 2011). This situation is different from the REILA project, where legal boundaries are drawn in the field on printouts of satellite images and aerial photos, together with holders and neighbors.

1.4 Ethiopia

Ethiopia is a landlocked country located in eastern Africa, on the Horn of Africa, with an area of 1 104 300 km². The population of the country is 91.2 million people (CIA 2013). In the north, Ethiopia borders Eritrea, and to the west Ethiopia borders Sudan and South Sudan. Ethiopia borders to Kenya to the south, and Somalia and Djibouti to the east (MFA 2013). The rural population makes up approximately 84 % of the country's total population, and agriculture constitutes 46 % of the gross domestic product (Tenaw et al. 2009).

1.4.1 Coordinate system, datum and ellipsoid

The coordinate system which is used in Ethiopia is based on the Universal Transverse Mercator (UTM) projection. The UTM projection is divided into 60 zones, and in Ethiopia the zones 36, 37 (Amhara) and 38 are used. The coordinate system used for all GIS layers in this thesis is UTM zone 37 National. The datum used in Ethiopia is named UTM Adindan 37AM, and the ellipsoid used is Clarke 1880 (Dubois 2011).

1.4.2 Land management in Ethiopia

Land tenure in Ethiopia has been a sensitive issue for many years. During the 19^{th} century and until 1975 farmers living in the south were subject to powerful landlords. The farmers only had tenant relationship to their land which was highly insecure (Gebreselassie 2006; Crewett et al. 2008).

In the northern part of Ethiopia there was a land use system called rist land. The rist system was based on descent that granted usufruct rights, the right to appropriate the return from the land (Hoben 1973; Crewett et al. 2008). The land was owned by the lineage or community, rather than the individual, who was entitled to rent his or her use-rights but could not mortgage, sell, or give the land away (USAID 2011). In many localities redistribution of land within the kinship group occurred regularly (Crewett et al. 2008).

A turning point in Ethiopian land tenure occurred in 1975, when Emperor Haile Selassie was overthrown by the Derg. The Derg is another name used for the socialist regime which ruled from 1975 to 1991. The Derg nationalized all rural land and set out to redistribute it to its tillers and to organize farmers in cooperatives (Ali et al. 2007; Crewett et al. 2008). Abolishing feudal and colonial forms of landownership, the Derg redistributed land from the landlords to landless farmers. On March 4^{th} 1975 the Derg announced an agrarian reform program known as ‘Proclamation to Provide for the Public Ownership of Rural Lands’. The proclamation declared all rural land to be the property of the state, and no compensation was given to the previous rights holders. The reform was the first uniform tenure system imposed upon Ethiopia as a whole (Crewett et al. 2008). The state thereby abolished the remains of traditional institutions of landlords, tenants, and rist.

The reform of the Derg generated new sources of insecurity regarding land tenure in the population. Periodic redistribution of land, the implementation of cooperatives and compulsory resettlement was among the potential actions used, which created uncertainty and unproductivity (Ali et al. 2007; Crewett et al. 2008).

The Derg lost its governmental power in 1991 when the Transitional Government of Ethiopia took power. However, the current land tenure system is a continuation of the land policy of the Derg (Gebreselassie 2006; Crewett et al. 2008). Article 40 (3) in the Constitution of the Democratic Republic of Ethiopia states that ‘The right to ownership of rural and urban land, as well as of all natural resources, is exclusively vested in the State and in the peoples of Ethiopia. Land is a common property of the Nations, Nationalities and Peoples of Ethiopia and shall not be subject to sale or to other means of exchange’ (Federal Democratic Republic of Ethiopia 1995). Through the state ownership of land only usufruct rights are bestowed upon landholders, and mortgaging of land is prohibited (Gebreselassie 2006; Crewett et al. 2008; Ambaye 2012). Usufruct rights are transferable through inheritance, gifting, divorcing and rent (USAID 2011). At the moment, the government is carrying out a land registration program which is planned for the whole country. The land certification project in Ethiopia is implemented by the government, and is possibly the largest land administration program carried out in Africa, and possibly the world, over the last decade (Deininger et al. 2011).

1.4.3 Tenure security and land certification

Many articles, papers and reports have stressed the importance of tenure security in Ethiopia. UNECA, the United Nations Economic Commission for Africa, states that land tenure is among 'the most pressing areas requiring institutional reforms in Ethiopia' (UNECA 2002). In the same report, reallocation of land and the threat of future redistribution of land are among the risks UNECA address for the land tenure security in Ethiopia. It is also found that tenure insecurity is exacerbated by the absence of contractual agreement or land certificates. Incentives to invest in land improvement become minimal, which in turn influences the production (Adenew & Abdi 2005; Gebreselassie 2006). Fear of sudden expropriation without proper compensation is also affecting the perceived tenure security (Deininger et al. 2011). Tenure insecurity also promotes short term profit maximizing of crops at the cost of long term sustainable decisions, which shows that land tenure and food security are interlinked (Tenaw et al. 2009).

Many academics agree that land certification alone cannot eliminate tenure insecurity, but land certification may provide some assurance for a predictable future (Adenew & Abdi 2005; Gebreselassie 2006; Deininger et al. 2007; Tenaw et al. 2009). Sida concludes that 1st level certification through the Sida-Amhara project has 'realized substantial benefits in terms of perceived improvement in land tenure security' (Sida 2009). A 1st level certification includes a registration of the holders of the land, type of land tenure, their legal rights and obligations, and a sketch of the holders parcels. This sketch is not an accurate map, but is a drawing where every land parcel is relatively identified by the name of the surrounding neighbors. The process of identifying the right holder and determining the boundaries is known as adjudication (Bäckstrom 2006). Two research papers on the same project finds that 1st level certification has increased tenure security, land related investment and rental market participation (Deininger et al. 2009; Deininger et al. 2011).

Sida also reports that there is 'a demand for maps to accompany books of holding and to help resolve boundary disputes' (Sida 2009). Deininger has also found that there is a high demand and willingness to pay for a spatial reference. His study has found that 82.4 % of all households were interested in a 2nd level certification, and that 90.4 % would like to add a map to their 1st level certificate (Deininger et al. 2007). A 2nd level certification involves the process of adjudication, as for 1st level certification, but also includes surveying with accurate geodetic measurements of all parcel boundaries to make parcel maps (Bäckstrom 2006; SARDP 2010; Orgut 2011). These measurements will serve as basis for a cadastral map which gives a precise location of where each farmer has legal rights. The process of demarcation for 2nd level certification requires the holder to be present on his/her land and to point out the boundaries to the surveyor who will 'walk' the boundary and mark these clearly onto an orthorectified image in the presence of the holder, neighbors and the kebele Land Administration Committee (LAC) (REILA 2012).

1.4.4 Land certification

The process of registering land rights in Ethiopia is divided into two parts, 1st level certification and 2nd level certification. The reason for this is that mapping of all land parcels in the country is very time and resource consuming, and by dividing the process the certification progression is accelerated (Dubois 2011). For both levels a certificate known as the Book of Holding, or the Green Book according to its color (Fig. 1), is issued to the farmers. The 1st level certification is part of a governmental program of rural land registration that started in 2003. Land certification was first introduced in some areas to increase tenure security by allowing rural landholders to certify their usufruct rights. The federal Ministry of Agriculture is supporting a broad titling and certification initiative which is being implemented in the regions Amhara, Oromiya, Tigray and Southern Nations, Nationalities and Peoples (SNNP) (USAID 2011).

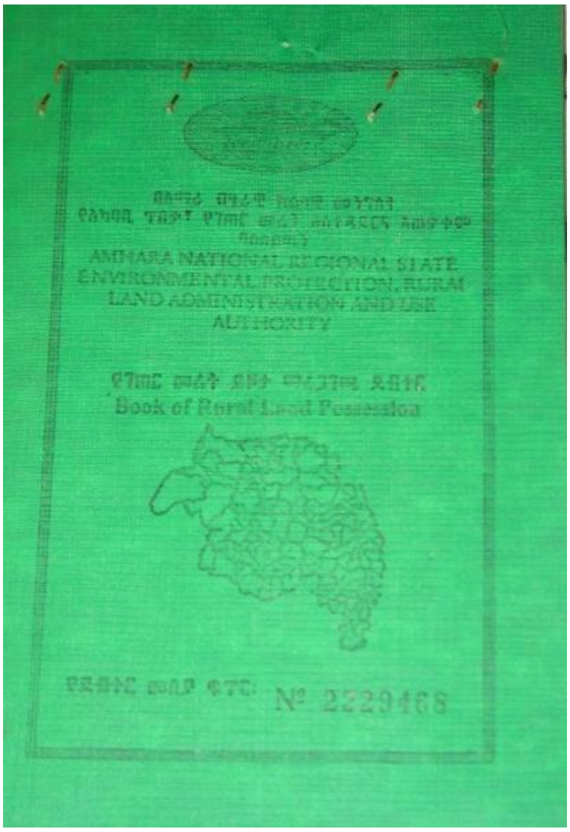

Fig. 1 The Book of Holding, which is the holders land certificate.

The primary goal is to issue every rightful holder of farm land a certificate of usufruct rights, and to have his/her plots recorded in a registry kept at the local kebele office (Rahmato 2009). Because land in Ethiopia is owned by the state, land registration and certificates merely confirms the right of use of the land for the households' livelihood, and the documents handed out to farmers are strictly speaking user certificates and not land certificates in the proper sense of the term (Rahmato 2009). For Amhara Regional State 94 % of all rural households has a 1st level certification (REILA 2012).

1.5 Research area

1.5.1 Angot Yedegera

Angot Yedegera is a kebele located 350km north of Addis Ababa and 200km south of Bahir Dar, along the Addis road between Addis Ababa and Bahir Dar. The kebele is a part of Amhara Regional State (Table 1). For the Amhara region there are, in average, 6241 parcels per kebele and 5.3 parcels per household (REILA 2012). The border of the kebele follows two different rivers in the south, west and north, while the border in the east is made up by a line between two distinct trees (Fig. 2). Agriculture is the main source of income for people in

Angot Yedegera, and the cultivation of maize, teff, wheat, barley and millet is most common. Cattle and mule make up the livestock for most of the families. The total population of Angot Yedegera is 5414 (per 2011), and the distribution of males and females are, respectively, 2715 and 2699 (Bureau of Amhara Regional State 2011).

Table 1 Short facts about kebele Angot Yedegera.

Type	Variable
Region	Amhara Regional State (154 709 km²)
Zone	West Gojjam
Woreda	Dembecha
Kebele	Angot Yedegera
Length of boundary	42.8 km
Area	42.6 km²

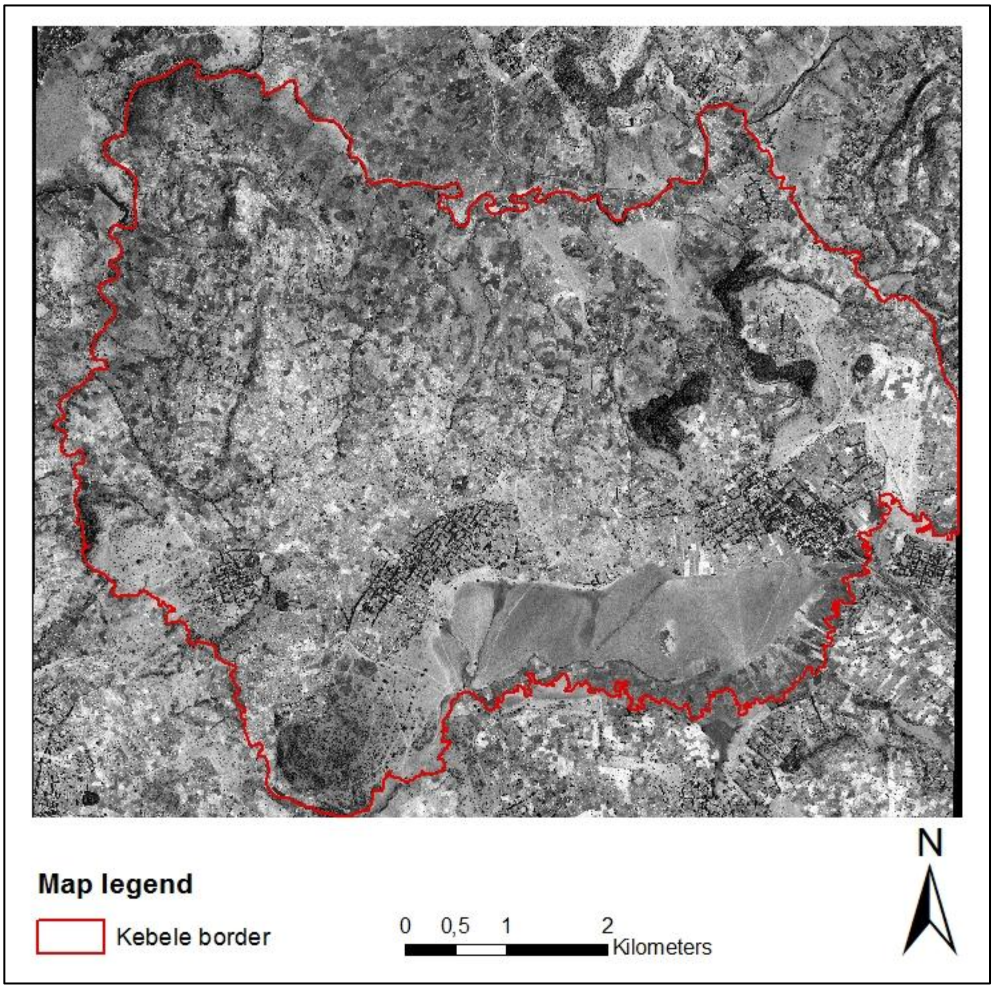

Fig. 2 The border of kebele Angot Yedegera.

The terrain of the kebele is characterized by a high plateau in the south with an elevation between 2000m above mean sea level (amsl.) and 2040m amsl. (Fig. 3 and Fig. 4). Most of the southern area is wetland and is used as pastureland for cattle. The two main villages in Angot Yedegera are also located on this plateau, northeast and northwest of the pastureland. The central and western parts are made up by slopes and eroded river valleys with elevations ranging from 1740m amsl. to 2000m amsl. In the north the terrain gradually becomes flatter towards the river, which makes up the kebele border.

I have not chosen the research area myself. The research area is chosen by the REILA project, to be a part of the trials of the use of satellite imagery.

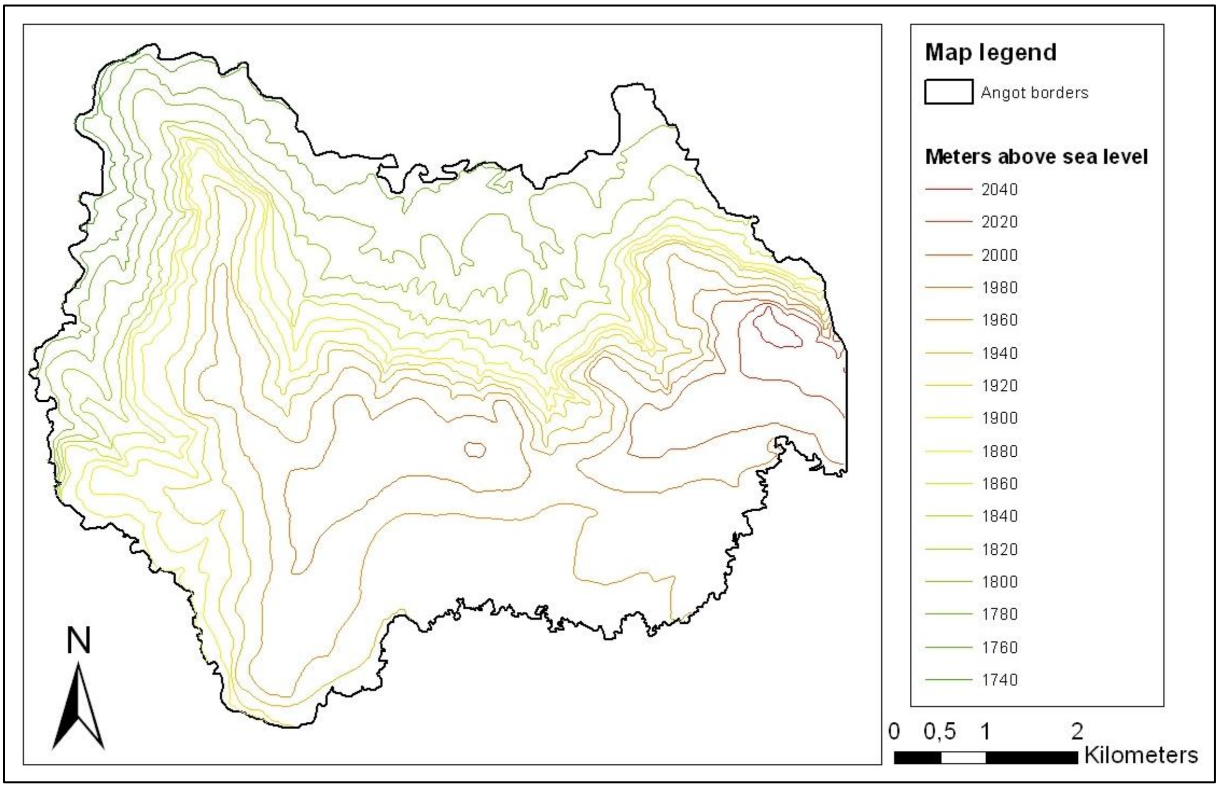

Fig. 3 Contour lines displaying the elevation in Angot Yedegera.

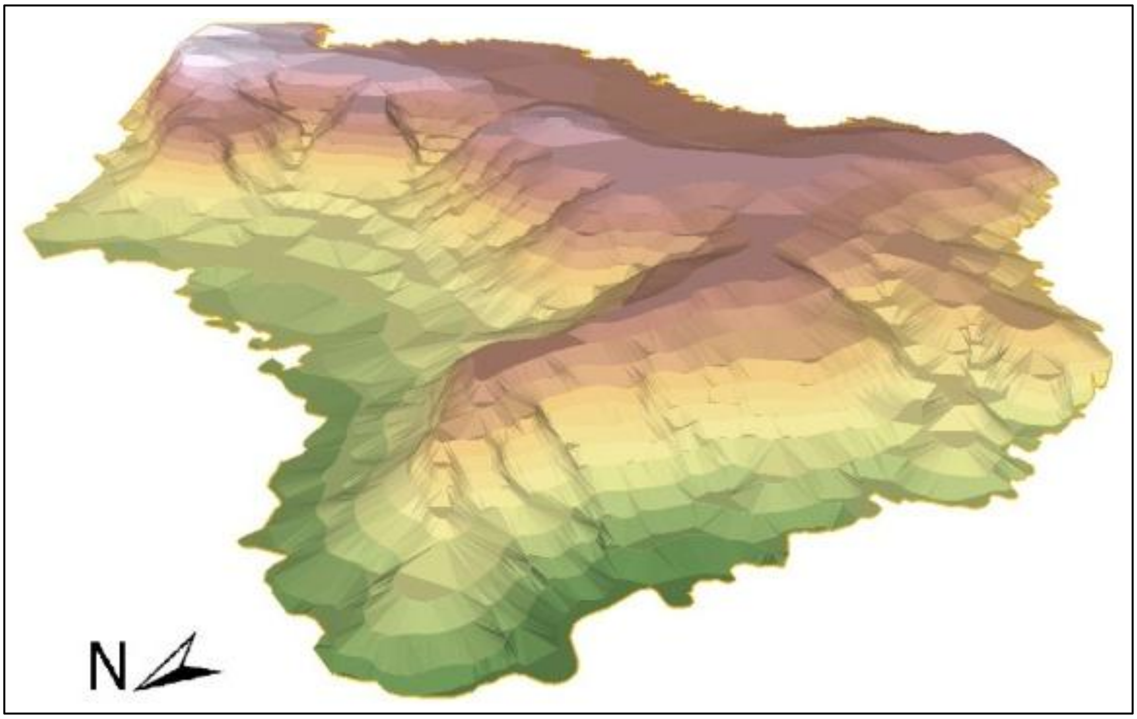

Fig. 4 TIN - model of Angot Yedegera.

1.5.2 Ilu

The initial plan was to conduct field work both in Angot Yedegera and in a kebele named Ilu. Ilu is located in the region SNNP, southwest of Addis Ababa. In Ilu I had planned to conduct an accuracy test of coordinates derived from aerial images, and compare these with coordinates derived from RTK GPS. I spent three days on the Ilu project, including one day of driving from Bahir Dar to Ilu. The two days of field work included the establishment of second order points and one day of RTK GPS surveying. However, after two days the field work had to be stopped due to circumstances out of my control. Hence, I had insufficient surveying data and could not complete the study.

1.6 Responsible and Innovative Land Administration

REILA is a bilateral cooperation between Ethiopia and Finland which started July 18th 2011. Finland has over 40 years of history cooperating with Ethiopia, and REILA is currently Ethiopia's single largest land administration program (Hautala 2011). The focus of the program is on technical assistance for improved land administration. The overall objective of REILA is to 'improve livelihood and economic well-being of the rural population through promotion of sustainable land management practices' (REILA 2012). REILAs vision is to inform all stakeholders of their rights and obligations related to land, and to enhance participation of all stakeholders in all phases of the registration and certification process (Orgut 2011; REILA 2012). The rationale for the Finnish project is to improve land tenure security for Ethiopian farmers, giving the farmers a more predictable future where it is safe to invest in land and agriculture. Further, the project aims to help combat climate change by addressing land degradation and promoting sustainable land management (REILA 2012).

1.6.1 Imagery Trials

Imagery Trials is a cooperation project between REILA and the Sustainable Land Management Project. The primary objective of the trials is to test the use of orthophotos and satellite images in land registration and surveying of land parcel boundaries in rural Ethiopia. The surveying will serve as the basis for countrywide systematic 2nd level registration, with issuing of 2nd level certificates and parcel maps. The aim of the trials is to complete the process of 2nd level certification for the whole of Ethiopia (Dubois et al. 2012).

The orthophotos/satellite-based methodology is influenced by a countrywide systematic land registration programme, which has been successfully performed, in Rwanda. This programme started in 2009 and is planned for completion in 2013. Experts from the Ethiopian Government went to Rwanda to study how the orthophoto methodology was performed. As a result of this, the Ethiopian Ministry of Agriculture decided that the use of orthophotos was a suitable option for completing rural land registration in Ethiopia. The initial part of the project shows positive results, but it is necessary to know more about the achieved accuracy of the method. There are several potential sources of errors. Among these the image resolution (0.5m) may be too low for detecting the parcel borders. Additionally, the georeferencing of the satellite image may distort the correct location of the parcel boundaries. (Dubois et al. 2012).

A prerequisite for the methodology is that the majority of the parcel boundaries follow easily recognizable physical features on the ground and which is visible from the orthophoto or satellite images. If the corner of a border is obscured by trees or is too diffuse to be visible in the image, a measuring tape is used to measure the distance on the ground from an object visible in the image to the corner. The distance is then converted to the image scale and drawn directly on the image using a ruler. The images are printed out on A3 format sheets, and are then brought to the field for parcel registration (Dubois et al. 2012).

The parcels are registered by a field team in cooperation with the involved land holder and neighbors. There are four field teams per kebele, each consisting of four people. The team consists of a team leader, a surveyor, a registrar and a LAC member. The team leader is responsible for field quality control and organization. The registrar records the attribute information for each parcel such as land holders' names, parcel number, neighbors, and any existence of a dispute, in a field form. After consultation with the land holders and the LAC member, the surveyor draws the agreed boundary feature in pencil on the printed orthophoto. A unique parcel number is allocated to each parcel and written in the orthophoto inside the relevant parcel boundaries. In the office the orthophotos are georeferenced. After the georeferencing the parcels are digitized sheet by sheet, using the agreed boundaries marked by hand (Dubois et al. 2012).

1.6.2 Is there a need for RTK-accurate property maps?

It is an expensive and demanding process to establish an accurate database of property maps from scratch. Such a process demands, among many, technical equipment, extensive training of staff and people who can update the system. It is reasonable to ask whether the accuracy on RTK GPS-level can be justified when other more efficient and cheaper methods are available. There are certainly different needs at the local level compared to the governmental level. At the moment there are other projects in Ethiopia concerning the use of handheld GPS for cadastral purposes (USAID 2011), which is a cheap and easy method for many purposes. The handheld GPS has been used extensively for cadastral purposes in Ethiopia, but the accuracy is too poor and should not be used for making cadastral maps.

There are several arguments for choosing accuracy received from RTK GPS surveying. First of all, the cadastral maps must be trusted by everyone, including governmental workers, farmers, and people at the kebele and woreda level. Inaccurate maps showing wrong parcel size or wrong parcel shape will easily be discovered, and does not make the farmers trust the system (Dubois 2011).

Secondly, for land valuation an area calculation of the parcels is needed. It is also needed if the land is to be expropriated, to ensure that the farmer receives the exact compensation of the land. In Amhara region, some parcels are as small as 25m x 40m. If a handheld GPS is used and two points are displaced by the average error of 6m, the farmer might lose or gain approximately 25% of the current area (Dubois 2011).

As a third argument, high accuracy is needed for land reallocation and for irrigation projects (Dubois 2011). In most irrigation projects the farmers land must be reallocated in connection to a canal. If the area is erroneously measured the farmer can lose a substantial part of the ground. High accuracy is also needed in the irrigational planning, by making a terrain model to detect where the water can flow. If the surveying data is wrong there is a risk that the water does not reach every farmer.

2. Theory

2.1 Global Navigation Satellite Systems

Global Navigation Satellite Systems (GNSS) is a term used for positioning and navigation satellite systems which include the American Navstar GPS and the Russian Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS). The European Galileo system is also under progress, and all three systems are compatible with each other. Most of today’s GNSS receivers are capable of collecting data from both GPS and GLONASS (Skogseth & Wangen 1998). The GPS and GLONASS follow the same principles, however this thesis will focus most on the GPS.

2.1.1 Global Positioning System

GPS was established within the American military, as a satellite based system for navigation and positioning (Leick 1995). It is funded and controlled by the US Department of Defense. Civilian users obtained free access to the system in 1983 (Hofmann-Wellenhof et al. 2008).

The GPS consists of two segments, respectively the space segment and the control segment. The space segment consists of 24 GPS satellites. The satellites orbit the earth in six evenly spaced planes, with four satellites per plane, providing global satellite coverage with the number of four to eight simultaneously observable satellites above the elevation mask of 15° (Hofmann-Wellenhof et al. 2008). The satellites are constantly orbiting the earth at an altitude of 20200 km (Fig. 5). The orbit timereal is approximately 11 hours and 58 minutes, which makes the satellites circle the earth twice a day (Skogseth & Wangen 1998).

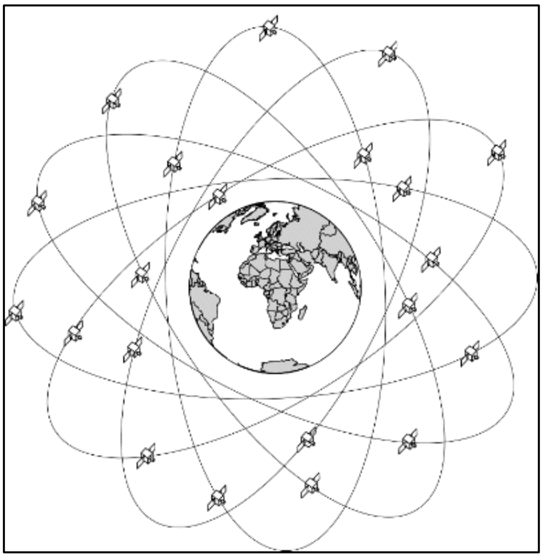

Fig. 5 GPS satellites orbiting the earth at an altitude of 20200km (ESF 2008).

The control segment on the ground consists of a master control station, six monitor stations and ground antennas. The main task of the control segment is to track the satellites for orbit and clock determination, and to upload navigation data to the satellites. The master control station is located in Colorado Springs, and the six monitor stations are located in Hawaii, Colorado Springs, Cape Canaveral in Florida, Ascension Island in the South Atlantic Ocean, Diego Garcia in the Indian Ocean and Kwajalein in the North Pacific Ocean. Each of the six monitor stations is equipped with very accurate atomic clocks and receivers, and orbit parameters and satellite clock corrections are calculated and sent to the satellites (Hofmann-Wellenhof et al. 2008).

The key to the accuracy of GPS is that the satellites are precisely controlled by atomic clocks, with a stability of 1 second error over 300 000 years (Skogseth & Wangen 1998). These clocks produce a frequency of 10.23 MHz. From this frequency the carrier waves L1 and L2 are derived by multiplying the fundamental frequency by 154 and 120, yielding1575.42 MHz for L1 and 1227.60 MHz for L2 (Hofmann-Wellenhof et al. 2008).

The two frequencies L1 and L2 are modulated by P-code (Precise), which has been reserved for US military and other authorized users. A decryption key is needed to use this code. L1 is also modulated by the Coarse Acquisition (C/A) code, and is available for civilian use. The C/A code is omitted from L2, which allows denying nonmilitary users from the best accuracy (Hofmann-Wellenhof et al. 2008).

A GPS receiver measures the distance between the receiver antenna and the satellites at each measurement point. There are two different ways to determine positions on the earth from the signals received from the satellites. Pseudodistances can be measured on a code modulated on the satellite signal, but the accuracy for such measurements range from a meter and more. For land surveying it is necessary to use phase measurements to get the accuracy on centimeter level (Skogseth & Wangen 1998).

In the initial part of a phase measurement the exact number of carrier wave cycles between the satellites and the base station antenna is ambiguous. If the GPS receiver is locked on a GPS signal it is possible to determine the carrier wave cycles. The ambiguity is established during the data processing. If the ambiguity is determined as an integer value, it is called fix solution (Hofmann-Wellenhof et al. 2008). With fixed integer solution the coordinates of a point can be determined with accuracy below 1 cm. If the ambiguity determination results in a real value it is called a float solution and the coordinates will only have meter-level accuracy (WSDNR 2004).

Dilution of Precision (DOP) values describe the geometry of the visible satellites, and is an important factor in achieving high quality results for point positioning and kinematic surveying. The values are constantly changing during the day, depending on the numbers of satellites which have an unobstructed line of sight between the receiver and the satellite (Skogseth & Wangen 1998; Hofmann-Wellenhof et al. 2008). There are several DOP-values, but Geometric Dilution of Precision (GDOP) is one of the most commonly used. GDOP is a value describing the geometry of the available satellites. The mathematic correlation for GDOP, where σ is the standard deviation follows this formula:

$$\sigma_{position} = GDOP \times \sigma_{distance}$$

If the satellite geometry is good (GDOP is low), the standard deviation for the position decreases. The uncertainty of distance measurements is difficult to handle, thus it is best to choose an observation period with good satellite geometry (Skogseth & Wangen 1998). During a surveying session it is important to be aware of the GDOP values. General requirements when performing RTK surveying is that the GDOP value should be less than 5 (WSDNR 2004).

2.1.2 Static GNSS

Static GNSS is a relative position determination method. Static GNSS imply the use of several GNSS receivers with longer periods of measurements, from 20 minutes up to several days, providing results with accuracy on millimeter level. One of the receivers has to be mounted on a known point, so that coordinates of the new points can be determined. The receivers are collecting data simultaneously, by logging vectors which are used in the post processing. Static GNSS is suitable for long baselines, over 20 kilometers, but should not be used for baselines exceeding 50km. This method is often used to establish first and second order points, which require high accuracy (Statens Kartverk 2005).

The vectors are saved internally in each receiver, and the vectors between the receivers and the known reference point is determined by post processing the data. The horizontal accuracies, which can be achieved by static surveying, follow the formula in Table 2. As an example for a baseline of 20km, the resulting accuracy will be 1.5cm (Hofmann-Wellenhof et al. 2008).

Table 2 Achievable accuracies for relative positioning (Hofmann-Wellenhof et al. 2008)

Mode	Horizontal accuracy
Static	5mm + 0.5ppm
Kinematic	5cm + 5ppm

2.1.3 Real-Time Kinematic Global Positioning System

Real-Time Kinematic Global Positioning System (RTK GPS) is a surveying method performed with a link between a reference GPS (base station), rover units and available satellites (Fig. 6). The base station must be mounted on a known reference point, while the rover is moveable. The base station acts as the known position, with predetermined x-, y- and z-coordinates, from which the unknown positions are derived (WSDNR 2004). Data from the base station to the rover is transmitted either through radio contact or through an internet connection, which enables RTK GPS coordinates to appear in real-time in the rover (WSDNR 2004). Normally, RTK surveying is limited by the maximal distance the rover can be from the base station, approximately 4-5km when using radio contact. RTK GPS is often used in field work because of the short observation time in each point, and because the quality of the coordinates is verifiable in the field and coordinates appear in real-time (Statens Kartverk 2005).

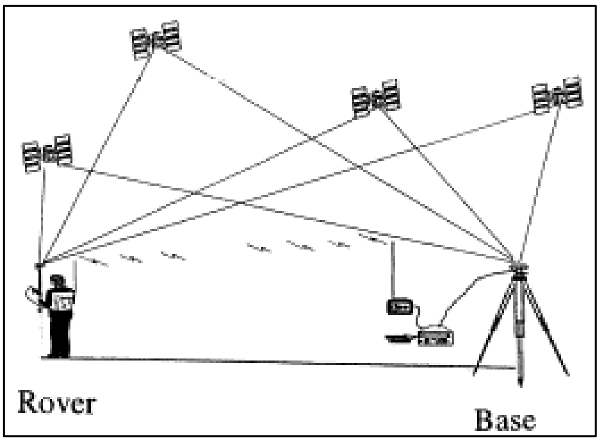

Fig. 6 The basic principles of RTK GPS (Corominas et al. 2000).

When performing RTK surveying all receivers must observe at least four common satellites. It is important that the elevation mask should not be less than 15°. This means that only satellites above 15° relative to the rover are tracked, to avoid interference caused by the atmosphere, buildings and trees. (WSDNR 2004).

2.2 Satellite images

Remote sensing is a broad science dealing with a wide range of disciplines. For the aim of this thesis it is too comprehensive to explain all in detail. Thus, the main focus for this theory chapter is on geometric distortions and correction of satellite images. This focus also calls for an explanation of ground control points (GCPs) and how they impact the satellite image. A brief description of satellite imagery is also given.

A satellite images is a representation of reflected electromagnetic radiation from the earth. This depends on whether the electromagnetic radiation is absorbed, scattered or reflected off of features on the surface of the earth (Lillesand et al. 2008; Clifford et al. 2010). Satellite images are captured in either panchromatic or multispectral format. A panchromatic image is composed of one spectral band, and is displayed in black-and-white. A multispectral image is composed of either two or more spectral bands (Curran 1985). Spatial resolution of a satellite image refers to the pixel size of the image (Clifford et al. 2010). The pixel size of the panchromatic high resolution WorldView-1 satellite image used in this thesis is 0.5m.

The point where the image resolution and geographic location is most accurate is called nadir. Nadir is an Arabic word, referring to the opposite of zenith. The definition of nadir is the point on the ground vertically beneath the perspective center of a sensor (Curran 1985). In terms of satellite images this refers to the point directly below the satellite's position.

2.2.1 Image distortions and geometric correction

All remote sensing imagery contains some geometric distortions (Levin 1999; Lillesand et al. 2008). Raw images can contain significant distortions which make them useless as maps (Lillesand et al. 2008). Geometric corrections are intended to transform the satellite image to be as close as possible to the real world location. Usually, the distortions in the image are complex, and a combination of the transformations translation, scaling and rotation are needed (Levin 1999). Some of the distortions are systematic, such as image motion caused by spacecraft, platform velocity, atmospheric refraction, and distortions due to the topography of the earth (Khorram et al. 2012). Non-systematic distortions can occur when the scale changes in the image because the satellite platform differs from its normal altitude, or if the terrain increases in elevation (Levin 1999).

Distortions can also be caused due to relief displacement, which can occur in locations with a large relief. The position of an object can shift in the image because of the object's local elevation (Robinson et al. 1995; Janssen & Weir 2001). The object is displaced away from the nadir point of the image, and the higher or lower the point is located relatively to nadir, the farther the object will be displaced (Levin 1999).

2.2.2 Ground Control Points

GCPs are geographical features identifiable both on the ground and in the satellite image. They are used in the geometrical transformation of the satellite image, which can reduce systematic distortions in the satellite image (Janssen & Weir 2001; Lillesand et al. 2008). The GCPs must be accurately surveyed, e.g. with RTK GPS (Lillesand et al. 2008). The GCPs should have high contrast and consist of intersections of straight, long lines, such as house corners or distinct junctions (Baltsavias & Gruen 2003; Lillesand et al. 2008). Baltsavias and Gruen (2003) also states that such features are more common in urban areas than in rural, and thus an accurate transformation is more easily obtained in cities than in rural areas.

The satellite image distributor does not have all the information which is needed to obtain an accurate orthorectified image. The satellite image provider issues the satellite image with inadequate local accuracy, so surveying on the ground is necessary to make the map fit with the national coordinate system. GCPs can provide the solution for obtaining a satellite image with the best possible accuracy. For most situations the GCPs must be evenly distributed in the chosen area. In a homogenous landscape the number of GCPs can be sparse, but in landscapes with more complex terrain relief the number of GCPs is more critical (Wang & Ellis 2005). Accurate surveying of GCPs is essential for orthorectifying a satellite image, because remote sensing surveying is only as reliable as the GCPs on which they are based (Lillesand et al. 2008).

It is also important to note that using GCPs for the geometric transformation may introduce new distortions in other parts of the image, in areas far from the GCPs. This means that distortions cannot be entirely eliminated in areas between the GCPs (PCI Geomatics 2003).

2.2.2.1 Orthorectification of satellite images

The mathematical model Thin Plate Spline is the transformation method used in REILA when orthorectifying images. The Thin Plate Spline fits the GCPs exactly, and distributes the warping in the image with minimum curvature between the GCPs. Compared to the polynomial methods used for georeferencing, the Thin Plate Spline can handle more variation in the terrain, because it can use x-, y- and z-coordinates. When using the Thin Plate Spline, a higher number of GCPs should be collected for rough terrain than for homogenous terrain (PCI Geomatics 2003).

2.3 Statistics

The major focus in this thesis is on statistical results related to the accuracy of surveyed coordinates. Results concerning dispersion and central tendency will therefore be given considerable attention. The normal distribution, standard deviation, percentiles, range, mean, mode and median, are variables which are described in more detail in the following sections.

2.3.1 Types of data

There are three different types of data which are analyzed in different ways, respectively nominal, ordinal and scale, which sometimes is divided into interval and ratio. Nominal data are data with no order, for example nationality and gender. It can consist of two or more different categories. Ordinal data are data in which the categories are ordered, for example grades. Scale data are either discrete or continuous data. Discrete data take only integer variables, whereas continuous data can take any value (Marston 2010). Distance is an example of continuous scale variable.

2.3.2 Dispersion

One of the distributions most frequently used is the normal distribution. It is characterized by a high number of observations around the middle values of the sample and a low number of observations at both the low and high extremes (Fig. 7 a). If the sample is normally distributed, 68 % of the data is within one standard deviation, and 95 % is within two standard deviations. The standard deviation is a measure of the average difference between the individual observations and the overall mean. 2.5 % of the data is located at each extreme of the distribution (Marston 2010). If the standard deviation of a sample is high then the distribution within the data set is high, while with a low standard deviation the data set is distributed close to the mean value.

The standard deviation should only be used if the sample is normally distributed (Laerd 2013). A distribution can also be skewed, in either negative or positive direction (Fig.

7 b and c), which results in different characteristics compared to the normal distribution. When running a skewness test, a high positive value indicates a positively skewed distribution, while a high negative indicates a negatively skewed distribution (Andersen & Jakobsen 2004). It is possible to make a skewed distribution fit a log-normal distribution, calculating the logarithmic values for the variables (Limpert et al. 2001).

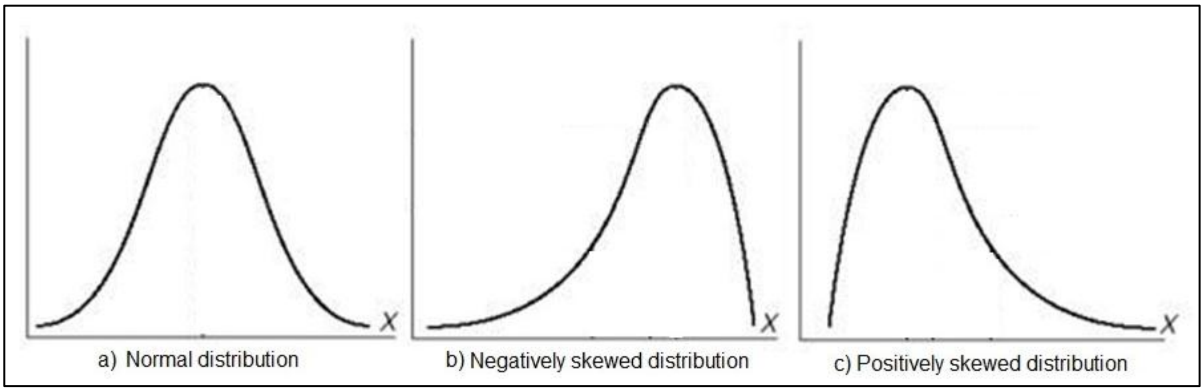

Fig. 7 A normal distribution (Johnson 2006).

Percentiles are also used to describe the dispersion within a data set. When using percentiles the sample is divided into equal parts (Robinson et al. 1995). Based on the middle value of the sample, it is common to calculate the 25^{th}, the 50^{th} and the 75^{th} percentile, also called quartiles (Marston 2010). The 25^{th} percentile is the observation where 25 % of the data have values below it, whereas the 75^{th} percentile is the observation where 25 % of the data have values exceeding this value. The 50^{th} percentile is equal to the median of the sample. Quartiles are useful measures to describe spread because they are less affected by outliers. When a sample is skewed (Fig. 7 b and c) it is therefore more appropriate to use percentiles rather than standard deviation, to describe the dispersion of a sample (Laerd 2013).

A boxplot is an illustrative representation related to quartiles (Fig. 8). The median is represented by the horizontal line going through the box. The 25^{th} percentile and 75^{th} percentile is represented by the upper and lower boundaries of the box. The minimum and maximum value is represented by the upper and lower whisker. If outliers occur, the whiskers extend a maximum of 1.5 times the length of the box. Outliers can be detected outside the whiskers, recognized by circles for normal outliers and stars for extreme outliers. A low dispersion is recognized by a small box and small distance between the lower and upper whisker. And opposite, a high dispersion is recognized by a large box and large distance between the whiskers (Marston 2010).

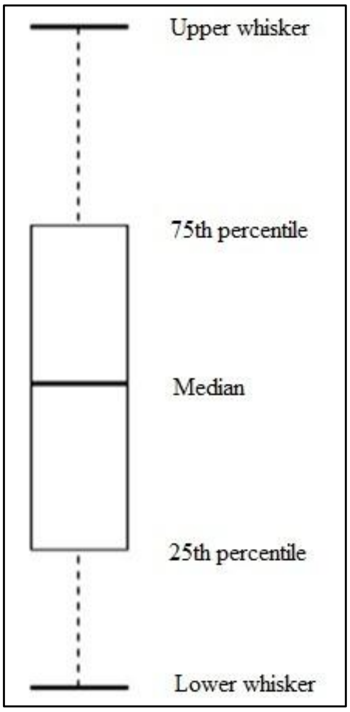

Fig. 8 Example of a boxplot (Dill 2008).

The range value for a data set describes the variation, defined by the maximum value subtracted by the minimum value (Andersen & Jakobsen 2004). A high range can give indications of extreme values and errors in the sample (Laerd 2013).

2.3.3 Central tendency

Values of central tendency describe important properties of a data set. It describes which values the data is centered around and which values are representable for the whole data set. The most frequently used is the mean, mode and the median. The mean is the sum of the observations within a variable divided by the total number of observations. The mode is the most frequent value, while the median is the middle value when observations in the dataset are put into order of magnitude (Robinson et al. 1995; Marston 2010).

The measures of central tendency work differently under different conditions, and sometimes one of them is more appropriate to use (Laerd 2013). When a sample is normally distributed the central values mean, median and mode are approximately the same (Fig. 9 b), and it is suitable to use all three measures of central tendency. However, when the distribution is skewed, the mean is pulled away from the central values. The mean is influenced by small numbers of high value observations, also called outliers, and the mode is influenced by the densest distribution (Andersen & Jakobsen 2004). When a sample is skewed, it is often better to use the median, as this best retains its central position (Andersen & Jakobsen 2004; Laerd 2013).

When the data is negatively skewed, the mode has the highest value, while the mean is less than the median (Fig. 9 a). If the data is positively skewed, the median is less than the mean, while the mode has the lowest value (Fig. 9 c) (Andersen & Jakobsen 2004; Johnson 2006).

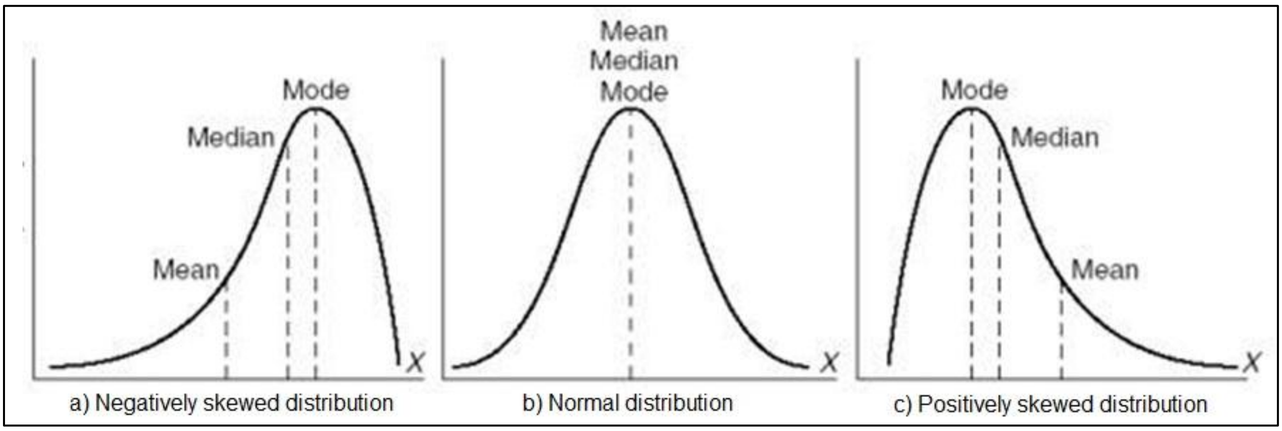

Fig. 9 The relationship between central tendency and a) a negatively skewed distribution, b) a normal distribution and c) a positively skewed distribution (Johnson 2006).

2.3.4 Correlation

Correlation tests give some clues about the relationship between variables, and how strong this relationship is. The Pearson r test is frequently used. This test is described in more detail in the following section.

2.3.4.1 Pearson r

The Pearsons r is a correlation test used to find the relationship between two variables. The variables must be on either scale or interval level (Laerd 2013). Another requirement for using the Pearson r is that the samples must be normally distributed. Pearson r measures the degree of linearity between two variables (Andersen & Jakobsen 2004). It is possible to interpret the strength and the direction of the relationship. The Pearson r value can be interpreted using Table 3. A value of 0 indicates no relationship between the variables (Laerd 2013). A positive value between 0 and 1 indicate that when one variable increases the other variable is increasing as well. A negative value between 0 and -1 indicate that when one variable is decreasing the other one is increasing.

Table 3 Pearsons r interpretation table (Laerd 2013)

Pearson r	Interpretation
< ± 0.1 - ± 0.3	Weak relationship
± 0.3 – ± 0.5	Moderate relationship
< ± 0.5	Strong relationship

2.3.5 Spatial Autocorrelation

A spatial statistic which is suitable to measure a data set's spatial autocorrelation is the Global Moran's I test, which uses both the features' locations and values. Based on a z-score, ranging from -1 to +1, the Global Moran's I evaluate patterns to be clustered, dispersed or random. A value of -1 indicates dispersion, values close to zero indicates a random pattern, while a value of +1 indicates clustering (Lentz 2009).

2.3.6 Reliability and validity

Both reliability and validity is important to address when conducting any kind of research. Reliability is understood, in this study, as the degree of repeatability of a study, i.e. if the same results could have been reproduced in a different study, and with different people (Golafshani 2003). Validity is understood as the extent to which the research truly measures what it is intended to research, and how truthful the results are (Golafshani 2003). This can be related to the instruments used in the study, and if the instruments really measure what is intended to be measured.

3. Methods

3.1. Preparatory work

Information meetings about the surveying in Angot Yedegera were held by the LAC prior to my field work, and farmers and their families were informed. Because of the large majority (98.7 %) of Christians in the area, the information meetings about the surveying were held during Sunday church service (Bureau of Amhara Regional State 2011). There are six churches in the kebele, and each Sunday 400-500 people attend church service in each of the churches (Bureau of Amhara Regional State 2011).

3.1.1 Survey instruments

Before the field work could start all survey instruments were checked. This was done at the Bureau of Environmental Protection, Land Administration and Use (BoEPLAU) office in Bahir Dar two days prior to the field work. Thomas Dubois (Orgut consultant) and Gebeyehu Belay (BoEPLAU) participated in this session. Mr. Belay was responsible for the lending of the equipment through BoEPLAU. Four Leica 900 GPSs were available, and it was necessary to confirm whether all the accessories for each instrument were in their correct positions. I also tested that the radio signals from the base were received in the rover, and that the GPS obtained fix solution.

3.1.2 Selecting land parcels

The preselecting of parcels was done at the BoEPLAU office. Distinct and visible land parcels were selected from the satellite image from different parts of the research area. The parcels were marked in QGIS with one point in the middle of each parcel. These central points were thereafter exported to a handheld GPS. Having a reference point for each selected parcel stored in a handheld GPS was expected to make it easier to locate each of these parcels in the field. It was important to achieve an even distribution of selected parcels in the area because the parcels were intended to represent the whole kebele. Land parcels were also selected on the background of the slope of the terrain. It was important to cover both flat and hilly terrain to collect data for the slope analysis.

3.2 Field work

The field work was conducted during a ten day period, from 10 to 19 October 2012 in kebele Angot Yedegera. The first two days were used to establish four second order points by static surveying, by the use of already established first order points (Miskas & Molnar 2009). The last eight days were used for RTK GPS surveying of land parcels in Angot Yedegera. Mr. Dubois participated in the first two days of the field work, helping to conduct the static surveying. Mr. Belay participated during the whole field work campaign.

When we arrived at Dembecha we drove directly to the woreda land administration office. At the office a meeting was held together with the employees in the land administration. Information about the surveying was given, and there was also a discussion about the upcoming land registration with the use of the georeferenced satellite image. After the meeting a representative from the land administration office joined the group to find suitable locations to establish second order points. A kebele expert, Alemerew Atnaf, also joined, contributing with local knowledge about the kebele and parcel boundaries. Finally, a farmer from Angot Yedegera joined in the process of establishing second order points.

The equipment used during field work was four Leica 900 GPSs, which could be used both for static surveying and RTK GPS surveying, a Garmin 60C handheld GPS, and a number of 12 satellite image printouts in scale 1:8000, covering the research area. Further, a digital camera, a notebook and a pencil was used.

3.2.1 Establishing second order points

Second order points are benchmarks which are determined with high relative accuracy. The accuracy of these of these points influences the accuracy of all further surveying and mapping. The points should also have high durability and be established on stable ground, preferably solid rock (Robinson et al. 1995). The points must be established before the RTK GPS surveying can begin, because the second order points are used as base stations during the RTK surveying. When planning and establishing second order points it is critical that they are evenly distributed in the research area. The second order points also require locations which are optimal to obtain radio contact between the base and the rover. Each point was marked with a drilling machine, with a point surrounded by a triangle, and the point name (Fig. 10). The four new second order points were named AY1, AY2, AY3 and AY4, where AY is an abbreviation for Angot Yedegera. All of the second order points were established inside the kebele border (Fig. 11). The second order points were accessible by car on dirt roads.

Fig. 10 The second order point AY1 established in solid rock.

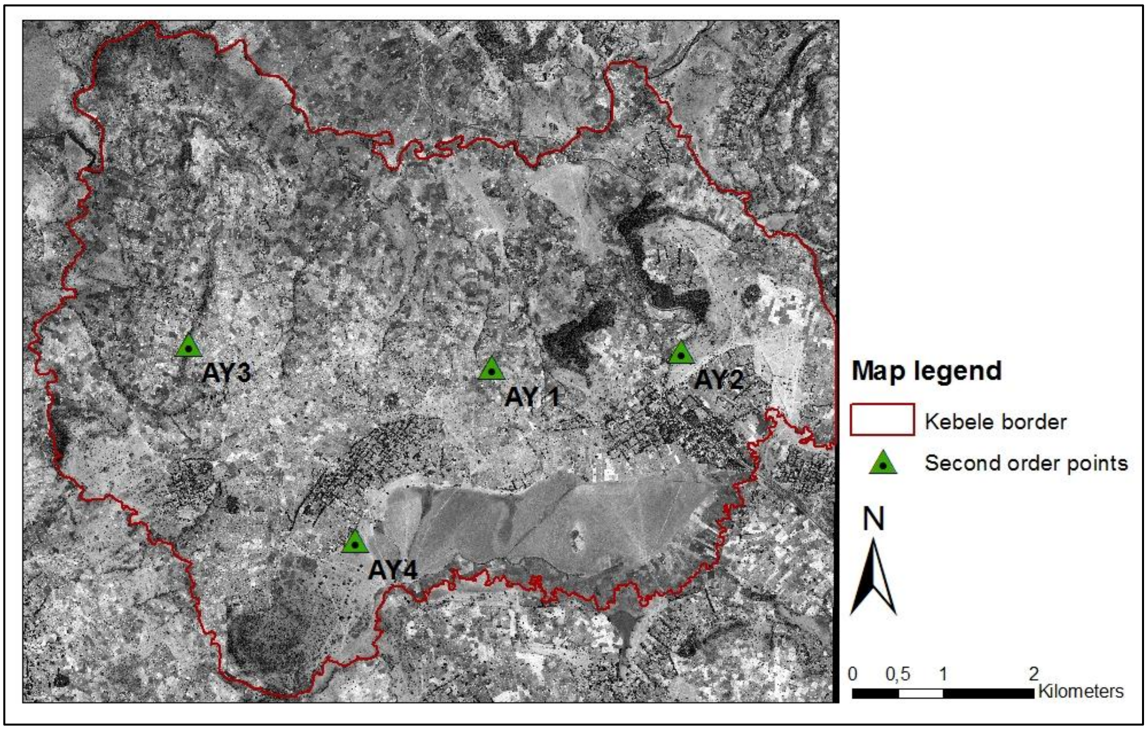

Fig. 11 Map of Angot Yedegera showing the established second order points, AY1, AY2, AY3 and AY4.

3.2.2 Static surveying

The first two days in the field were used for static surveying. The first day, October 10th 2012, the existing benchmarks in Bure, Jiga and Adis ena Gulit (Fig. 12) were used for establishing the new second order point AY2. The existing benchmarks were established in

2009 by static surveying. During the static surveying a number of four different base stations were logging satellite positions simultaneously (Fig. 13), with two hour long sessions. The chosen epoch interval was set to 5 seconds. The session period and epoch interval was chosen to ensure as high accuracy as possible. The length of the baseline between Bure and Jiga was 36,5km, while the baseline between Jiga and Adis ena Gulit was 39,5km. On the second day, October 11th 2012, static surveying was performed in the second order points AY1, AY2, AY3 and AY4 (Fig. 11).

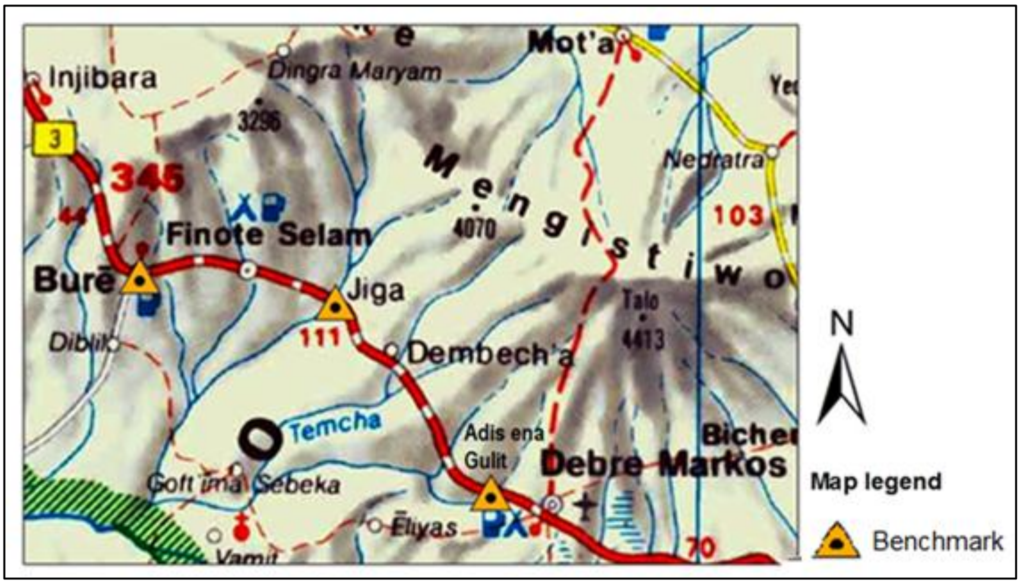

Fig. 12 Map of the benchmarks in Bure, Jiga and Adis ena Gulit used during the static surveying (Israj 2013).

Fig. 13 Base station logging satellite positions in Bure.

3.2.3 RTK GPS surveying

Prior to each day of surveying, a plan of which parcels to survey was made. In the field the handheld GPS was complemented with printouts of the satellite image to make it easier to find and identify each parcel. The daily plan was often modified, due to poor radio contact with the base or crop changes which had occurred after the satellite image was obtained. In these situations, new parcels nearby had to be found to replace the preselected ones. For one full day of surveying it was possible to survey an amount of 10 – 15 parcels.

The terrain was quite rough, so it was impossible to drive from one parcel to another to conduct the RTK GPS surveying. This made it necessary to walk on foot between each parcel. Paths and narrow roads were extensively used, and these were found on the satellite image printouts. The handheld GPS was mainly used to get an indication of the direction and for identifying the parcels. Moving on foot with the surveying equipment was often time consuming due to rough ground conditions, large detours to access parcels, and dense crops which were difficult to move through.

Many of the preselected parcels had changed shape from when the satellite image was obtained to the start of the field work. This created challenges in the field, and it was a time consuming process to judge whether the parcel shape was the same as in the image or whether it was necessary to find new parcels which could replace the rejected parcels.

Four second order points were created in Angot Yedegera, and the base station was positioned in these points. For RTK GPS surveying, radio contact had to be established between the base and the rover before the surveying could begin. The radio has a maximum range of 3km under optimal conditions. Hills and valleys influence the radio signals and can cause radio shadows. These shadows can break the connection between the base and the rover, and it will then be impossible to get a fix solution. The radio signals at base AY2 was of poor quality, and it was difficult to obtain a fix solution. The radio signals at AY1 were constant and stable. This made it an excellent base.

A kebele expert, Alemerew Atnaf, from the land administration in Angot Yedegera participated in the RTK GPS field work, contributing with his local knowledge on boundaries and with carrying equipment. During the different days of surveying local farmers were also hired to protect the base stations located at the second order points. These people received salary from the REILA project.

All parcel corners were surveyed with fix solution, which means that the maximum horizontal error for the RTK GPS measurements is 10cm (Appendix A). The status of a point with fix solution is ‘Measured’, seen in the table in Appendix A. A point with accuracy exceeding 10cm will not be measured and saved. All parcel corners were also surveyed with GDOP values below 5, which ensure that the geometry of the satellites is sufficient.

3.2.4 Categorization of border types

During the field work and the RTK surveying an assessment of each parcel corner was performed to determine the characteristic of the border type. This information was recorded manually. Such an assessment is not straight forward, as some parcel corners can consist of several border types or the parcel corner can be hard to categorize. A parcel border can for example be delimited by a walking path and a surrounding fence. In such cases the border type which constitutes the border to the largest extent has been chosen.

The border types have been categorized in six different categories, and been assigned with the following numbers: Fence (1), Forest (2), Pasture land (3), Parcel (4), Path (5) and Diffuse (6) (Appendix B).

Most of the categorized borders consisted of only the neighboring parcels, without any fences or other barriers. As an example from Fig. 14, the left image shows one parcel corner surrounded by a parcel with maize, which makes the parcel corner very distinct. Other parcel borders consisted of narrow drainage runs, which can be seen on the right image (Fig. 14). The drainage runs were often difficult to spot immediately, as the same crop could be cultivated on neighboring parcels. These drainage runs had been dug out by hand by the holders of the parcels.

Fig. 14 Examples of border characterized as ‘parcel’.

Some of the parcels in the research area were surrounded by fences, which made up the border of the parcel (Fig. 15). These constructions were made by trees or by more stable terraces of stone. Fences were mostly used to prevent cattle, mules or other animals from gaining access to the crops.

Fig. 15 Examples of borders characterized as ‘fence’.

‘Pasture land’ and ‘path’ are border types frequently found in Angot Yedegera (Fig. 16). The majority of the parcels close to pasture land were surrounded by fences. All parcels bordering pasture land without fences were characterized as ‘pasture land’. The category ‘path’ includes both narrow walking paths and broader roads which are intended for mules and wagons. Some paths are changing due to seasonal changes like the rainy season. Other paths are more sustainable and fixed.

Fig. 16 Examples of borders characterized as ‘pasture land’ (left) and ‘path’ (right).

The last two border types are ‘forest’ and ‘diffuse’ (Fig. 17). The border type ‘forest’ includes forests, large bushes and large single trees. In satellite images forests and large trees can cause shadows and dark areas, which can make it difficult to determine the correct location of the parcel border. High and dense forest can also impede good satellite geometry and fix solution. 'Diffuse' is a category which includes borders with unclear limits. Examples of this can be open spaces between a crop and a path or a crop and a forest, where it may be questioned where the correct parcel corner should be.

Fig. 17 Examples of borders characterized as 'forest' (left) and 'diffuse' (right).

3.3 Ground Control Points

Forty-two GCPs were used to orthorectify the satellite image (Table 4). The surveyed GCPs were evenly distributed all over the research area (Fig. 18). Parcel corners were most frequently used as a GCP, while roof corners and water pumps were also used. Roof corners are often the best choice among these, as these are well defined in the image. But due to few house roofs outside the villages in Angot Yedegera, a number of parcel corners had to be used. Michal Lodin, a remote sensing consultant from NIRAS, performed the orthorectification of the satellite image. I attended the session when he performed the orthorectification. The satellite image was orthorectified in Geomatica using a Thin Plate Spline method.

Table 4 Type of Ground Control Points used for the orthorectification of the satellite image.

Type of GCP	Number of GCPs
Parcel corner	27
Roof corner	13
Water pump	2
Total number of GCPs	42

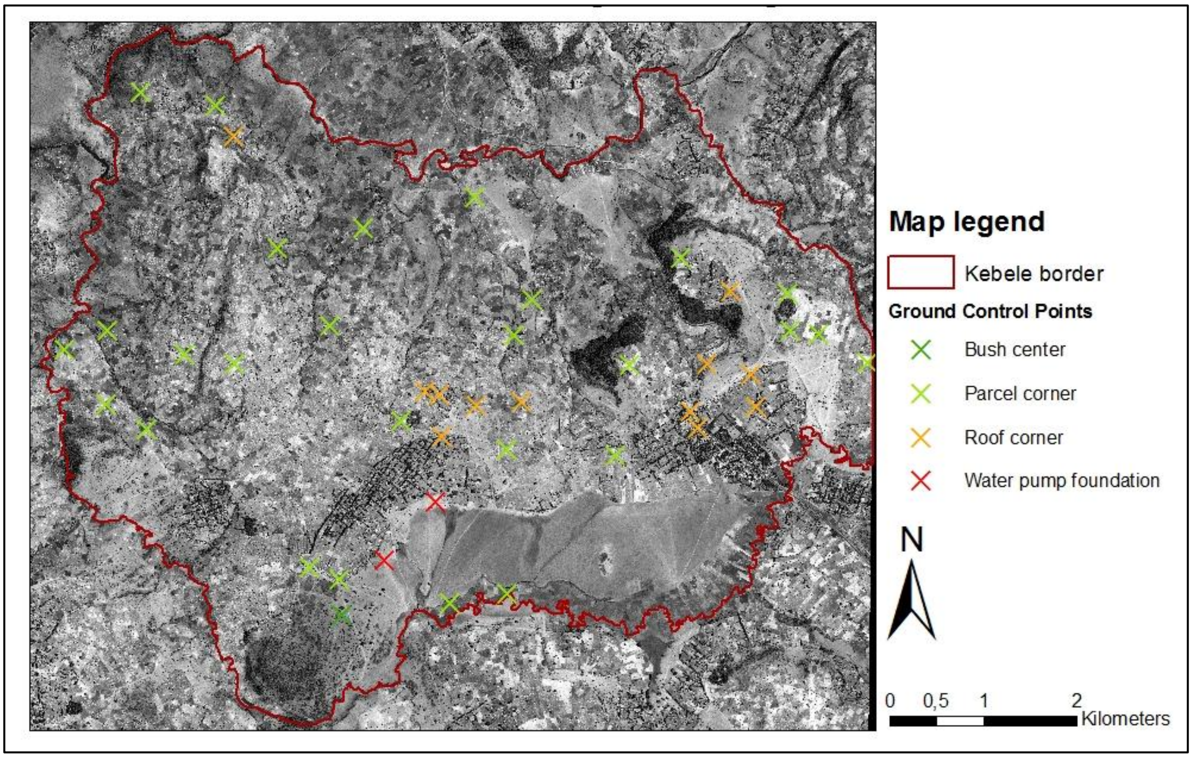

Fig. 18 The spatial distribution of the Ground Control Points in kebele Angot Yedegera.

3.4 GIS and statistical analysis

3.4.1 GIS

All the GPS data from the static surveying was imported and processed in the GIS software Leica Geo Office. For the post processing the first order points were used as control points. First, the first order points Bure, Jiga and Adis ena Gulit (Fig. 12) were used as control points to determine the coordinates of the second order point AY2. The coordinates of the first order points, and their respective horizontal quality, is given in Table 5. The complete report of how these benchmarks were surveyed is described by Miskas and Molnar (2009).

Table 5 Coordinates of the first order points, and their quality, used for static surveying post processing (Dubois 2011)

ID	X coordinate	Y coordinate	Quality (mm)
Bure	287846.416	1184454.206	10.7
Jiga	323607.955	1177671.958	10.0
Adis ena Gulit	347845.303	1146313.655	8.8

Secondly, the second order point AY2 was used as a control point to determine the coordinates of the second order points AY1, AY3 and AY4. The horizontal quality of the second order points were calculated together with the coordinates.

In the GIS process both QGIS and ArcGIS were used. QGIS, which is a freeware program, is the program intended to be used in Ethiopia for the REILA program and the future land registration process. I have only used ArcGIS in the GIS analysis and map making process.

3.4.1.1 Digitizing parcel corners

The parcel corner points were digitized using the editor function in ArcGIS, by zooming close to each of the surveyed parcel corners on the satellite image. Most of the parcels had distinct boundaries and the parcel points were digitized in the exact location of the parcel corner. In situations where the parcel corner points were vague, I had to use my better judgment. During this process I also assigned the correct border type to each of the parcel corner points in the attribute table.

3.4.1.2 Slope analysis

As preparation for the slope analysis, contour lines from a topographical map of Angot Yedegera were digitized manually (Fig. 19). This was the only elevation source available for this area. The contour interval for the map was 20m. The topographical map was georeferenced in QGIS using the gridline coordinates.

To perform the slope analysis for kebele Angot Yedegera a Triangulated Irregular Network (TIN) model was created based on contour lines. The TIN model was then converted to an elevation raster. From the raster layer a slope analysis was performed to find the slope for all of Angot Yedegera. Slope values were expressed using degrees. I finally extracted the slope values to each of the parcel points. The final data table was exported to a SPSS readable format for further analysis.

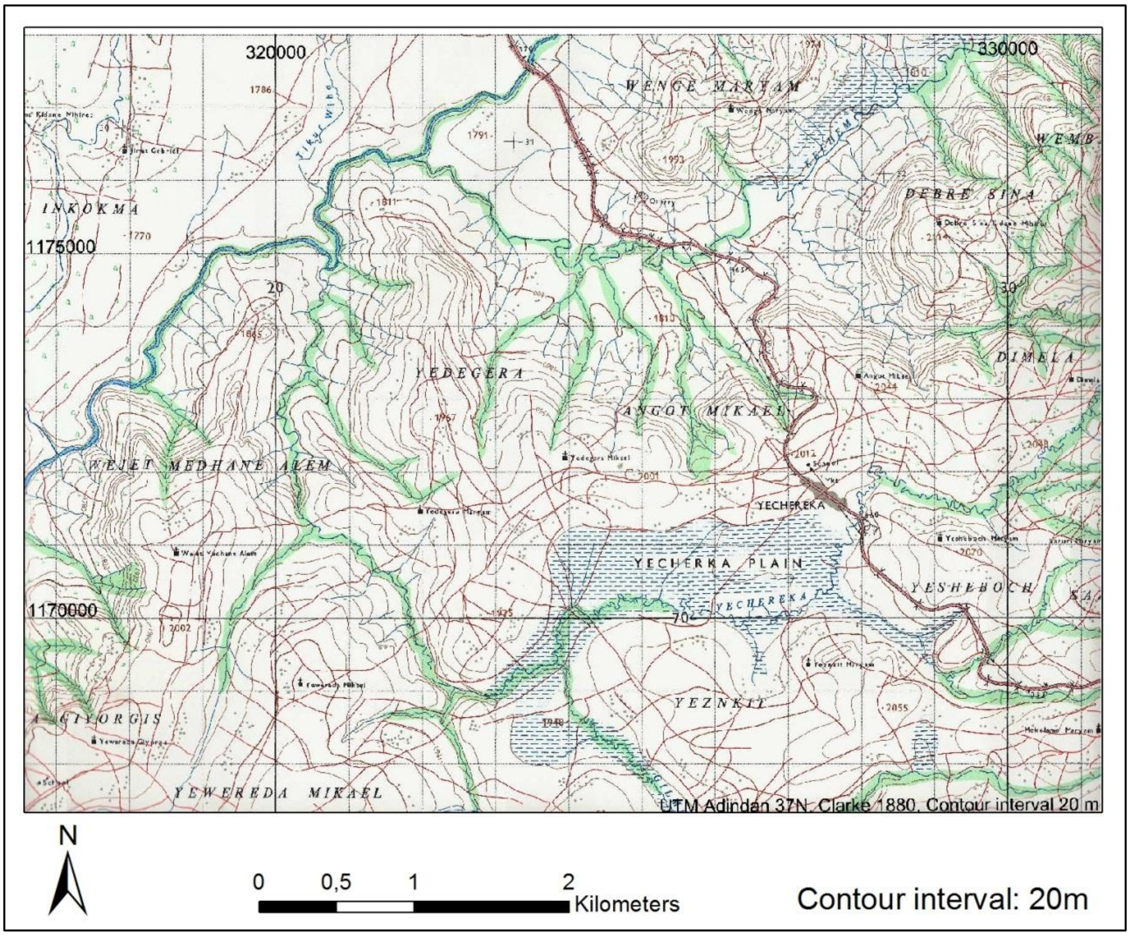

Fig. 19 Topographical map of Angot Yedegera.

3.4.2 Statistical analysis

For the statistical analyses I have used SPSS. In SPSS I edited the data from the shapefiles in ArcGIS, and calculated the difference between the coordinates from RTK GPS and the coordinates from the satellite image. The difference between the X coordinates was first calculated and named delta x, and thereafter the difference between the Y coordinates was calculated and named delta y. These results had values with both positive and negative values.

The calculated difference between the coordinates from the satellite image and the GPS measurements was named ‘delta xy’. For this calculation I used the distance formula (Robinson et al. 1995):

$$d = \sqrt{(x_{2-}x_{1)}{}^{2} + (y_{2-}y_{1)}{}^{2}}$$

The distance formula converted all results to absolute values with positive values. I also performed a logarithmic transformation of delta xy, and named the new variable ‘Log delta xy’. This resulted in both positive and negative values (Appendix B).

In SPSS I have conducted several analyses and tests. I conducted descriptive statistics analysis of central tendency and dispersion for delta xy and for the border types. From this I derived the values for mean, median, standard deviation, percentiles, range and skewness. A histogram of the distribution of delta xy was created. I also made boxplots of the border types and delta xy. I conducted a bivariate Pearson r correlation test. The significance level was 0.05. The Pearson r was run on the ‘Log delta xy’ variable. Finally, a scatterplot of slope and delta xy was created.

The results will be analyzed both separately and together, and the final discussion and conclusion must be based on a comprehensive approach, taking into account all statistical information available.

I have categorized the data categories according to the different types of data; i.e. nominal, ordinal and scale. For the different categories please see Appendix B. The category ‘ID Sat’, ‘ID GPS’ and ‘Border type’ is assigned the data type nominal. There are no ordinal categories in the data set. Scale is the most frequent data type in the data set. The scale category includes ‘X Sat’, ‘Y Sat’, ‘X GPS’, ‘Y GPS’, ‘Delta x’, ‘Delta y’, ‘Delta xy’, ‘Slope’ and ‘Log delta xy’.

4. Results

4.1 Results from static surveying

The results from the post processing of the GPS data from the static surveying can be seen in Table 6. All of the second order points have a horizontal quality better than 1cm, ranging from 1.1mm to 5.3mm. The coordinates of the new second order point AY2 have been averaged based on all the baselines to the first order points. For the post processing the initial coordinates of Bure, Jiga and Adis ena Gulit is used (Table 5). The coordinates of the second order points AY1, AY3 and AY4 have been averaged based on the baselines to AY2 and the baselines between each other.

Table 6 Coordinates and quality of the second order points in Angot Yedegera

Name	Type	Date	X	Y	H	Quality (mm)
AY2	Averaged	10 Oct 12 11:19	327227.225	1172744.547	1970.999	5.3
AY1	Averaged	11 Oct 12 14:04	325132.219	1172560.764	1948.832	3.1
AY3	Averaged	11 Oct 12 14:04	321772.992	1172818.952	1929.104	1.1
AY4	Averaged	11 Oct 12 14:04	323620.816	1170639.691	1934.783	3.2

4.2 Statistical results

4.2.1 Descriptive statistics of delta xy

The total number of parcel corners used for the statistical analysis was 210 (Table 7) (Appendix A). The GPS-points used as GCPs are not included, as these points would give a wrong impression of the accuracy. Delta xy is expressing the difference between the coordinate values from the RTK GPS surveying and the digitization of parcel corners from the satellite image. The number of points with a delta xy deviation less than 1m is 98, corresponding to 46.4 %, which means that 112 points have a deviation exceeding 1m (Appendix B).

The mean deviation for delta xy is 1.869m (Table 7). All values in Table 7, except skewness, are given in meters. The median for delta xy, or the middle value of the data set, is 1.088m. The difference between the mean and the median is 0.781m. The standard deviation for the sample is 1.940m. The range for delta xy is 10.030 m, which is rather high. The lowest deviation value for delta xy is 0.073m. The skewness is determined to 1.866, which indicates a positive right tailed distribution. The 25th percentile is 0.611m, the 50th percentile equals the median, while the 75th percentile is 2.386m.

Table 7 Descriptive statistics for delta xy

Total number of points		210
Mean		1.869
Median		1.088
Standard deviation		1.940
Range		10.030
Minimum		0.073
Maximum		10.103
Skewness		1.866
Percentiles	25th	0.611
	50th	1.088
	75th	2.386

The distribution of delta xy is shown in the histogram below (Fig. 20). The dashed line to the right is the mean, while the dashed line to the left is the median. The thick line displays a normal distribution curve. The histogram shows a right skewed distribution, with the densest distribution left of the mean between 0 - 1.5m. The three tallest columns to the left are representing a total of 133 delta xy points. This skewness is also demonstrated in the descriptive statistics with the value 1.866 (Table 7). The data to the right of the mean is spread out, with some high delta xy values. Between 8m and 10m there are no data, while there are a total of ten delta xy values above 6m and two delta xy values exceeding 10m. The normal distribution curve does not fit the sample, which means that the sample is not normally distributed. Thus it is not appropriate to use the mean and standard deviation in the further analysis and discussion, but they will be displayed in the tables in this chapter. Based on the positive skewness of the data set (Fig. 20 and Table 7) I will only use the median value and the percentiles further in the analysis, since these values describe a positively skewed distribution better than the other variables (Laerd 2013; Laerd 2013).

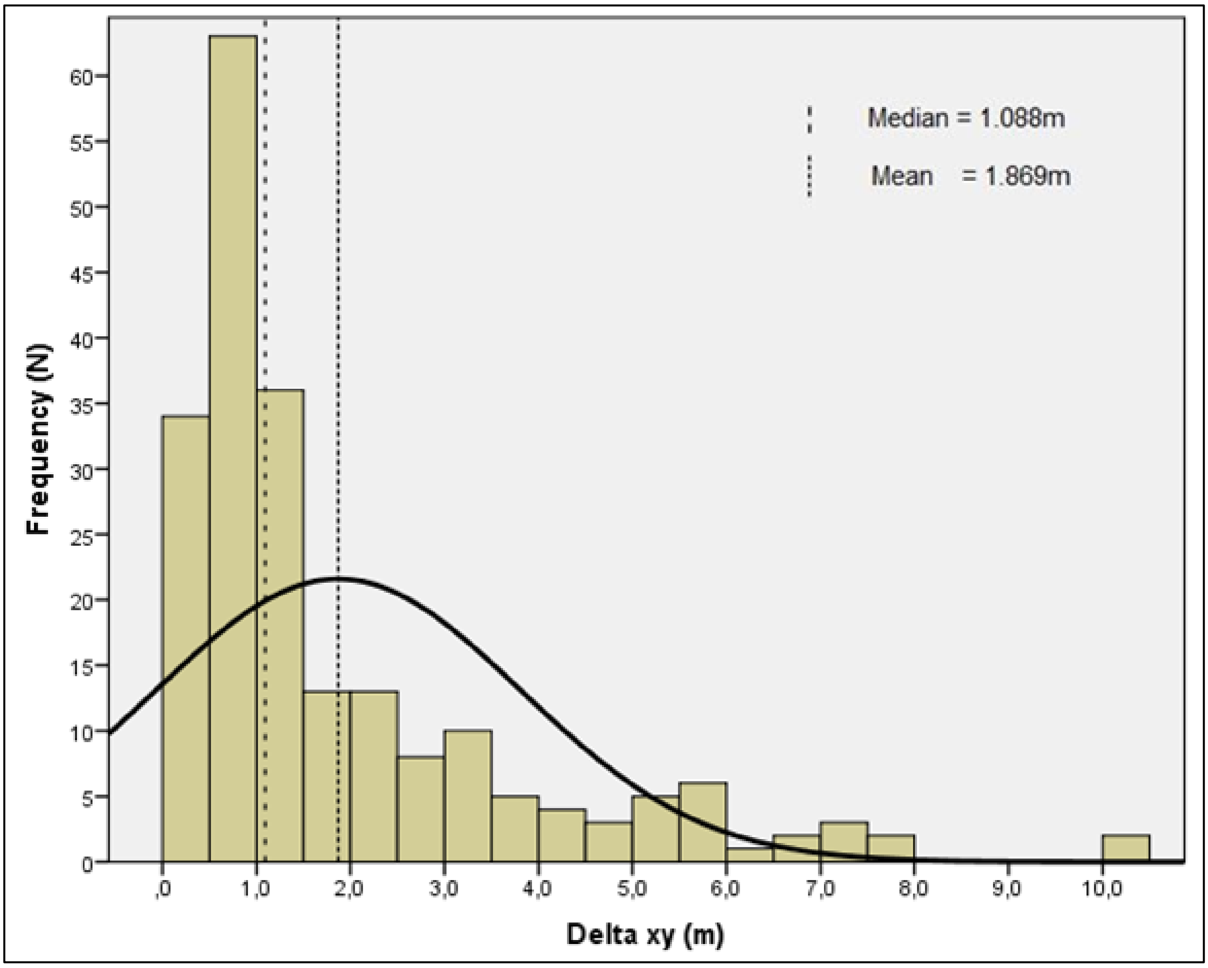

Fig. 20 Histogram displaying the distribution of delta xy.

4.2.2 Descriptive statistics of delta xy with respect to border type

The number of points representing the border types is uneven among the six categories. The border types 'parcel' is represented by 87 parcel points, which make up the largest proportion. The border type 'pasture land' is the least frequent, with only 13 parcel points. When taking into account the different border types for delta xy, the median for the border types 'fence', 'pasture land' and 'parcel' is below the 1m requirement (Table 8). The border type 'fence' has a median of 0.725m, 'pasture land' has a median of 0.814m, while 'parcel' has a median of 0.870m. The other three border types have medians varying from 1.777m to 2.367m. The minimum and maximum values vary considerably among the different border types. The border type 'pasture land' has the smallest range of 3.368m, with a minimum value of 0.073m and a maximum value of 3.441m. The largest range is 9.972m for the border type 'fence'. The border types 'forest', 'parcel' and 'diffuse' has almost similar ranges, ranging between 6.989m and 7.849m.

Table 8 Descriptive statistics for delta xy, with respect to different types of borders.

	N	Mean	Median	Standard deviation	Minimum	Maximum	Range
Fence	37	1.218	0.725	1.894	0.131	10.103	9.972
Forest	26	2.623	1.838	2.034	0.157	7.831	7.674
Pasture land	13	1.219	0.814	1.153	0.073	3.441	3.368
Parcel	87	1.508	0.870	1.584	0.105	7.954	7.849
Path	24	2.567	1.777	2.178	0.348	10.088	9.740
Diffuse	23	3.072	2.367	2.354	0.492	7.481	6.989

The percentile values for delta xy are seen in Table 9. The border type 'fence', which had the lowest median, has the lowest 75th percentile value of 1.115m. 'Parcel' and 'pasture land' has the second and third lowest 75th percentile values, with 1.884m and 2.221m respectively. 'Path', 'Forest' and 'Diffuse' has 75th percentiles of 3.533m, 3.910m and 5.722m respectively. The border types 'path' and 'diffuse' are the only border types with 25th percentile values exceeding 1m.

Table 9 Delta xy percentiles based on border types.

		Fence	Forest	Pasture land	Parcel	Path	Diffuse
N		37	26	13	87	24	23
	25th	0.573	0.881	0.350	0.540	1.094	1.121
Percentiles	50th	0.725	1.838	0.814	0.870	1.777	2.367
	75th	1.115	3.910	2.221	1.884	3.533	5.722

In addition to the percentile values given in Table 9, the dispersion of the different border types is also illustrated in the boxplot below (Fig. 21). It is important to stress that the estimated outliers in this figure are measured relatively based on each border type. The border type 'diffuse' has a large dispersion, recognized by a large box and long whiskers. The border type 'fence' has the smallest box and whiskers of all the border types, with almost all parcel points close to the 1m requirement. At the same time, 'fence' has one normal outlier and two extreme outliers, with the highest delta xy value exceeding 10m. The border type 'forest' has a large dispersion, with the longest whiskers of all the border types. However, 'forest' has a smaller box and a lower median compared to the border type 'diffuse'. The border type 'parcel' has the second smallest box and whiskers with most of the parcel points below 3m. At the same time, eight parcel points have been defined as outliers, including 3 extreme outliers. The border type 'pasture land' has almost the same median and length of the whiskers as 'parcel', but is recognized by a larger box. The last border type, 'path', has the third largest box and whiskers, with the upper whisker slightly above 5m. One parcel point is detected as outlier, with a delta xy value just over 10m.

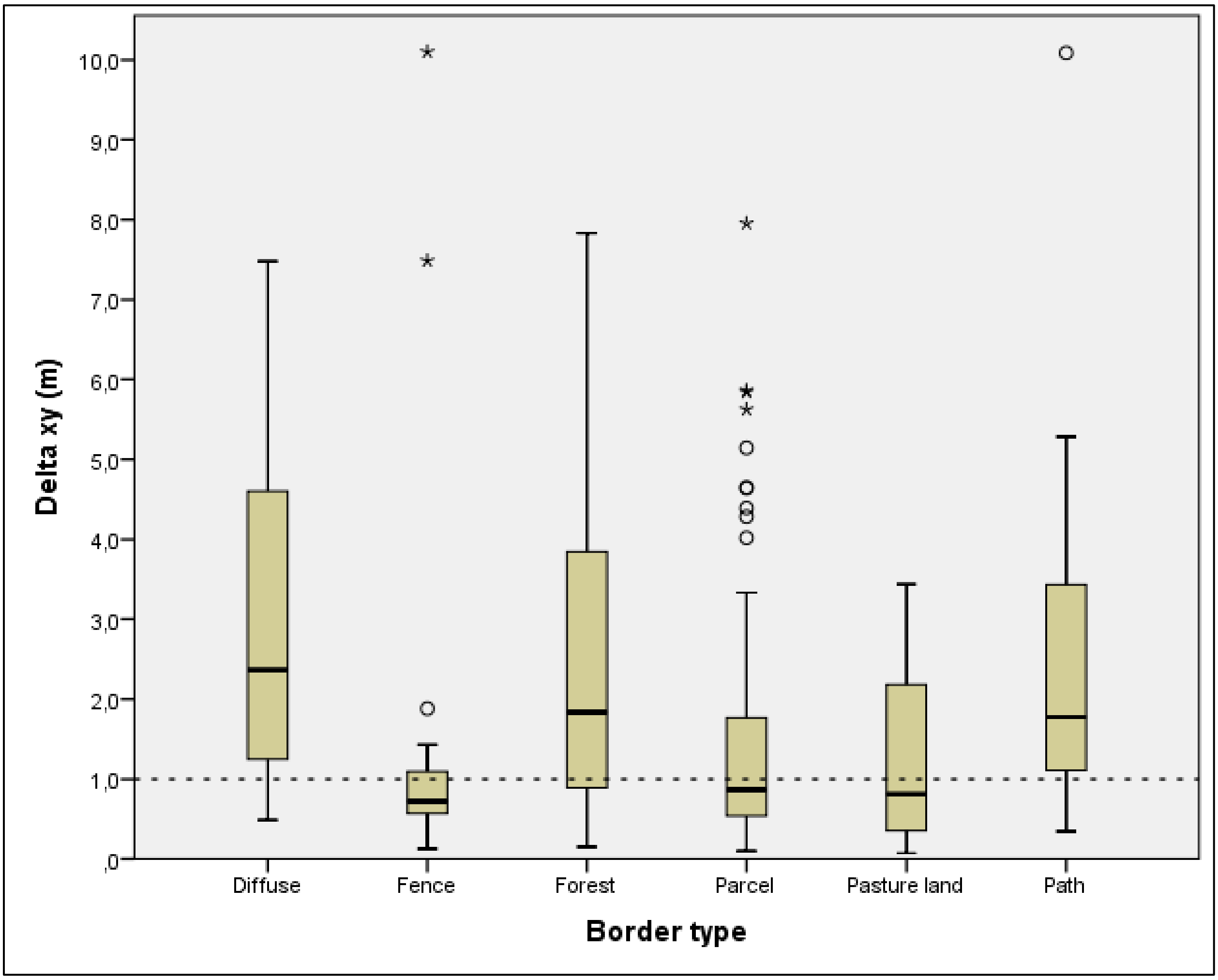

Fig. 21 Boxplot of the relationship between delta xy and border type. Dashed line is equivalent to 1m.

4.2.3 Delta xy outliers

A statistical outlier analysis has been performed for detailed analysis of the outlier values. Based on the skewness value in Table 7 and the histogram in Fig. 20 it was decided to use the boxplot based on percentiles to detect outliers (Fig. 22). Since the sample is not normally distributed, it is not appropriate to use the standard deviation for detecting outliers. Delta xy values which are outside of the boxplot, in this case exceeding the value 5.050m, have been defined as outliers. A total of 21 outliers have been detected, which means that 10 % of all the parcel points in the data set are outliers.

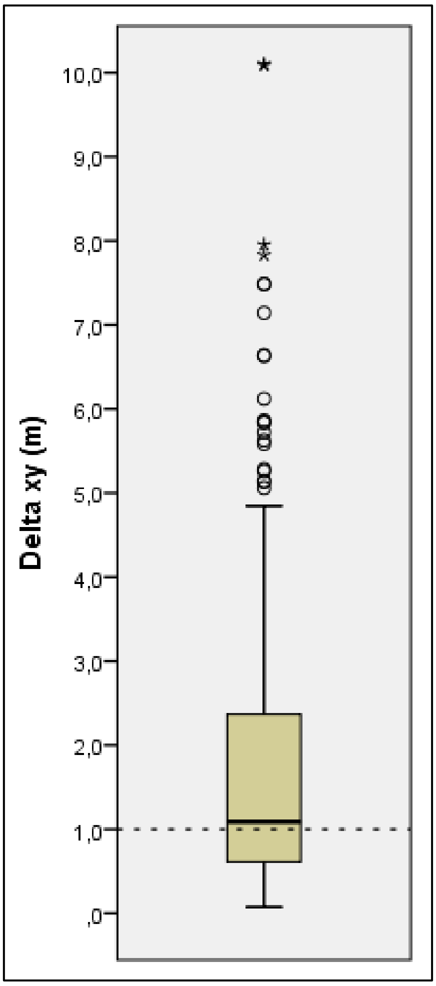

Fig. 22 Boxplot of delta xy. Dashed line is equivalent to 1m.

Five of the outliers have the border type 'parcel' (Table 10). Six of the outliers have been detected as the border type 'diffuse', four as the border type 'path', four as the border type 'forest' and two as the border type 'fence'. None of the parcel points with the border type 'pasture land' have been detected as outliers. Four of the outliers have been detected as extreme outliers, one of them represented by the border type 'path', one by the border type 'fence', one as 'forest' and the last one as 'parcel'.

The border types 'fence' and 'parcel' have low percentages of outliers, 5 % and 6 % respectively (Table 10). These are the border types with the lowest amount of outliers, together with 'pasture land', which has no outliers. The border type 'diffuse' has the highest percentage of outliers, with >25 % of the parcel points being outliers. Of the border types 'forest' and 'path' the amount of outliers is 15 % and 17 % respectively.

Table 10 Table of delta xy outliers.

Border type	N	Percent of total	Parcel ID
Parcel	5	6 %	26, 95, 100, 190, 197
Diffuse	6	26 %	101, 102, 118, 122, 139, 235
Path	4	17 %	28, 29, 77, 129
Forest	4	15 %	52, 63, 64, 191
Fence	2	5 %	50, 51

The distribution of the outliers is shown in the map below (Fig. 23). The green points represent parcel points with delta xy values under the 1m requirement. The yellow points represent parcel points with delta xy values between 1m and 5.050m. The red points represent the outliers outside the whiskers (Fig. 22), which are values with discrepancies above 5.050m. The outliers can be found consistently across the entire research area. The yellow points, which count 102 parcel points, are also scattered all over the research area. Based on Moran's I spatial autocorrelation measure, the distribution of the delta xy outliers got a z-value of -0.09 (Appendix C). This means that the distribution is significantly similar to a random pattern.

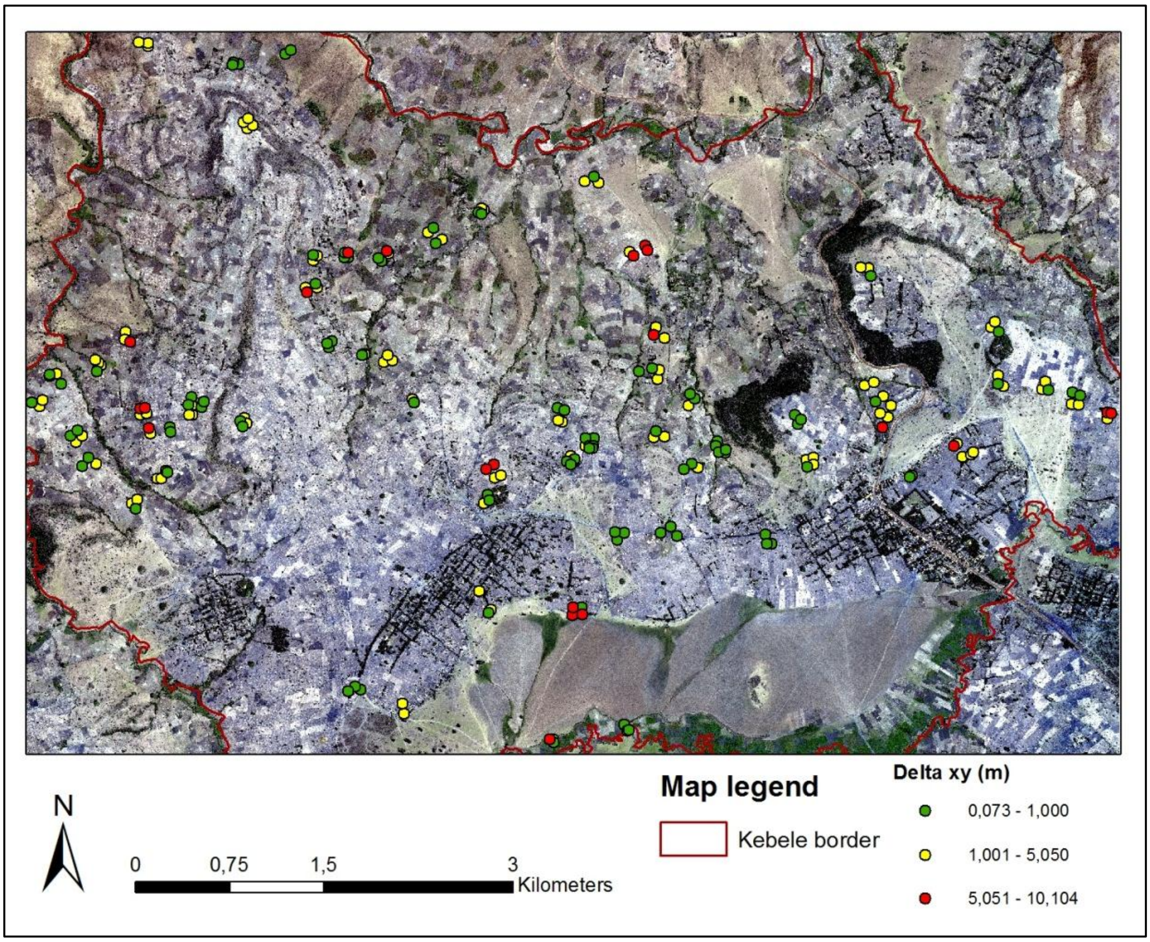

Fig. 23 Map of delta xy based on outlier values.

4.2.4 Correlation analysis between delta xy and slope

To investigate whether there was any relationship between slope and delta xy, a correlation analysis was performed between delta xy and slope value. A Pearson r correlation test was used to investigate the relationship between slope and delta xy, and the direction and statistical strength of the relationship. This correlation test was the most suitable since a Pearson r can take the data type scale, and both slope and delta xy are scale data. A requirement for using the Pearson r is, however, that the data set should have a normal distribution. Delta xy was not normally distributed, so a log–normal distribution of delta xy was calculated, named Log delta xy (Fig. 24).

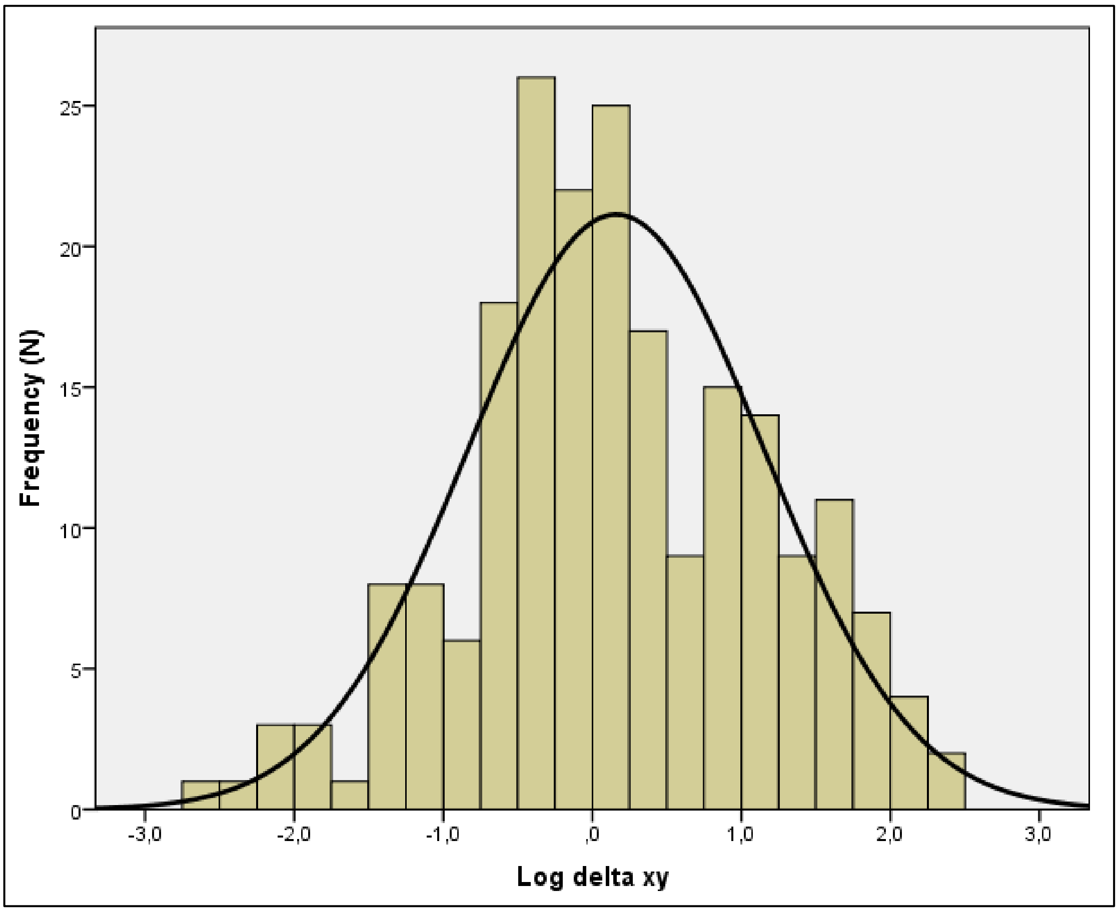

Fig. 24 A normal distribution based on 'Log delta xy'.

The Pearson r value of 0.029 in Table 11 indicates that there is no relationship between delta xy and slope. The significance value of 0.676 indicates that the result is not significant at the 0.05 level. The value also indicates that there is a probability of 32.4 % of getting the same result if the research had been repeated.

Table 11 The result of the Pearson r correlation test for delta xy and slope.

	Pearson Correlation	Sig. (2.tailed)
Scale by scale	0.029	0.676

The result of the Pearson r test is supported by the scatterplot in Fig. 25 which illustrates the relationship between delta xy and slope value. The dashed line in the scatterplot represents the 1m accuracy requirement for rural areas in Ethiopia. The scatterplot shows that a large proportion of the points are located below the dashed line for all the different slope values along the x-axis. It is also apparent that the distribution of parcel points display a random distribution, with high delta xy values both for low and high slope values. There are points close to slope values of 0° with delta xy values of 6m, which can be seen along the y-axis. Most of the parcel points which have been surveyed are between the slopes of 0° and 12.5°, with fewer points at the steeper slopes.

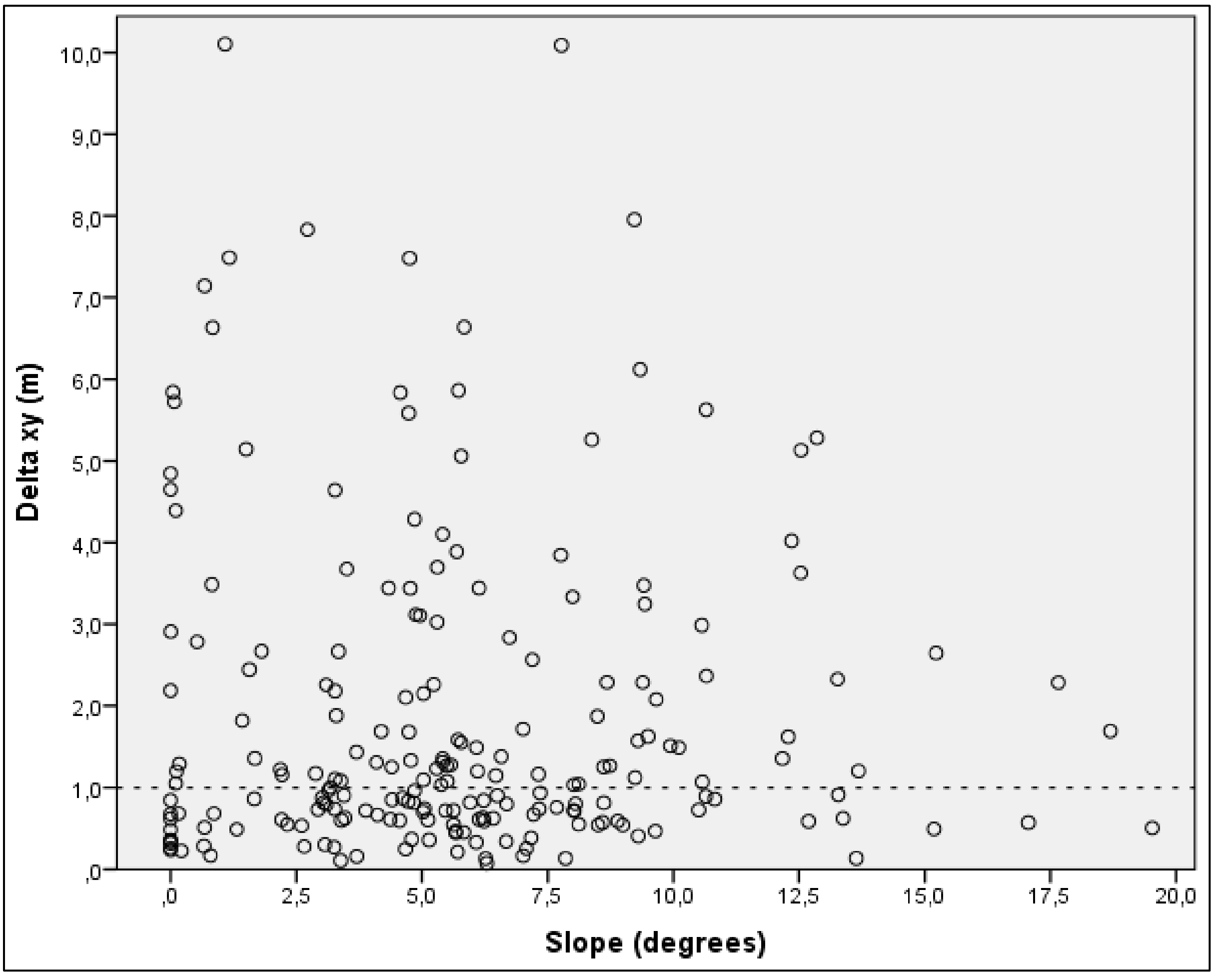

Fig. 25 Scatterplot of delta xy and slope. Dashed line is equivalent to 1m.

5. Discussion

This chapter contains the discussion of statistical results of the discrepancies between the coordinates derived from a WorldView-1 satellite image and coordinates derived from RTK GPS. The resolution of the satellite image is 0.5m, and the image covers the kebele Angot Yedegera of 42.6 km². This thesis had the aim of analyzing how suitable this satellite image is for land registration purposes in Ethiopia, and whether the accuracy of the derived coordinates meets the demands of 1m.

5.1 Reliability

Concerning the reliability of the conducted study, the categorization of the border types is based on my own assessment in the field. There is, as far as I know, no method developed for categorizing border types in Ethiopia. Even though I tried using the most adequate categories, it is difficult to determine whether a similar categorization of border types would have been preferred by other researchers. This does not improve the reliability of the study.

A factor which may, however, have contributed to enhance the reliability is the participation of a kebele expert in the field work. The kebele expert, Alemerew Atnaf, helped me understand the local conditions in the kebele, since I had never been in that specific area before. This may have contributed to a cohesive and consistent study. If a similar study is to be carried out in Ethiopia it is recommended to use a kebele expert.

5.2 Validity

A factor which may affect the validity is sample size. In this study 210 parcel points have been surveyed and analyzed. This number corresponds to 61 parcels. Compared to the total number of parcels in Angot Yedegera, this study covers only a fraction of the total sum. It can be assumed that there is between 5000 and 6000 parcels in Angot Yedegera (Bureau of Amhara Regional State 2011). It is difficult to determine whether the results in this thesis are representative for all land parcels in the kebele, but for the aim of this study 210 parcel points are considered sufficient. However, it is likely to assume that an increased sample size to a larger extent could have increased the validity of the final results.

Another factor which may influence the validity of a study is the possible distortions in the satellite image after the transformation. This is not a study of GCPs and orthorectification, however it is obvious that this is crucial for achieving the highest accuracy as possible. A number of 42 GCPs have been surveyed for the orthorectification of the satellite image. Roof corners, water pumps and parcel corners were used as GCPs when the image was orthorectified, with the majority of the GCPs being parcel corners, although it would have been optimal to use only roof corners as GCPs. It is easier to accurately determine the location of roof corners compared to parcel corners and water pumps, as found by Baltsavias & Gruen (2003), who stated that GCPs was easier to survey in cities than in remote areas. However, there were few suitable spots outside of the villages in Angot Yedegera for the surveying of roof corners as GCPs. This may have influenced the final orthorectified satellite image. Wang & Ellis (2005) found that the accuracy of the orthorectification was higher for landscapes with complex terrain relief compared to a more homogenous terrain. The terrain relief in Angot Yedegera was complex, with elevations ranging from 1740m amsl. to 2040m amsl., including valleys and steep slopes (Fig. 4). Using the Thin Plate Spline orthorectification method for complex landscapes required more GCPs than for homogenous landscapes. Thus, collecting a higher number of GCPs may have enhanced the orthorectified satellite image. These factors may reduce the validity of the final results of the study.

The distribution of parcel points surveyed by RTK GPS may also affect validity. The parcel points are spread out in the research area, covering large areas, making it a good representation of the kebele. However, the parcel points could have had a wider distribution, with a higher number of points in each corner of the kebele. This could have further enhanced the validity of the data sample. Due to a limited number of days in the field, this was, however, not possible to accomplish. In addition it was time consuming to walk around in the area, which made it necessary to select parcels which were close to the established second order points.

A source of uncertainty in the data can occur if a parcel with a changed shape has been surveyed and included in the data set. This can decrease the validity of the final statistical results. However, the parcel borders which have been surveyed are true borders, but are not necessarily the correct juridical borders of one holder. This may have led to the surveying of a parcel which is actually two parcels with two different holders. The most important aim has been to survey parcels visible in the satellite image. It is the coordinates themselves which are of interest for the accuracy test, not the juridical border.

Sources of reference for the ground truthing may also influence the validity. The quality of the second order points (Table 4) and the quality of the RTK GPS surveying data (Appendix A) indicate that the baseline data is accurate. These RTK GPS data serve as the basis of comparison for the coordinates derived from the satellite image. The RTK GPS surveying has been carried out together with a land administration kebele expert from Angot Yedegera to ensure that the correct borders were surveyed. He contributed with his local knowledge on how borders in the kebele were constructed and where they were located. This strengthens the validity of the surveyed data.

5.3 Statistics

5.3.1 Central tendency and dispersion of delta xy

The descriptive results give an indication of how accurate the coordinates derived from the satellite image is. Both results regarding central tendency and dispersion of delta xy are essential when considering the accuracy.

The aim of this thesis was to investigate whether the accuracy of the derived coordinates from a WorldView-1 satellite image meets the demands for accurate rural cadastral mapping in Ethiopia. The requirement is set to 1m (Dubois 2011). The overall results for delta xy revealed that 46.4 % of all 210 coordinates had discrepancies less than 1m, which means that 53.6 % of the sample has a delta xy value greater than 1m. It is apparent that the discrepancies are large, and the number of points exceeding the 1m requirement is too high. However, this result does not give any information concerning the degree in which the discrepancies vary above 1m. Thus, a valid statement cannot be based on this result only.

The data set of delta xy was found to be positively skewed. Both the skewness value (Table 7) and the delta xy histogram (Fig. 20) confirmed this. The median and percentile values are therefore used. The median for delta xy was 1.088m. According to the research question values describing central tendency were required to have values below 1m to meet the accuracy requirements. However, the median of delta xy indicate that the discrepancies between the GPS measurements and the coordinates derived from the satellite image do not meet these requirements. Although the median is close to 1m, it is the middle value of the data set, which means that several delta xy values exceed the median value. This is apparent from the 75th percentile for delta xy of 2.386m, and the maximum value of 10.103m (Table 7).

According to the boxplot of delta xy (Fig. 22) it is evident that most of the delta xy values are below 5m. The boxplot also illustrates that the lowest 50 % delta xy values, which constitute the space between the median and the lower whisker, are very dense. The upper 50 % are, however, stretched out. The reason for this is difficult to determine. However, the boxplot reveals that there are some outliers in the data set, which are not representative for the whole data set. The outliers are stretching the data set and this influences the statistical results.

For delta xy, the maximum value is high, thus the range is wide. For optimal results, the range value would have been 1m or less, with discrepancies between 0m and 1m. This result indicates that the discrepancies are too high. Even though 46.4 % of the coordinate values are below the 1m requirement, and thus acceptable, the rest of the coordinates have too poor accuracy to be accepted for cadastral purposes. The high range indicates that the coordinate values derived from the satellite image have too high discrepancies compared to the accuracy derived from RTK GPS, and are thus not useful for land registration. The results explaining central tendency and dispersion do not support the results in the article of Ahn and Song (2011). They found that using orthorectified images could be as accurate as ground surveying. This study does not give support for such claims, as the large discrepancies found in this study can result in incorrect coordinates and cause inaccurate cadastral maps. As found in the Norwegian study by Mjøs & Sevatdal (2011), inaccurate cadastral maps may cause boundary disputes. This is not a desirable situation for Ethiopia in the future.

5.3.2 Border types

The second research question concerned whether different border types could affect the accuracy of coordinates derived from satellite imagery. This can be of high relevance if this method is going to be used for land registration in Ethiopia in the future. Border types which achieve high accuracy can then be mapped from satellite imagery, whereas border types which achieve poor accuracy can be surveyed with surveying equipment which can achieve higher accuracy.

The number of the different border types in this study is not equal. The border type 'parcel' has a number of 87 parcel points, while the border types 'pasture land' and 'diffuse' has 13 and 23 parcel points respectively. This is not optimal for conducting a comparison between the results for each border type. It would have been better to have an even, and higher, number of points for the various border types. As an example the border type 'pasture land', represented by only 13 parcel points, may be very responsive to large changes if one or more points had been added.

The median is below 0.885m for the border types 'fence', 'pasture land' and 'parcel'. The median of these border types differ from the border types 'path', 'diffuse' and 'forest' where the median is between 1.772m and 2.367m. The border types 'fence' and 'pasture land' has both a low mean value and a low median value. This may indicate that these border types are easy to detect, and that such borders can achieve the best accuracy when using satellite images. Although the median values are low, it is important to emphasize that the values are still high compared to the 1m requirement, acknowledging the median being the middle value. The border type ‘fence’ has the lowest 75th percentile (1.115m), whereas the other border types have 75th percentile values between 1.884m and 5.722m. This can indicate that fences are the easiest to detect from the satellite image, compared to the other border types, making it suitable for mapping purposes.

It is worth noticing that the border types ‘path’ and ‘diffuse’ has 25th percentiles which exceed the 1m requirement. The border type ‘path’ has a value of 1.094m and ‘diffuse’ has a value of 1.121m, which indicates that these border types are particularly prone for achieving poor accuracy when using satellite imagery.

All the border types have wide ranges, except from ‘pasture land’, which stands out from the others with a range of 3.368m. The other border types have range values between 6.989m and 9.972m. This high range may be caused by either a large dispersion or by outlier values which influence the total range values.

Based on the median, percentiles and outlier values it is appropriate to state that the border types ‘fence’, ‘parcel’ and ‘pasture land’ achieve the highest accuracy when using satellite imagery. The border types ‘path’, ‘forest’ and ‘diffuse’ has high median, percentile and outlier values, which indicates that these border types are difficult to detect, and thus causes poor accuracy when using satellite imagery. In addition, the border types ‘path’ and ‘diffuse’ has high minimum delta xy values, respectively 0.348m and 0.492m, which further support this indication. This finding supports Corlazzoli and Fernandez (2004), who found that the accuracy of parcel coordinates derived from satellite images depend directly upon the vegetation cover and the shape of the surveyed parcels.

5.3.3 Delta xy outliers

A number of 21 outliers were detected in the sample. From a total of 210 points, this is a very high proportion of outliers, making up 10.0 % of the total number of points. For optimal results, such extreme values should not have occurred.

A large proportion of the border types ‘diffuse’, ‘path’ and ‘forest’ were outliers, where approximately 20 % of the points had a deviation exceeding 3.884m. The border types ‘fence’ and ‘parcel’ had a relatively low proportion of outliers, and the border type ‘pasture land' contained no outliers. The reason for this difference between the border types can be complex, but the border types 'diffuse', 'path' and 'forest' might be harder to determine than the other types. The diffuse borders were often difficult to determine because there were no visible border demarcation. For this border type the kebele expert was also unsure of the exact location of the border. Paths can change due to seasonal changes, for example during the rainy season, and it can be difficult to tell exactly where the border is in the image. Forest and vegetation can also change due to seasonal changes, and is also sensitive to shadows, which can cover the parcel corner. In these situations errors might have occurred on the ground when surveying with the GPS, but also when detecting the borders in the image.

A pattern which can be observed in Fig. 23 is that the outliers are scattered in the research area. The points with delta xy values between 1m and 3.884m are even more scattered. The outliers do not appear to be concentrated in only one or two areas, which could have indicated that there was something wrong with the instrument in those certain areas. The observed pattern can indicate that the error and inaccuracy is related to the image itself.

There may be many reasons for the outliers to occur. A possible reason is that errors have occurred due to human mistakes. During field work incorrect boundaries may have been surveyed with the RTK GPS. There is a risk of interference of the sample if such parcel points have been added to the data in the analysis. It is also possible that the satellite image has been distorted when the image was orthorectified in Geomatica. Although the locations around the GCPs are accurate, the areas between the GCPs can be distorted (PCI Geomatics 2003). Distortions in the satellite image results in inaccurate coordinates.

5.3.4 Correlation analysis between delta xy and slope

The second research question concerned how different slopes could affect the accuracy of a WorldView-1 satellite image. To determine this, a Pearson r correlation test was performed. The Pearson r test gave a value of 0.029, which means there is no relationship between slope and delta xy. One can thus not conclude that slope degrades the coordinates derived from the satellite image. The result of the Pearson r correlation test was not significant at the 0.05 level, so there is uncertainty associated with the Pearson r value. Still, the low Pearson r value can give an indication that slope does not affect the accuracy.

Even though the result of the correlation test was not significant it was also possible to observe the relationship between delta xy and slope from the scatterplot in Fig. 25. From the scatterplot it was evident that delta xy values were high both in flat terrain and in steeper slopes. The pattern of where the location of the highest accuracy was achieved seemed random. The results do not indicate that terrain influences the accuracy of parcel coordinates. From this result I cannot give any recommendations for what types of terrain this method is most suitable for.

The slope analysis was based on a topographical map covering Angot Yedegera. The map had contour lines with contour intervals of 20m, and the contours were edited manually from the map. The map was not a very detailed elevation source, and the contour lines did not describe the landscape perfectly. There may be features in the landscape which were not mapped because it had elevations lower than 20m. Thus, many topographical details are lost between the contour lines, and some slope values may be wrong. The slope value is probably most accurate close to the contour lines, not in between them. The contour lines were used as input for the interpolation resulting in a TIN model for the area. It is likely to assume that the elevation model could have been more accurate if more elevation data were available for the areas between the contour lines.

6. Conclusion

The endeavour of this thesis has been to research the suitability of using a WorldView-1 satellite image for cadastral mapping in rural Ethiopia. Satellite images have previously been used for cadastral purposes in other countries. However, as far as I know, these studies have been performed on images with low resolution, and extensive statistical analysis of the derived coordinates has not been performed. As have been seen through reviewed literature, enhanced tenure security in Ethiopia is an urgent issue, and to achieve this it is necessary to obtain high accuracy when land parcels are mapped. Knowing exactly where the border of one's parcel is can strengthen the rights of land holders, and give incentives for farmers to invest more in the land.

The results of this thesis, based on the difference between the coordinates derived from RTK GPS and coordinates derived from the WorldView-1 satellite image, have been analysed using GIS and SPSS. Further, statistical accuracy tests have been performed to investigate whether the accuracy of derived coordinates from the image meets the requirement of 1m, and whether different border types and slope affect the accuracy. The outcome of these tests can be used to identify which border types achieve the highest accuracy and whether coordinates derived from certain slopes achieve higher accuracy than other slopes.

The first research question concerned whether the coordinates derived from of a WorldView-1 satellite image met the requirement of 1m accuracy. Based on the results, the sample was found to be positively skewed. Hence, it was necessary to use the median and percentiles values to conduct the statistical analysis, in addition to the range value. These results revealed that the difference between coordinates derived from RTK GPS and the satellite image was large. A proportion of 46.4 % of all the coordinates had discrepancies below 1m. The median was found to be 1.088m, and the maximum difference between the coordinates was 10.103m. The 75th percentile value revealed that 75 % of the parcel points had a difference below 2.386m. Even though the histogram of delta xy illustrates that most of the parcel points are below 1.5m, it is not satisfactory that only 46.4 % of all the coordinates have discrepancies below 1m. Based on the results, it can be concluded that the coordinates derived from the WorldView-1 satellite image covering Angot Yedegera, do not meet the requirement of 1m.

The second research question concerned how different border types could affect the accuracy of the coordinates derived from the satellite image. The statistical analysis has been based on six different categories of border types, respectively 'diffuse', 'fence', 'forest', ‘parcel’, ‘pasture land’ and ‘path’. The results revealed differences in accuracy between the different border types. The border types ‘fence’, ‘pasture land’ and ‘parcel’ had median values below 1m, in addition to a low proportion of outliers. The border types ‘path’, ‘forest’ and ‘diffuse’ had medians above 1.777m, and also had the largest proportion of outliers. A proportion of 26 % of the parcel points with the border type ‘diffuse’ was outliers, with discrepancies above 5.050m. This indicates that some border types are more difficult to detect, and that coordinate values from parcels with the border types ‘forest’, ‘path’ or ‘diffuse’ may be more inaccurate than coordinate values from the border types ‘fence’, ‘parcel’ and ‘pasture land’. The results thus depicts that some parcels, consisting of only the suitable border types, can, at its best, achieve accuracies below the 1m requirement. In the opposite case, parcels consisting of only the border types ‘path’, ‘forest’ and ‘diffuse’ can risk being mapped very inaccurately.

The second research question also concerned whether slope could affect the accuracy of coordinates derived from satellite imagery. The slope analysis was based on digitized contour lines from a topographical map, which was further used as input for a TIN model. The results from a Pearson r correlation test indicated that no relationship exists between slope and delta xy, however the results were not significant at the 0.05 level.

Until more research is performed on the use of satellite imagery for cadastral mapping, one may risk making inaccurate maps of no use by continuing the use of this method. Extensive economic and human resources will be spent on this mapping project in Ethiopia, and it is recommended to use these resources in the best possible manner. A situation where the parcels have been wrongly mapped may exacerbate land disputes between neighbors, and tenure security is thus not enhanced. An incorrect and outdated map has no use, and it is of no value using human and economic resources to make inaccurate maps.

6.1 Future work

It is highly recommended to conduct a similar accuracy test for the coordinates derived from aerial photos. Aerial photos are, at the moment, used as the main method for land registration in the regions Oromiya and SNNP in Ethiopia. The aerial photos covering Oromiya and SNNP have a resolution of 15cm. This resolution is better than the resolution from any available satellite image, making it an interesting research field.

It is also recommended to conduct a test of how Ground Control Points affect the accuracy of satellite images. Such a project can be conducted by performing similar accuracy tests of a satellite image using different numbers of GCPs in each test. The total number of GCPs, the selection of their location and the selection of which orthorectification method to use can to a large extent influence the accuracy of the satellite image.

Several articles state that the conventional methods of land surveying are expensive, but fail to elaborate this statement any further. It is also therefore recommended to study whether the use of satellite imagery and aerial photos are less expensive, in the long run, than the use of RTK GPS and total stations. Such a study should take into consideration education, training, cost of equipment, updating of data etc.

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Appendices

Appendix A - RTK GPS coordinates and quality

ID	Status	Date	X-coordinate	Y-coordinate	Quality
386.3	Measured	10/18/2012 10:47:41	326126.6092	1171798.2811	0.0913
174.3	Measured	10/15/2012 13:08:24	322547.9309	1173827.1828	0.0851
263.4	Measured	10/14/2012 13:00:44	320798.4910	1173161.6940	0.0821
219.1	Measured	10/13/2012 16:03:19	328602.2173	1172897.4095	0.0769
274.2	Measured	10/14/2012 14:15:49	321145.4092	1172817.4492	0.0768
440.2	Measured	10/16/2012 17:06:59	324655.9474	1171233.1496	0.0750
174.4	Measured	10/15/2012 13:11:35	322468.4872	1173794.3694	0.0745
271.2	Measured	10/14/2012 11:36:15	320684.4719	1172414.1243	0.0736
350.3	Measured	10/18/2012 13:03:44	323904.5697	1172184.9499	0.0731
464.1	Measured	10/14/2012 12:04:32	320369.7379	1172934.3437	0.0727
218.1	Measured	10/13/2012 16:28:41	328336.6001	1173083.4776	0.0722
350.4	Measured	10/18/2012 13:08:27	323917.7217	1172141.8023	0.0717
29.2	Measured	10/17/2012 13:58:39	321204.7191	1175749.5510	0.0709
79.4	Measured	10/15/2012 10:12:54	325175.9505	1174128.4045	0.0702
219.4	Measured	10/13/2012 16:18:38	328546.3150	1172903.5705	0.0698
291.5	Measured	10/18/2012 12:19:43	324010.2197	1172340.8249	0.0690
93.4	Measured	10/15/2012 12:53:44	322517.6601	1174087.6234	0.0678
89.4	Measured	10/15/2012 12:13:17	323103.8142	1174119.9651	0.0654
271.4	Measured	10/14/2012 11:43:06	320790.7598	1172429.9463	0.0650
270.1	Measured	10/14/2012 11:49:22	320634.7903	1172602.3368	0.0649
84.4	Measured	10/15/2012 11:47:14	323490.6915	1174183.2881	0.0642
295.2	Measured	10/18/2012 13:37:43	324568.1870	1172489.6814	0.0637
306.3	Measured	10/18/2012 10:05:51	326394.5752	1172784.1975	0.0610
438.2	Measured	10/16/2012 16:31:59	323913.1612	1171247.1658	0.0597
270.2	Measured	10/14/2012 11:53:47	320682.6460	1172652.1262	0.0591
319.1	Measured	10/13/2012 13:26:16	327768.1777	1172520.3522	0.0587
308.2	Measured	10/18/2012 10:17:52	326442.8452	1172461.1124	0.0570
209.4	Measured	10/13/2012 17:00:25	327938.8534	1173556.4270	0.0553
271.3	Measured	10/14/2012 11:38:04	320730.8208	1172478.5599	0.0534
275.1	Measured	10/14/2012 14:32:47	321224.3551	1172672.6089	0.0531
335.3	Measured	10/14/2012 10:47:08	321345.8351	1172373.0771	0.0525
302.4	Measured	10/18/2012 09:25:50	325741.5727	1172522.9560	0.0518
354.2	Measured	10/18/2012 08:59:11	325463.4560	1172388.1756	0.0512
354.4	Measured	10/18/2012 09:03:26	325575.7384	1172400.3202	0.0502
295.3	Measured	10/18/2012 13:38:55	324594.4593	1172467.6933	0.0494
230.11	Measured	10/12/2012 12:55:32	326905.2396	1173054.8381	0.0494
139.2	Measured	10/15/2012 10:28:53	324748.7176	1174713.3316	0.0486
219.2	Measured	10/13/2012 16:07:11	328616.9462	1172973.7101	0.0481
280.3	Measured	10/14/2012 15:49:01	321956.7855	1172723.6087	0.0463
334.3	Measured	10/14/2012 11:13:28	321106.0912	1172073.5466	0.0449
367.4	Measured	10/13/2012 12:40:31	327278.0637	1172340.4950	0.0431
312.4	Measured	10/13/2012 13:13:39	327681.6295	1172483.7251	0.0428

ID	Status	Date	X-coordinate	Y-coordinate	Quality
275.4	Measured	10/14/2012 14:39:28	321388.4096	1172680.7804	0.0425
329.4	Measured	10/13/2012 15:38:05	328834.9502	1172839.7814	0.0425
65.4	Measured	10/19/2012 08:45:38	326949.2924	1173924.0065	0.0422
265.2	Measured	10/14/2012 12:20:06	320425.2696	1173126.6727	0.0413
265.5	Measured	10/14/2012 12:25:22	320481.4847	1173145.3496	0.0412
319.4	Measured	10/13/2012 13:35:03	327746.2043	1172506.3803	0.0399
253.4	Measured	10/15/2012 14:30:49	323150.3978	1173250.6945	0.0398
355.5	Measured	10/18/2012 11:33:56	324915.8413	1171888.3958	0.0397
358.2	Measured	10/18/2012 11:08:29	325363.3977	1171934.4416	0.0395
251.2	Measured	10/15/2012 13:53:02	322908.2917	1173292.4558	0.0381
193.2	Measured	10/15/2012 09:45:25	325228.1376	1173452.1857	0.0378
219.3	Measured	10/13/2012 16:12:16	328553.2576	1172995.9966	0.0377
299.1	Measured	10/15/2012 08:49:10	325224.4413	1172641.6554	0.0375
464.3	Measured	10/14/2012 12:07:37	320282.7092	1172915.1058	0.0374
312.1	Measured	10/13/2012 13:04:18	327637.7732	1172590.5946	0.0372
91.2	Measured	10/15/2012 12:39:10	322799.8347	1174110.3587	0.0371
306.2	Measured	10/18/2012 10:04:34	326349.5924	1172817.3274	0.0370
265.4	Measured	10/14/2012 12:23:41	320517.8348	1173067.9547	0.0358
335.1	Measured	10/14/2012 10:42:39	321312.3725	1172313.5584	0.0356
164.2	Measured	10/14/2012 13:37:14	321029.6230	1173478.7791	0.0356
302.7	Measured	10/18/2012 09:37:49	325797.5031	1172541.2211	0.0355
358.1	Measured	10/18/2012 11:05:53	325408.1424	1171857.9028	0.0352
386.2	Measured	10/18/2012 10:37:28	326115.7848	1171867.9300	0.0348
274.4	Measured	10/14/2012 14:19:04	321182.8261	1172875.3889	0.0344
473.4	Measured	10/16/2012 16:00:53	323227.1125	1170527.3323	0.0339
302.3	Measured	10/18/2012 09:20:24	325718.8454	1172572.1036	0.0338
335.5	Measured	10/14/2012 10:58:20	321277.7137	1172311.6340	0.0334
358.4	Measured	10/18/2012 11:21:09	325278.4890	1171882.0497	0.0334
335.2	Measured	10/14/2012 10:45:10	321357.8725	1172361.2143	0.0329
280.4	Measured	10/14/2012 15:49:52	321989.1939	1172750.8338	0.0328
29.1	Measured	10/17/2012 13:52:16	321204.7342	1175771.9274	0.0320
263.1	Measured	10/14/2012 12:57:36	320789.7598	1173254.2037	0.0319
130.2	Measured	10/15/2012 11:15:48	323876.2959	1174446.1466	0.0318
334.4	Measured	10/14/2012 11:14:51	321076.4321	1172118.7329	0.0314
250.1	Measured	10/15/2012 13:24:20	322670.3256	1173405.6813	0.0313
193.1	Measured	10/15/2012 09:43:34	325310.1110	1173429.4145	0.0305
334.1	Measured	10/14/2012 11:09:45	321120.8923	1172148.0670	0.0302
246.4	Measured	10/15/2012 14:46:01	323309.9533	1172944.1170	0.0301
468.2	Measured	10/16/2012 13:23:29	325019.3003	1170311.3213	0.0294
440.4	Measured	10/16/2012 17:15:33	324585.8698	1171292.8051	0.0294
239.3	Measured	10/15/2012 09:13:35	325551.8465	1172950.1579	0.0293
263.3	Measured	10/14/2012 12:59:25	320832.6396	1173216.4518	0.0292
296.4	Measured	10/18/2012 13:55:29	324739.7994	1172554.5249	0.0287
250.4	Measured	10/15/2012 13:29:53	322642.2389	1173357.9737	0.0285
253.2	Measured	10/15/2012 14:26:16	323080.2558	1173238.3330	0.0279

ID	Status	Date	X-coordinate	Y-coordinate	Quality
27.1	Measured	10/17/2012 13:24:44	321930.0225	1175603.5267	0.0279
274.1	Measured	10/14/2012 14:11:40	321146.0949	1172871.2886	0.0278
265.1	Measured	10/14/2012 12:19:14	320424.9156	1173138.2082	0.0276
89.1	Measured	10/15/2012 12:05:25	323117.3622	1174100.0787	0.0276
230.15	Measured	10/12/2012 13:02:21	327049.6242	1172965.1700	0.0275
438.1	Measured	10/16/2012 16:30:28	323934.1665	1171271.9206	0.0266
84.6	Measured	10/15/2012 11:49:35	323543.9190	1174214.7929	0.0265
29.4	Measured	10/17/2012 14:09:06	321130.6975	1175779.8631	0.0264
277.2	Measured	10/14/2012 09:43:03	321554.4077	1172894.8220	0.0263
230.13	Measured	10/12/2012 13:00:54	326986.8263	1172921.9889	0.0259
130.1	Measured	10/15/2012 11:15:07	323858.8854	1174461.4651	0.0255
79.1	Measured	10/15/2012 10:02:39	325161.1457	1174160.5706	0.0252
280.2	Measured	10/14/2012 15:48:06	321940.1213	1172768.6531	0.0249
240.3	Measured	10/15/2012 09:30:34	325216.0265	1173187.5720	0.0248
130.4	Measured	10/15/2012 11:17:57	323829.8817	1174425.0234	0.0248
244.1	Measured	10/18/2012 14:22:04	324519.0316	1172858.0512	0.0245
93.3	Measured	10/15/2012 12:52:09	322522.6151	1174046.9629	0.0244
274.3	Measured	10/14/2012 14:17:45	321191.7743	1172829.2117	0.0243
79.2	Measured	10/15/2012 10:07:26	325034.0032	1174113.7279	0.0242
87.2	Measured	10/15/2012 11:27:58	323473.3110	1174307.6556	0.0242
296.5	Measured	10/18/2012 13:56:13	324717.1935	1172554.5273	0.0241
250.5	Measured	10/15/2012 13:31:19	322630.2062	1173386.3650	0.0240
296.6	Measured	10/18/2012 13:59:04	324713.5898	1172571.0406	0.0240
34.3	Measured	10/17/2012 15:20:57	321966.7885	1175142.9930	0.0239
354.3	Measured	10/18/2012 09:01:36	325527.3425	1172431.7123	0.0235
27.3	Measured	10/17/2012 13:26:40	321879.6069	1175599.3126	0.0235
438.3	Measured	10/16/2012 16:52:00	323836.4381	1171417.6814	0.0233
130.3	Measured	10/15/2012 11:17:01	323858.7586	1174413.3935	0.0229
244.3	Measured	10/18/2012 14:26:31	324467.8709	1172775.1348	0.0228
139.1	Measured	10/15/2012 10:27:11	324790.3127	1174661.7539	0.0226
79.3	Measured	10/15/2012 10:08:53	325067.4653	1174081.8405	0.0220
139.3	Measured	10/15/2012 10:35:09	324678.0282	1174673.3415	0.0218
209.1	Measured	10/13/2012 16:55:57	327906.6467	1173513.8256	0.0217
291.1	Measured	10/18/2012 12:05:56	323958.6209	1172424.8690	0.0217
329.3	Measured	10/13/2012 15:35:42	328829.6956	1172788.4899	0.0216
253.1	Measured	10/15/2012 14:22:55	323109.8507	1173292.2929	0.0215
277.1	Measured	10/14/2012 09:41:48	321557.0345	1172816.4623	0.0214
464.4	Measured	10/14/2012 12:09:36	320346.1090	1172886.3434	0.0214
291.4	Measured	10/18/2012 12:15:48	323961.7980	1172320.0210	0.0213
473.2	Measured	10/16/2012 15:58:38	323238.5989	1170444.1000	0.0210
218.3	Measured	10/13/2012 16:34:49	328365.3778	1173015.5157	0.0209
468.3	Measured	10/16/2012 13:24:32	325030.7986	1170316.3339	0.0209
367.3	Measured	10/13/2012 12:38:12	327259.8761	1172326.8227	0.0205
308.4	Measured	10/18/2012 10:21:07	326494.2934	1172427.2395	0.0204
275.2	Measured	10/14/2012 14:34:18	321213.4533	1172712.1860	0.0204

ID	Status	Date	X-coordinate	Y-coordinate	Quality
308.1	Measured	10/18/2012 10:16:37	326497.2981	1172481.1428	0.0202
174.2	Measured	10/15/2012 13:04:43	322536.0736	1173863.0093	0.0200
26A.2	Measured	10/17/2012 13:15:06	322338.7184	1175714.7854	0.0198
209.2	Measured	10/13/2012 16:57:56	327971.7281	1173480.5175	0.0197
193.3	Measured	10/15/2012 09:48:51	325246.7424	1173512.8909	0.0196
329.1	Measured	10/13/2012 15:32:38	328862.3166	1172831.3392	0.0195
291.2	Measured	10/18/2012 12:12:51	323894.3200	1172387.8477	0.0195
89.3	Measured	10/15/2012 12:11:04	323038.1271	1174061.3480	0.0194
277.3	Measured	10/14/2012 09:43:41	321527.7211	1172897.6927	0.0194
221.4	Measured	10/13/2012 16:47:30	327961.8493	1173068.5906	0.0192
218.4	Measured	10/13/2012 16:35:54	328315.8898	1173021.8460	0.0192
258.4	Measured	10/14/2012 09:33:19	321551.5243	1172960.8689	0.0189
258.1	Measured	10/14/2012 09:30:28	321631.3980	1172882.8858	0.0189
91.4	Measured	10/15/2012 12:41:08	322767.4927	1174068.9233	0.0189
34.4	Measured	10/17/2012 15:22:41	321996.9192	1175093.6574	0.0186
355.3	Measured	10/18/2012 11:32:15	324937.6579	1171828.2569	0.0185
295.1	Measured	10/18/2012 13:26:10	324535.8547	1172447.1541	0.0185
296.1	Measured	10/18/2012 13:51:36	324685.6658	1172631.9353	0.0183
308.3	Measured	10/18/2012 10:19:39	326443.9566	1172407.2145	0.0182
34.2	Measured	10/17/2012 15:19:45	322001.7923	1175170.9953	0.0182
270.3	Measured	10/14/2012 11:55:23	320645.0587	1172694.6178	0.0182
440.1	Measured	10/16/2012 17:05:26	324576.4202	1171230.8608	0.0180
251.4	Measured	10/15/2012 13:56:52	322896.3293	1173359.6147	0.0179
244.4	Measured	10/18/2012 14:27:33	324499.0758	1172763.4889	0.0178
221.3	Measured	10/13/2012 16:46:25	327962.8901	1173133.8335	0.0177
270.4	Measured	10/14/2012 11:56:59	320592.0113	1172653.9405	0.0176
84.3	Measured	10/15/2012 11:44:37	323431.2319	1174264.6150	0.0176
275.3	Measured	10/14/2012 14:38:27	321376.5843	1172720.6271	0.0175
164.3	Measured	10/14/2012 13:45:11	321065.5651	1173400.8856	0.0173
93.1	Measured	10/15/2012 12:49:34	322553.4172	1174082.8963	0.0173
240.6	Measured	10/15/2012 09:37:41	325257.3035	1173102.9158	0.0172
26A.3	Measured	10/17/2012 13:16:09	322296.8297	1175685.1241	0.0172
240.4	Measured	10/15/2012 09:33:11	325105.7806	1173167.2328	0.0168
311.10	Measured	10/12/2012 12:24:12	327042.2371	1172722.0491	0.0166
89.2	Measured	10/15/2012 12:10:01	323063.9314	1174038.2412	0.0166
280.1	Measured	10/14/2012 15:47:07	321972.4119	1172792.1896	0.0165
240.1	Measured	10/15/2012 09:28:03	325271.0076	1173173.9176	0.0163
239.2	Measured	10/15/2012 09:12:15	325516.7348	1172987.7828	0.0162
65.1	Measured	10/19/2012 08:42:10	326936.1890	1173986.1870	0.0161
311.13	Measured	10/12/2012 12:28:13	327088.3293	1172802.5560	0.0160
244.2	Measured	10/18/2012 14:23:37	324463.3564	1172873.0846	0.0159
91.3	Measured	10/15/2012 12:40:09	322770.1320	1174106.7352	0.0157
91.1	Measured	10/15/2012 12:38:06	322796.9666	1174068.6386	0.0157
295.4	Measured	10/18/2012 13:40:35	324568.1713	1172424.6618	0.0156
296.7	Measured	10/18/2012 13:59:52	324685.2760	1172570.7820	0.0156

ID	Status	Date	X-coordinate	Y-coordinate	Quality
306.4	Measured	10/18/2012 10:07:10	326370.5820	1172743.3154	0.0156
263.2	Measured	10/14/2012 12:58:47	320813.9286	1173230.2912	0.0154
230.5	Measured	10/12/2012 12:50:20	326975.1355	1173080.6846	0.0152
503.3	Measured	10/16/2012 13:10:42	324433.5865	1170219.2309	0.0151
503.4	Measured	10/16/2012 13:11:15	324427.5178	1170240.8207	0.0150
251.3	Measured	10/15/2012 13:54:16	322928.7957	1173302.9181	0.0150
355.1	Measured	10/18/2012 11:27:20	324989.6535	1171883.3812	0.0150
350.1	Measured	10/18/2012 13:00:08	323879.0225	1172119.1127	0.0147
296.3	Measured	10/18/2012 13:54:40	324747.0154	1172571.4737	0.0147
296.2	Measured	10/18/2012 13:53:02	324748.5379	1172632.4114	0.0144
164.1	Measured	10/14/2012 13:35:25	321021.7307	1173415.6434	0.0144
277.6	Measured	10/14/2012 09:46:26	321531.6286	1172818.9443	0.0143
311.7	Measured	10/12/2012 12:17:41	327027.2175	1172831.3828	0.0143
246.3	Measured	10/15/2012 14:44:59	323321.6709	1172917.9187	0.0142
174.1	Measured	10/15/2012 13:02:35	322459.5613	1173832.6957	0.0141
468.1	Measured	10/16/2012 13:22:35	324993.3540	1170356.5883	0.0141
503.1	Measured	10/16/2012 13:08:59	324398.5587	1170241.3793	0.0137
221.1	Measured	10/13/2012 16:43:56	328008.8604	1173045.9516	0.0137
311.2	Measured	10/12/2012 12:11:35	327109.5199	1172894.4248	0.0136
65.2	Measured	10/19/2012 08:43:10	326874.6649	1173987.7907	0.0135
27.4	Measured	10/17/2012 13:27:22	321887.0663	1175620.4772	0.0133
258.2	Measured	10/14/2012 09:31:20	321651.8848	1172926.1182	0.0131
312.2	Measured	10/13/2012 13:06:22	327610.7958	1172572.4630	0.0129
34.1	Measured	10/17/2012 15:18:06	322036.0710	1175117.8032	0.0127
440.3	Measured	10/16/2012 17:11:19	324651.0456	1171292.2563	0.0123
302.6	Measured	10/18/2012 09:36:27	325794.1916	1172515.9497	0.0122
299.7	Measured	10/15/2012 08:58:45	325245.7351	1172687.6940	0.0121
299.4	Measured	10/15/2012 08:56:00	325314.8534	1172648.6427	0.0121
491.2	Measured	10/16/2012 15:39:00	322855.1194	1170662.2312	0.0119
491.3	Measured	10/16/2012 15:44:23	322798.5716	1170624.3989	0.0119
239.4	Measured	10/15/2012 09:16:04	325504.9459	1172893.0742	0.0113
302.2	Measured	10/18/2012 09:19:24	325728.8945	1172610.3907	0.0108
491.1	Measured	10/16/2012 15:35:02	322895.0790	1170635.4811	0.0100

Appendix B - Coordinate list

ID Sat	X Sat	Y Sat	ID GPS	X GPS	Y GPS	Delta x	Delta y	Delta xy	Slope	Border type	Border type	Log delta xy
1	324937,953	1171827,436	355.3	324937,658	1171828,257	0,295	-0,821	0,872	3,012	1	Fence	-0,137
3	324989,547	1171883,919	355.1	324989,654	1171883,381	-0,106	0,538	0,548	2,322	1	Fence	-0,601
219	324915,673	1171888,854	355.5	324915,841	1171888,396	-0,168	0,458	0,488	1,316	1	Fence	-0,717
4	326116,023	1171867,745	386.2	326115,785	1171867,930	0,238	-0,185	0,301	3,067	1	Fence	-1,199
7	326126,636	1171797,606	386.3	326126,609	1171798,281	0,027	-0,675	0,676	0,000	2	Forest	-0,392
8	326443,994	1172407,341	308.3	326443,957	1172407,215	0,037	0,126	0,132	7,855	3	Pasture land	-2,028
9	326441,526	1172461,967	308.2	326442,845	1172461,112	-1,319	0,854	1,572	9,294	2	Forest	0,452
10	326498,969	1172483,434	308.1	326497,298	1172481,143	1,671	2,291	2,835	6,739	4	Parcel	1,042
213	326494,789	1172426,324	308.4	326494,293	1172427,239	0,496	-0,915	1,041	8,117	2	Forest	0,040
11	326371,027	1172743,130	306.4	326370,582	1172743,315	0,445	-0,185	0,482	0,000	4	Parcel	-0,731
13	326349,860	1172817,092	306.2	326349,592	1172817,327	0,267	-0,236	0,356	0,000	4	Parcel	-1,032
14	326394,408	1172784,393	306.3	326394,575	1172784,198	-0,167	0,196	0,257	0,000	4	Parcel	-1,357
15	325526,478	1172431,994	354.3	325527,343	1172431,712	-0,865	0,282	0,910	13,281	4	Parcel	-0,095
16	325462,964	1172388,284	354.2	325463,456	1172388,176	-0,492	0,109	0,504	19,527	3	Pasture land	-0,686
17	325575,360	1172402,616	354.4	325575,738	1172400,320	-0,379	2,296	2,327	13,267	5	Path	0,844
18	325728,515	1172610,531	302.2	325728,894	1172610,391	-0,380	0,140	0,405	9,302	1	Fence	-0,904
19	325718,442	1172572,530	302.3	325718,845	1172572,104	-0,404	0,427	0,587	12,689	1	Fence	-0,532
20	325794,157	1172516,013	302.6	325794,192	1172515,950	-0,035	0,063	0,073	6,288	3	Pasture land	-2,624
21	325742,017	1172523,458	302.4	325741,573	1172522,956	0,444	0,502	0,670	7,218	1	Fence	-0,400
226	325797,424	1172540,889	302.7	325797,503	1172541,221	-0,080	-0,332	0,341	6,673	3	Pasture land	-1,075
22	327278,083	1172340,148	367.4	327278,064	1172340,495	0,020	-0,347	0,348	0,000	5	Path	-1,057
23	327260,349	1172326,123	367.3	327259,876	1172326,823	0,473	-0,700	0,844	0,000	2	Forest	-0,169
24	327639,094	1172589,345	312.1	327637,773	1172590,595	1,321	-1,250	1,819	1,424	4	Parcel	0,598
25	327682,214	1172484,740	312.4	327681,629	1172483,725	0,584	1,015	1,171	2,884	1	Fence	0,158
26	327615,434	1172568,914	312.2	327610,796	1172572,463	4,638	-3,549	5,841	0,044	4	Parcel	1,765
27	328829,579	1172785,156	329.3	328829,696	1172788,490	-0,117	-3,333	3,336	7,996	4	Parcel	1,205
28	328831,047	1172830,480	329.4	328834,950	1172839,781	-3,903	-9,302	10,088	7,774	5	Path	2,311
29	328860,023	1172826,606	329.1	328862,317	1172831,339	-2,294	-4,733	5,260	8,378	5	Path	1,660
30	328545,236	1172903,348	219.4	328546,315	1172903,570	-1,079	-0,223	1,102	3,269	1	Fence	0,097
31	328599,295	1172893,804	219.1	328602,217	1172897,410	-2,922	-3,605	4,641	3,269	4	Parcel	1,535
32	328552,988	1172995,981	219.3	328553,258	1172995,997	-0,270	-0,016	0,270	3,252	4	Parcel	-1,308
33	328616,384	1172973,235	219.2	328616,946	1172973,710	-0,563	-0,475	0,737	3,263	4	Parcel	-0,306
34	328366,135	1173015,814	218.3	328365,378	1173015,516	0,757	0,299	0,814	3,044	3	Pasture land	-0,206

ID Sat	X Sat	Y Sat	ID GPS	X GPS	Y GPS	Delta x	Delta y	Delta xy	Slope	Border type	Border type	Log delta xy
35	328315,282	1173024,022	218.4	328315,890	1173021,846	-0,608	2,176	2,259	3,094	3	Pasture land	0,815
36	328334,186	1173083,093	218.1	328336,600	1173083,478	-2,414	-0,385	2,444	1,567	4	Parcel	0,894
38	328007,926	1173047,586	221.1	328008,860	1173045,952	-0,934	1,634	1,882	3,296	1	Fence	0,632
40	327964,194	1173133,726	221.3	327962,890	1173133,833	1,304	-0,107	1,308	4,093	4	Parcel	0,269
41	327961,111	1173068,070	221.4	327961,849	1173068,591	-0,738	-0,521	0,903	3,447	1	Fence	-0,102
43	327972,591	1173480,289	209.2	327971,728	1173480,518	0,863	-0,228	0,893	10,645	2	Forest	-0,114
44	327903,773	1173512,317	209.1	327906,647	1173513,826	-2,874	-1,508	3,246	9,431	5	Path	1,177
45	327935,397	1173555,326	209.4	327938,853	1173556,427	-3,457	-1,101	3,628	12,534	5	Path	1,289
46	326949,139	1173924,823	65.4	326949,292	1173924,006	-0,153	0,816	0,830	4,724	5	Path	-0,186
47	326938,869	1173988,345	65.1	326936,189	1173986,187	2,680	2,158	3,441	4,764	3	Pasture land	1,236
48	326877,497	1173989,066	65.2	326874,665	1173987,791	2,832	1,275	3,106	4,958	3	Pasture land	1,133
50	324656,534	1171223,063	440.2	324655,947	1171233,150	0,586	-10,086	10,103	1,084	1	Fence	2,313
51	324575,465	1171223,434	440.1	324576,420	1171230,861	-0,955	-7,427	7,488	1,166	1	Fence	2,013
52	324586,049	1171284,976	440.4	324585,870	1171292,805	0,179	-7,829	7,831	2,720	2	Forest	2,058
53	324650,978	1171291,538	440.3	324651,046	1171292,265	-0,068	-0,728	0,731	2,929	4	Parcel	-0,314
54	323913,086	1171247,304	438.2	323913,161	1171247,166	-0,075	0,138	0,157	3,703	2	Forest	-1,852
55	323935,444	1171272,572	438.1	323934,166	1171271,921	1,277	0,651	1,433	3,697	1	Fence	0,360
56	323837,833	1171421,083	438.3	323836,438	1171417,681	1,395	3,402	3,676	3,505	2	Forest	1,302
57	323877,985	1172121,037	350.1	323879,023	1172119,113	-1,038	1,925	2,187	0,000	4	Parcel	0,782
59	323904,474	1172184,646	350.3	323904,570	1172184,950	-0,096	-0,304	0,319	0,000	4	Parcel	-1,143
60	323918,026	1172142,340	350.4	323917,722	1172141,802	0,304	0,538	0,618	0,000	2	Forest	-0,482
61	323963,596	1172317,733	291.4	323961,798	1172320,021	1,798	-2,288	2,910	0,003	4	Parcel	1,068
62	324006,882	1172337,312	291.5	324010,220	1172340,825	-3,338	-3,513	4,846	0,000	2	Forest	1,578
63	323953,839	1172421,985	291.1	323958,621	1172424,869	-4,782	-2,884	5,584	4,734	2	Forest	1,720
64	323889,596	1172384,420	291.2	323894,320	1172387,848	-4,724	-3,427	5,836	4,568	2	Forest	1,764
65	324594,478	1172467,448	295.3	324594,459	1172467,693	0,019	-0,245	0,246	4,673	4	Parcel	-1,401
66	324569,313	1172487,904	295.2	324568,187	1172489,681	1,126	-1,778	2,104	4,675	2	Forest	0,744
67	324535,931	1172447,965	295.1	324535,855	1172447,154	0,077	0,811	0,814	4,836	4	Parcel	-0,206
68	324568,334	1172425,610	295.4	324568,171	1172424,662	0,163	0,948	0,962	4,853	4	Parcel	-0,039
69	324747,971	1172632,498	296.2	324748,538	1172632,411	-0,567	0,086	0,573	8,592	1	Fence	-0,557
70	324685,077	1172631,979	296.1	324685,666	1172631,935	-0,589	0,044	0,590	8,893	1	Fence	-0,527
71	324713,462	1172570,939	296.6	324713,590	1172571,041	-0,128	-0,102	0,164	7,011	4	Parcel	-1,810
72	324681,833	1172570,717	296.7	324685,276	1172570,782	-3,443	-0,065	3,443	6,134	2	Forest	1,236

ID Sat	X Sat	Y Sat	ID GPS	X GPS	Y GPS	Delta x	Delta y	Delta xy	Slope	Border type	Border type	Log delta xy
223	324747,748	1172571,552	296.3	324747,015	1172571,474	0,733	0,078	0,737	7,328	6	Diffuse	-0,305
225	324740,389	1172554,322	296.4	324739,799	1172554,525	0,590	-0,203	0,623	6,417	4	Parcel	-0,473
224	324717,734	1172554,289	296.5	324717,193	1172554,527	0,541	-0,238	0,591	6,236	4	Parcel	-0,527
73	324500,444	1172764,130	244.4	324499,076	1172763,489	1,368	0,641	1,511	9,942	4	Parcel	0,413
74	324469,362	1172776,585	244.3	324467,871	1172775,135	1,491	1,450	2,080	9,659	4	Parcel	0,732
75	324462,767	1172872,662	244.2	324463,356	1172873,085	-0,589	-0,422	0,725	10,503	1	Fence	-0,322
76	324518,564	1172858,039	244.1	324519,032	1172858,051	-0,467	-0,012	0,467	9,641	1	Fence	-0,761
77	327042,707	1172716,788	311.10	327042,237	1172722,049	0,469	-5,261	5,282	12,856	5	Path	1,664
78	327090,341	1172801,466	311.13	327088,329	1172802,556	2,011	-1,090	2,288	9,390	4	Parcel	0,827
79	327108,897	1172896,191	311.2	327109,520	1172894,425	-0,623	1,766	1,873	8,486	5	Path	0,628
80	327027,663	1172832,946	311.7	327027,218	1172831,383	0,445	1,564	1,626	9,497	5	Path	0,486
81	327048,437	1172965,610	230.15	327049,624	1172965,170	-1,187	0,440	1,266	8,734	4	Parcel	0,236
82	326986,527	1172922,732	230.13	326986,826	1172921,989	-0,299	0,743	0,801	8,053	5	Path	-0,222
83	326901,699	1173056,341	230.11	326905,240	1173054,838	-3,540	1,503	3,846	7,760	2	Forest	1,347
84	326972,109	1173077,913	230.5	326975,135	1173080,685	-3,026	-2,771	4,103	5,409	2	Forest	1,412
85	325226,074	1172642,099	299.1	325224,441	1172641,655	1,633	0,444	1,692	18,691	6	Diffuse	0,526
86	325245,172	1172687,787	299.7	325245,735	1172687,694	-0,563	0,093	0,571	17,062	1	Fence	-0,561
87	325316,424	1172650,304	299.4	325314,853	1172648,643	1,571	1,661	2,286	17,658	4	Parcel	0,827
88	325506,026	1172891,913	239.4	325504,946	1172893,074	1,080	-1,161	1,586	5,717	5	Path	0,461
89	325552,478	1172950,498	239.3	325551,846	1172950,158	0,631	0,340	0,717	5,468	4	Parcel	-0,332
90	325516,349	1172988,160	239.2	325516,735	1172987,783	-0,386	0,377	0,540	8,994	4	Parcel	-0,617
91	325260,294	1173105,090	240.6	325257,303	1173102,916	2,991	2,174	3,698	5,305	2	Forest	1,308
92	325270,948	1173175,011	240.1	325271,008	1173173,918	-0,060	1,093	1,095	5,028	1	Fence	0,091
94	325105,025	1173166,932	240.4	325105,781	1173167,233	-0,756	-0,301	0,813	8,616	1	Fence	-0,207
227	325216,369	1173187,887	240.3	325216,026	1173187,572	0,342	0,315	0,465	5,666	1	Fence	-0,766
95	325230,817	1173457,400	193.2	325228,138	1173452,186	2,680	5,214	5,862	5,726	4	Parcel	1,769
96	325311,092	1173432,277	193.1	325310,111	1173429,415	0,981	2,863	3,026	5,300	6	Diffuse	1,107
98	325246,647	1173516,333	193.3	325246,742	1173512,891	-0,095	3,442	3,444	4,336	6	Diffuse	1,237
99	325034,953	1174114,456	79.2	325034,003	1174113,728	0,950	0,728	1,197	0,114	4	Parcel	0,180
100	325064,282	1174085,881	79.3	325067,465	1174081,840	-3,183	4,041	5,144	1,502	4	Parcel	1,638
101	325159,524	1174166,058	79.1	325161,146	1174160,571	-1,621	5,487	5,722	0,070	6	Diffuse	1,744
102	325174,037	1174135,287	79.4	325175,950	1174128,404	-1,914	6,882	7,143	0,675	6	Diffuse	1,966
103	324789,854	1174662,814	139.1	324790,313	1174661,754	-0,458	1,060	1,155	2,214	1	Fence	0,144

ID Sat	X Sat	Y Sat	ID GPS	X GPS	Y GPS	Delta x	Delta y	Delta xy	Slope	Border type	Border type	Log delta xy
104	324748,265	1174712,927	139.2	324748,718	1174713,332	-0,452	-0,404	0,607	2,208	1	Fence	-0,500
105	324676,822	1174673,144	139.3	324678,028	1174673,342	-1,206	-0,198	1,222	2,184	4	Parcel	0,201
106	323876,339	1174447,148	130.2	323876,296	1174446,147	0,043	1,002	1,003	3,181	3	Pasture land	0,003
107	323860,675	1174462,714	130.1	323858,885	1174461,465	1,790	1,249	2,182	3,271	3	Pasture land	0,780
108	323830,172	1174424,101	130.4	323829,882	1174425,023	0,290	-0,923	0,967	3,141	4	Parcel	-0,033
109	323858,417	1174412,682	130.3	323858,759	1174413,394	-0,342	-0,712	0,790	3,101	4	Parcel	-0,236
110	323473,275	1174307,557	87.2	323473,311	1174307,656	-0,036	-0,098	0,105	3,383	4	Parcel	-2,257
111	323430,441	1174265,354	84.3	323431,232	1174264,615	-0,791	0,738	1,082	3,381	4	Parcel	0,079
112	323490,854	1174182,710	84.4	323490,692	1174183,288	0,162	-0,578	0,600	3,394	4	Parcel	-0,510
114	323541,499	1174215,916	84.6	323543,919	1174214,793	-2,420	1,123	2,667	3,340	5	Path	0,981
115	323064,648	1174038,199	89.2	323063,931	1174038,241	0,716	-0,042	0,718	3,881	4	Parcel	-0,332
116	323037,531	1174061,383	89.3	323038,127	1174061,348	-0,596	0,035	0,597	4,555	4	Parcel	-0,516
117	323115,996	1174101,071	89.1	323117,362	1174100,079	-1,366	0,992	1,688	4,189	6	Diffuse	0,524
118	323096,946	1174116,999	89.4	323103,814	1174119,965	-6,868	-2,966	7,481	4,751	6	Diffuse	2,012
119	322797,250	1174069,105	91.1	322796,967	1174068,639	0,283	0,466	0,545	5,626	4	Parcel	-0,607
120	322767,455	1174069,369	91.4	322767,493	1174068,923	-0,038	0,446	0,447	5,675	4	Parcel	-0,804
121	322770,365	1174105,952	91.3	322770,132	1174106,735	0,233	-0,783	0,817	5,958	4	Parcel	-0,202
122	322800,158	1174103,730	91.2	322799,835	1174110,359	0,323	-6,629	6,637	5,838	6	Diffuse	1,893
124	322518,139	1174087,509	93.4	322517,660	1174087,623	0,478	-0,114	0,492	15,185	6	Diffuse	-0,710
125	322524,621	1174045,236	93.3	322522,615	1174046,963	2,006	-1,727	2,647	15,227	6	Diffuse	0,973
229	322554,911	1174082,266	93.1	322553,417	1174082,896	1,494	-0,630	1,622	12,283	6	Diffuse	0,484
127	322536,203	1173863,039	174.2	322536,074	1173863,009	0,129	0,029	0,133	13,637	4	Parcel	-2,020
128	322544,546	1173825,014	174.3	322547,931	1173827,183	-3,385	-2,168	4,020	12,351	4	Parcel	1,391
129	322473,003	1173796,651	174.4	322468,487	1173794,369	4,516	2,282	5,059	5,778	5	Path	1,621
130	322462,380	1173835,373	174.1	322459,561	1173832,696	2,818	2,677	3,887	5,691	5	Path	1,358
131	322641,447	1173357,544	250.4	322642,239	1173357,974	-0,792	-0,430	0,901	6,497	4	Parcel	-0,105
132	322670,181	1173406,201	250.1	322670,326	1173405,681	-0,144	0,520	0,540	8,503	4	Parcel	-0,617
133	322630,335	1173387,151	250.5	322630,206	1173386,365	0,129	0,786	0,797	6,684	1	Fence	-0,227
134	323079,225	1173238,622	253.2	323080,256	1173238,333	-1,031	0,289	1,070	10,576	4	Parcel	0,068
136	323151,430	1173251,403	253.4	323150,398	1173250,695	1,032	0,708	1,252	8,617	5	Path	0,225
137	323112,139	1173292,347	253.1	323109,851	1173292,293	2,289	0,054	2,289	8,680	5	Path	0,828
138	324427,448	1170244,306	503.4	324427,518	1170240,821	-0,069	3,485	3,486	0,820	6	Diffuse	1,249
139	324392,418	1170243,882	503.1	324398,559	1170241,379	-6,141	2,503	6,632	0,836	6	Diffuse	1,892

ID Sat	X Sat	Y Sat	ID GPS	X GPS	Y GPS	Delta x	Delta y	Delta xy	Slope	Border type	Border type	Log delta xy
141	324433,428	1170219,287	503.3	324433,586	1170219,231	-0,158	0,056	0,168	0,792	4	Parcel	-1,784
143	323238,726	1170442,749	473.2	323238,599	1170444,100	0,127	-1,351	1,357	1,673	4	Parcel	0,305
144	323228,824	1170525,283	473.4	323227,112	1170527,332	1,711	-2,049	2,670	1,808	4	Parcel	0,982
146	322894,219	1170635,503	491.1	322895,079	1170635,481	-0,860	0,022	0,861	1,662	1	Fence	-0,150
147	322855,682	1170662,467	491.2	322855,119	1170662,231	0,563	0,235	0,610	4,368	1	Fence	-0,494
148	322798,518	1170625,099	491.3	322798,572	1170624,399	-0,053	0,700	0,702	5,022	2	Forest	-0,354
149	321939,986	1172768,831	280.2	321940,121	1172768,653	-0,136	0,178	0,224	0,214	4	Parcel	-1,497
150	321956,575	1172723,508	280.3	321956,786	1172723,609	-0,211	-0,101	0,234	0,000	4	Parcel	-1,454
151	321976,605	1172793,498	280.1	321972,412	1172792,190	4,193	1,309	4,392	0,101	4	Parcel	1,480
152	321993,737	1172751,826	280.4	321989,194	1172750,834	4,543	0,992	4,650	0,000	4	Parcel	1,537
153	321630,732	1172883,157	258.1	321631,398	1172882,886	-0,666	0,271	0,719	5,625	1	Fence	-0,330
154	321651,381	1172925,444	258.2	321651,885	1172926,118	-0,504	-0,674	0,842	6,225	1	Fence	-0,172
155	321551,970	1172961,460	258.4	321551,524	1172960,869	0,445	0,591	0,740	5,048	4	Parcel	-0,301
157	321553,560	1172895,410	277.2	321554,408	1172894,822	-0,848	0,588	1,032	5,381	5	Path	0,031
158	321556,455	1172815,554	277.1	321557,035	1172816,462	-0,580	-0,908	1,077	5,500	5	Path	0,075
159	321530,490	1172819,593	277.6	321531,629	1172818,944	-1,139	0,648	1,311	5,412	4	Parcel	0,270
234	321527,680	1172898,402	277.3	321527,721	1172897,693	-0,042	0,710	0,711	8,029	4	Parcel	-0,341
160	321345,339	1172373,600	335.3	321345,835	1172373,077	-0,496	0,522	0,720	8,016	4	Parcel	-0,328
161	321358,621	1172360,794	335.2	321357,873	1172361,214	0,749	-0,421	0,859	10,823	4	Parcel	-0,152
162	321276,399	1172310,932	335.5	321277,714	1172311,634	-1,315	-0,702	1,490	10,110	4	Parcel	0,399
163	321310,702	1172313,953	335.1	321312,373	1172313,558	-1,671	0,395	1,717	7,009	4	Parcel	0,540
164	321106,225	1172074,471	334.3	321106,091	1172073,547	0,134	0,925	0,934	7,351	1	Fence	-0,068
166	321076,847	1172119,679	334.4	321076,432	1172118,733	0,415	0,946	1,033	8,019	1	Fence	0,032
167	321118,929	1172146,091	334.1	321120,892	1172148,067	-1,963	-1,976	2,785	0,526	5	Path	1,024
169	320685,125	1172414,322	271.2	320684,472	1172414,124	0,653	0,198	0,682	0,158	4	Parcel	-0,382
170	320789,592	1172430,391	271.4	320790,760	1172429,946	-1,168	0,445	1,250	4,397	1	Fence	0,223
171	320731,412	1172478,423	271.3	320730,821	1172478,560	0,591	-0,137	0,606	5,115	1	Fence	-0,500
172	320633,853	1172603,283	270.1	320634,790	1172602,337	-0,937	0,947	1,332	4,776	1	Fence	0,287
173	320681,260	1172652,817	270.2	320682,646	1172652,126	-1,386	0,691	1,549	5,778	4	Parcel	0,437
174	320592,093	1172654,568	270.4	320592,011	1172653,941	0,082	0,627	0,632	6,211	4	Parcel	-0,458
175	320644,385	1172695,168	270.3	320645,059	1172694,618	-0,673	0,550	0,870	4,613	4	Parcel	-0,140
176	320282,926	1172914,976	464.3	320282,709	1172915,106	0,217	-0,130	0,253	7,077	4	Parcel	-1,376
178	320345,007	1172887,175	464.4	320346,109	1172886,343	-1,102	0,832	1,380	6,576	6	Diffuse	0,322

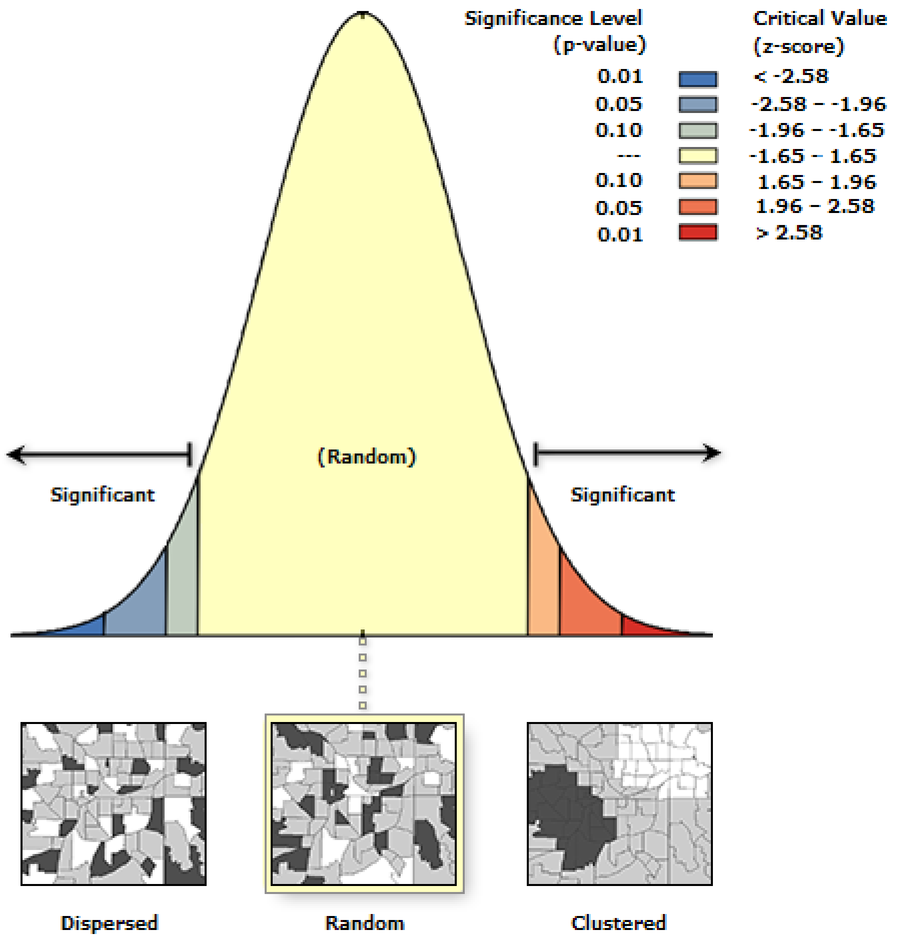
ID Sat	X Sat	Y Sat	ID GPS	X GPS	Y GPS	Delta x	Delta y	Delta xy	Slope	Border type	Border type	Log delta xy
179	320369,975	1172935,465	464.1	320369,738	1172934,344	0,237	1,121	1,146	6,467	5	Path	0,136
180	320483,351	1173143,589	265.5	320481,485	1173145,350	1,866	-1,760	2,565	7,194	4	Parcel	0,942
181	320425,090	1173138,549	265.1	320424,916	1173138,208	0,174	0,341	0,383	7,169	4	Parcel	-0,961
182	320425,050	1173125,531	265.2	320425,270	1173126,673	-0,220	-1,141	1,162	7,316	4	Parcel	0,150
236	320518,298	1173068,553	265.4	320517,835	1173067,955	0,463	0,598	0,756	7,679	6	Diffuse	-0,279
184	320798,373	1173161,870	263.4	320798,491	1173161,694	-0,118	0,176	0,211	5,708	4	Parcel	-1,554
185	320831,564	1173217,142	263.3	320832,640	1173216,452	-1,076	0,690	1,278	5,571	2	Forest	0,245
186	320812,584	1173230,117	263.2	320813,929	1173230,291	-1,344	-0,174	1,356	5,410	2	Forest	0,304
187	320787,730	1173253,204	263.1	320789,760	1173254,204	-2,030	-0,999	2,263	5,232	2	Forest	0,817
188	321028,126	1173478,018	164.2	321029,623	1173478,779	-1,497	-0,761	1,680	4,738	5	Path	0,518
189	321021,511	1173414,465	164.1	321021,731	1173415,643	-0,219	-1,178	1,199	6,105	4	Parcel	0,181
190	321071,756	1173395,891	164.3	321065,565	1173400,886	6,191	-4,995	7,954	9,224	4	Parcel	2,074
191	321144,730	1172876,235	274.1	321146,095	1172871,289	-1,365	4,946	5,131	12,540	2	Forest	1,635
192	321144,307	1172818,238	274.2	321145,409	1172817,449	-1,102	0,789	1,356	12,171	2	Forest	0,304
193	321189,141	1172831,481	274.3	321191,774	1172829,212	-2,634	2,269	3,476	9,410	2	Forest	1,246
235	321182,611	1172881,505	274.4	321182,826	1172875,389	-0,215	6,116	6,119	9,339	6	Diffuse	1,811
194	321376,318	1172721,436	275.3	321376,584	1172720,627	-0,266	0,809	0,851	4,405	4	Parcel	-0,161
195	321388,209	1172681,414	275.4	321388,410	1172680,780	-0,201	0,634	0,665	4,115	2	Forest	-0,408
196	321224,807	1172675,562	275.1	321224,355	1172672,609	0,452	2,953	2,987	10,564	4	Parcel	1,094
197	321214,603	1172717,692	275.2	321213,453	1172712,186	1,149	5,506	5,625	10,652	4	Parcel	1,727
198	321998,397	1175093,476	34.4	321996,919	1175093,657	1,478	-0,181	1,489	6,082	4	Parcel	0,398
199	322035,531	1175116,729	34.1	322036,071	1175117,803	-0,540	-1,074	1,202	13,683	2	Forest	0,184
200	321969,893	1175143,269	34.3	321966,789	1175142,993	3,105	0,276	3,117	4,874	6	Diffuse	1,137
237	322004,150	1175171,206	34.2	322001,792	1175170,995	2,358	0,211	2,367	10,656	6	Diffuse	0,862
202	321930,091	1175603,415	27.1	321930,023	1175603,527	0,069	-0,112	0,131	6,264	1	Fence	-2,029
203	321886,880	1175620,750	27.4	321887,066	1175620,477	-0,186	0,272	0,330	6,076	1	Fence	-1,109
204	321879,888	1175599,855	27.3	321879,607	1175599,313	0,281	0,543	0,611	6,134	4	Parcel	-0,492
205	322297,075	1175685,385	26A.3	322296,830	1175685,124	0,246	0,261	0,358	5,141	3	Pasture land	-1,026
206	322338,507	1175715,085	26A.2	322338,718	1175714,785	-0,211	0,299	0,366	4,791	3	Pasture land	-1,004
207	321205,741	1175749,799	29.2	321204,719	1175749,551	1,022	0,248	1,051	0,102	4	Parcel	0,050
208	321205,485	1175772,975	29.1	321204,734	1175771,927	0,751	1,048	1,289	0,172	5	Path	0,254
210	321131,614	1175780,739	29.4	321130,698	1175779,863	0,917	0,876	1,268	5,490	3	Pasture land	0,237
211	327746,708	1172507,505	319.4	327746,204	1172506,380	0,503	1,125	1,232	5,290	4	Parcel	0,209

ID Sat	X Sat	Y Sat	ID GPS	X GPS	Y GPS	Delta x	Delta y	Delta xy	Slope	Border type	Border type	Log delta xy
212	327771,129	1172523,460	319.1	327768,178	1172520,352	2,951	3,107	4,285	4,851	4	Parcel	1,455
218	325407,594	1171857,851	358.1	325408,142	1171857,903	-0,549	-0,051	0,551	8,117	5	Path	-0,595
216	325362,818	1171934,679	358.2	325363,398	1171934,442	-0,580	0,238	0,627	3,468	1	Fence	-0,467
217	325278,898	1171882,389	358.4	325278,489	1171882,050	0,409	0,339	0,532	2,607	4	Parcel	-0,632
221	324993,743	1170357,149	468.1	324993,354	1170356,588	0,389	0,561	0,682	0,861	6	Diffuse	-0,382
220	325019,564	1170311,217	468.2	325019,300	1170311,321	0,263	-0,104	0,283	0,663	4	Parcel	-1,262
222	325031,156	1170316,698	468.3	325030,799	1170316,334	0,358	0,364	0,510	0,673	6	Diffuse	-0,673
230	322908,900	1173292,585	251.2	322908,292	1173292,456	0,608	0,129	0,622	13,375	4	Parcel	-0,475
231	322929,906	1173303,072	251.3	322928,796	1173302,918	1,111	0,153	1,121	9,237	6	Diffuse	0,114
232	323321,413	1172918,290	246.3	323321,671	1172917,919	-0,258	0,371	0,452	5,830	4	Parcel	-0,794
233	323308,772	1172942,321	246.4	323309,953	1172944,117	-1,181	-1,796	2,150	5,029	6	Diffuse	0,765
6	326162,130	1171796,532	386.4	326162,313	1171796,324	-0,183	0,209	0,278	2,657	4	Parcel	-1,281

Appendix C – Moran I Spatial Autocorrelation Report

Spatial Autocorrelation Report

Moran's Index: -0,076681
z-score: -0,090204
p-value: 0,928125



Given the z-score of -0.09, the pattern does not appear to be significantly different than random.

Global Moran's I Summary

Input Feature Class:	Outliers
Input Field:	DELTA_XY
Conceptualization:	INVERSE_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold:	1005,440453 Meters
Weights Matrix File:	None
Selection Set:	False

Dataset Information

Moran's Index:	-0,076681
Expected Index:	-0,050000
Variance:	0,087487
z-score:	-0,090204
p-value:	0,928125