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March, 2016

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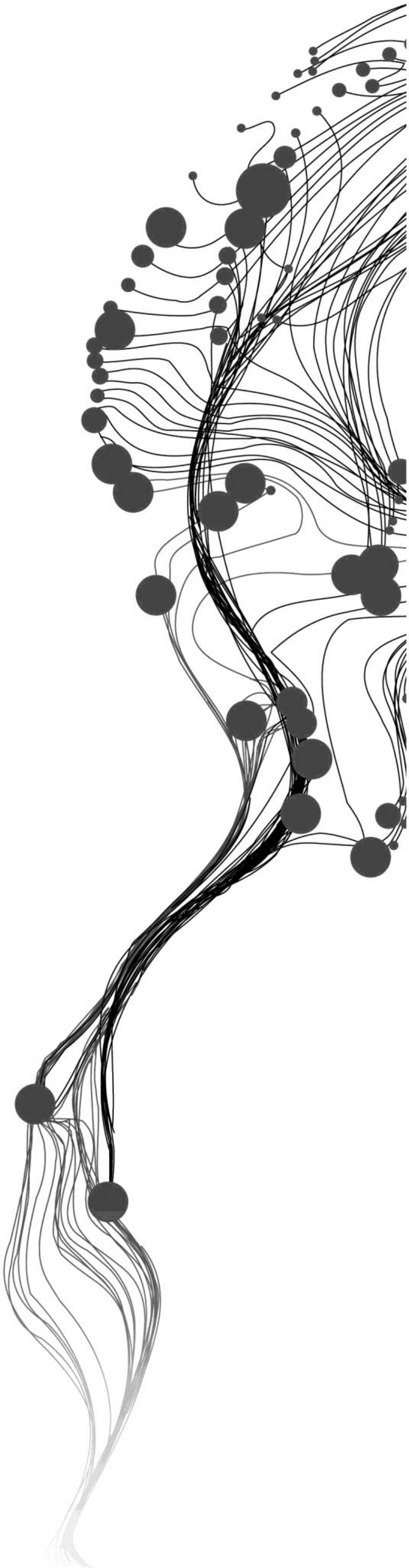

TOWARD AUTOMATIC CADASTRAL BOUNDARY MAPPING FROM SATELLITE IMAGERY

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Enschede, The Netherlands, March, 2016

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

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ABSTRACT

Using cheap and up-to-date fit-for-purposes technologies targeting on the existing societal needs is important to speed up cadastral boundary mapping so that land, and land sector, will play its underlying role in insuring sustainable development. While the priority should have been coverage and tenure security, the focus on high accuracy based conventional approaches lead to tenure insecurity. Particularly, accuracy for boundary surveying should not depend on what is technically possible. Rather it should depend on the current societal need and capacity of a country to implement the surveying. When high positional accuracies are not a matter of concern but when time is, high-resolution satellite images serve as a source of cadastral boundary information.

The aim of this study is to test the capabilities of automatic feature extraction algorithms to respond to the calls of the majorities who are suffering as a result of tenure insecurities. The main idea is to extract cadastral boundaries based on visible land cover information from World view 2 high-resolution satellite images (HRSI). Preliminary experimental results tested on an area of 730x656 pixels showed that mean-shift segmentation is better than Canny edge detection, and line segment detections methods. The mean-shift segmentation application plugin in QGIS is then used to extract cadastral boundaries on three subset images consisting of different cadastral features in rural areas. The segmentation yields promising results for boundaries of rivers, roads and parcels. The result is a vector file satisfying many cadastral boundary requirements and ready to be used in a GIS environment. The results were assessed visually and quantitatively against existing cadastral boundaries. The accuracy of extracted boundaries are assessed based on completeness, correctness and quality.

Based on the quantitative analysis obtained from image processing techniques, together with the information obtained during the discussion with land administration professionals and results from the SWOT analysis, the approach is believed to respond well to existing and pressing tenure insecurity issues happening in many developing countries. In line with this, a possible workflow to integrate the automatic feature extraction approach with current cadastral boundary mapping approaches is also suggested. In general, the approach is proved to support existing relatively slow boundary mapping approach by minimizing the effects of manual digitization and surveying.

Key words: *automatic, mean-shift segmentation, fit-for-purpose, cadastral boundary, satellite imagery*

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ACRONYMS

- BoEPLAUA Bureau of Environmental Protection Land Administration and Use Authority
- FAO Food and Agricultural Organization of the United Nations
- FIG International Federation of Surveyors
- FN False Negative
- FP False Positive
- GIS Geographical Information System
- GPS Global Positioning System
- HRSI High Resolution Satellite Image
- ISO International Organization for Standardization
- LIS Land Information System
- LSD Line Segment Detection
- LIFT Land Investment For Transformation
- ORFEO Optical and Radar Federated Earth Observation
- OTB Orfeo Tool Box
- QGIS Quantum Geographic Information System
- REILA Responsible and Innovative Land Administration
- SWOT Strengths, Weaknesses, Opportunities and Threats
- SVM Support Vector Machine
- TP True Positive
- UAV Unmanned Aerial vehicles

1. INTRODUCTION AND JUSTIFICATION

1.1. Introduction

High-resolution satellite images are considered a source of information to solve socio-economic problems in many contemporary fields of study. These images, together with remote sensing techniques support decision-making in many ways. Land use change detection, natural resource management, land use and urban planning, land cover mapping, crop monitoring and hazard assessment are all example application areas. This relatively new method of data collection and processing, along with the growing requirement for cadastral information, draws attention from land and geospatial professionals to use land cover information obtained from high resolution satellite images for cadastral boundary mapping purposes.

As the development of a cadastral system can help both citizens and the government (Henssen, 2010), The Food and Agricultural Organization of the United Nations (FAO) encourages states to provide cadastre systems to improve tenure security of individuals(FAO, 2012). For instance, cadastres play a great role in providing information about land ownership, use, and value (Dale & Mclaughlin, 1988). But, these benefits cannot often be achieved, in an efficient manner, by employing conventional, accuracy oriented cadastral surveying approaches. Most successful cadastral projects have used a general boundary approach (Henssen, 2010). From the practice of many countries, it was proved that relatively slow and expensive conventional techniques do not solve the land related problems of tenure insecurity, forced eviction and access to credit. Tenure security does not in itself need accurate surveys of boundaries (Enemark, Bell, Lemmen, & McLaren, 2014). Spatial accuracies could be improved over time after securing the tenure rights with available human and financial resources(FAO, 2012).

When the area to be covered is too large and high positional accuracy is not a matter of concern (Hyunil & Handon, 2012), fit-for-purpose image based approaches from HRSI are amongst the viable options for cadastral boundary mapping. Such instruments are already proven as helpful in the process of updating cadastral maps as in (c.f. Ali, Tuladhar, & Zevenbergen, 2012; Al-ruzouq & Dimitrova, 2006) and for automatic extraction of features (that are also cadastral features) like road extraction, streamline delineation as in (Mena, 2003; Hu & Tao, 2007). Remote sensing technologies for river boundary delineation was even found to reduce time, cost and labor as discussed in the work of (Horkaew, Puttinaovarat, & Khaimook, 2015).

Regarding extraction of information from satellite images particularly on object extraction, Katiyar and Arun (2014) put the issue of noise, missing of true edges and false edge detection among the main concerns. In the context of cadastral boundaries, such issues may arouse due to the fact that some boundaries are invisible from the image or because, for example, crops have identical reflectance on adjacent parcels. On the other hand, boundaries on the cadastral map sometimes don't correspond to actual boundaries on the ground. This happened when transactions/other changes on the ground are not updated on the cadastral map. Thus, while extracting features from satellite images automatically, it is good to develop a methodology that takes the above issues into consideration.

In this study, the capability of automatic feature extraction algorithms to extract cadastral boundaries from orthorectified and pan-sharpened WorldView-2 HRSI is tested. An appropriate edge based and region based segmentation algorithm are to be applied on a subset of images that were chosen as they included possible cadastral boundaries in the rural areas. Extracted boundaries are then examined against existing cadastral boundaries of the study area based for their correctness, completeness and quality (c.f. Kumar, Singh, Raju, & Krishnamurthy, 2014). In addition, the topological consistencies of the extracted data are checked. To understand the nature of parcel boundaries in the study area, interviews with key informants were also conducted. After analysis of information, the approach is customized so that it could support current cadastral boundary mapping practices in developing countries. Overall, the motivation of the study is to support the current relatively slow cadastral boundary mapping approaches by minimizing the effect of time, cost and labor constraints.

1.2. Background

In the contemporary era, it is estimated that only about thirty percent of the world's population have access to formal or statutory systems to register and protect their land rights (Enemark et al., 2014). This in turn, worsens the lifestyle of about seventy percent of the population, many of which are poor and vulnerable groups in sub-Saharan Africa. Building a system that can handle growing number of land transactions in the land sector is one of the challenges currently facing many land administration offices. The absence of a well-organized digital cadastral system is one of the key reasons for these problems.

To alleviate these problems, Enemark et al.(2014) suggested that land administration should be designed to meet the needs of people and their tenure security, to sustainably manage land use and natural resources. The authors also underlined that use of conventional, high accuracy, expensive land surveying techniques to record land rights are the key blockage in land administration services. Cadastral survey based on fixed boundary demarcation and field survey is a very expensive and time-consuming procedure (Onkalo, 2006). Now from the above statements, one may ask what other approaches/methods can be used for land surveying purposes?

Fit-for-purposes approaches are important to give an immediate and cost effective solution to land surveying. According to (Enemark et al., 2014) these approaches focus on the following four principles: using general boundaries to delineate land areas, especially in rural and semi-urban areas, the use of high-resolution satellite/aerial imagery, relates to the purpose rather than technical standards and opportunities for updating, upgrading and improvement. In line with this argument, using cheap technologies, targeting on the current societal needs is important for surveying purposes. Among these, high-resolution satellite imagery is the one that can be a suitable data source to capture cadastral boundary information as emphasized below.

In cases where a wide range of areas are not entirely registered or require to be newly registered, and when high positional accuracy is not a matter of concern, digital photogrammetry using high-resolution satellite imagery can be an extremely useful approach (Hyunil & Handon, 2012). To secure land rights priority should be given to coverage. It will help to manage land use and to safeguard social injustice resulting from land grabbing and forced eviction (Lemmen, Bennett, McLaren, & Enemark, 2015). Registration of a large number of parcels can be carried out at a cheaper cost in less time, compared to conventional high accuracy cadastral surveying methods (Hyunil et al., 2012). In particular, the cost of satellite imagery is estimated to be one-third for the rural areas and one-fifth for urban areas (Enemark et al., 2014). Availability, cost, coverage and the time it takes to map cadastral boundaries makes HRSI an ideal choice for current cadastral purposes in developing countries. Using satellite images for interpreting parcel boundaries is a much more rapid and effective method (Konecny, 2009) that doesn't require professionals to undertake the fieldwork (Enemark et al., 2014). In reducing the workload of image analysis, employing automatic image analysis methods appear as a preferable method over manual satellite image analysis.

Automated image analysis procedures have to be introduced when there are time constraints (Ventura, Rampini, & Schettini, 1990). In this study the capability to automatically delineate cadastral boundaries of edge based and region based segmentation algorithms, called canny edge detection algorithms, line segment detection, and mean shift segmentation algorithms are compared. This is because, these methods are robust to noise and can produce relatively accurate estimates of the line/boundary parameter (Bartl, Petrou, Christmas, & Palmer, 1996). The comparison is made based on the output results obtained from the algorithms. For the implementation of algorithms, pan sharpened WorldView-2 satellite imagery of 0.5 m resolution the QGIS plugin (for the mean-shift segmentation algorithm), and Matlab software (for the canny algorithm) are used. Then, by taking cadastral boundary requirements into consideration, availability of the software and steps involved in the process, a practical choice is made as in (Babawuro & Beiji, 2012). Accordingly the mean-shift segmentation application is chosen for further analysis.

1.3. Research problem

Generally speaking, due to a focus on fixed boundary approaches, land administration offices in many developing countries stayed passive for many years in providing efficient services for the citizens. The cadastral surveying methods and corresponding outputs don't fit and respond well to the purposes they are designed for. This is mainly depicted in the time it takes for registration, cost, human capacity, and/or coverage. In relation to accuracy standards, Dale and Mclaughlin (1988) described that the focus should be on what is necessary and sufficient accuracy level for the area not what is technically possible. Implementing a fixed boundary approach in urban areas may suit more than implementing it in rural areas: achieving higher accuracy is not as such a concern in rural areas compared to urban areas. On the other hand, the general boundary approach is more suitable in rural areas than urban areas. Going further, problems tend to come, when a fixed boundary approach is implemented in a larger country: it will take too much time to accomplish cadastral mapping. The cadastral registration being slow leads many land registration offices still to depend on paper-based land information. Not only this, the slower the registration, the more time it will take for certifying landholders. They remain more insecure especially for those around the periphery of urban cities, and are more unlikely to invest on land and hence benefit less from land. Figure 1 reveals the interconnectedness between the above arguments.

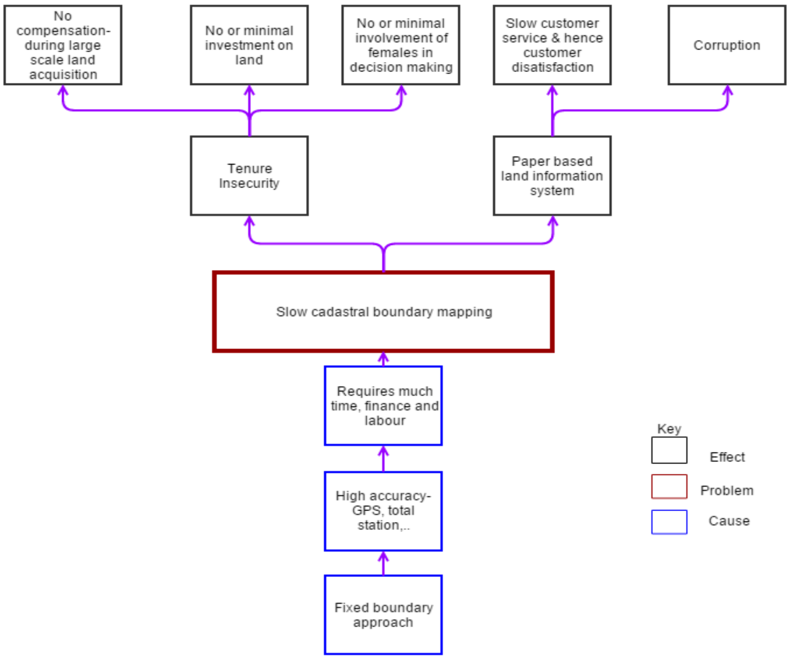


Figure 1-Generalized problem tree regarding slow cadastral boundary mapping approaches

These problems are more intensified for countries having larger area coverage and more population. For instance, in Ethiopia where 83 % of the population lives in rural areas, it has been nearly two decades since land registration and certification commenced. Though the experience from the first phase of certification was exemplary, mainly in terms of its cost and time, much work is still ongoing to update it in a second phase. The second phase includes parcel boundary descriptions that the first phase didn't include. For the second phase, conventional surveying methods in combination with orthophotos and/or high-resolution satellite imagery are being employed. For instance, amongst the active projects in the Amhara region, REILA project, which started in 2010, is able to map only two kebeles whereas the LIFT project accomplished around seventy kebeles each of them from two woredas (Personal communication, October 14, 2015). From the pace one can see that these processes will take decades to accomplish the boundary mapping. Such slow cadastral boundary mapping approaches as a problem trigger consideration of other innovative approaches, one that might speed up cadastral boundary mapping so that land, and land sector, will play its underlying role in insuring sustainable development. The problem guiding this that whilst automatic feature extraction methods appear a useful approach, the researcher of this study do not know whether these methods support cadastral boundary mapping or not. If they do, to which areas they are best suited to.

1.4. Conceptual framework

As outlined above, limited work has been completed that applies automatic feature extraction techniques for cadastral boundary mapping purposes. In this research, the potential is investigated for the specific case of general cadastral boundary mapping. Appropriate feature extraction algorithms are aimed at being selected and applied to satellite imagery: inputs (imagery and selected algorithms) are processed (through mean-shift segmentation application, a QGIS plugin) to give cadastral boundaries as output. Output boundaries are examined against existing cadastral boundaries.
The structure and relation of developed concepts are presented with the following diagram (Figure 1).

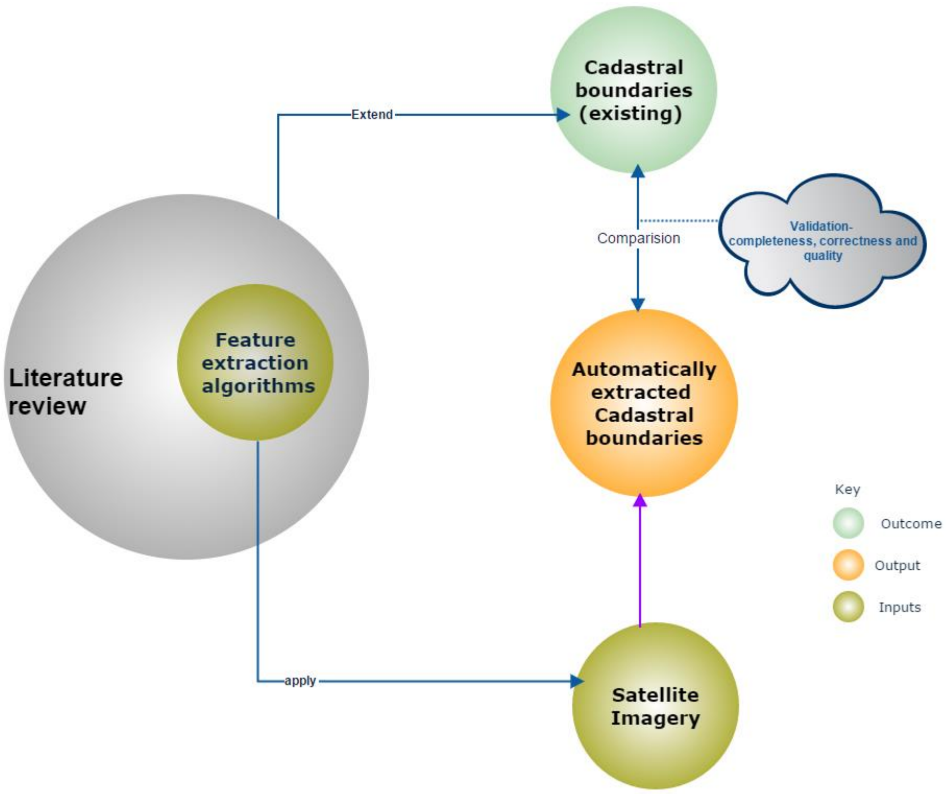


Figure 2-Conceptual framework

1.5. Research objectives and questions

1.5.1. Research objectives

The general objective of the study is to test the applicability of automatic feature extraction algorithms to support general boundary cadastral mapping from satellite imagery in Ethiopia.

To attain the above general objective the following specific sub-objectives are devised:

1. To review for a suitable feature extraction algorithms to extract cadastral boundaries from satellite imagery.
2. To apply feature extracting algorithms on a selected datasets.
3. To analyze applicability of automatic feature extraction algorithms for general cadastral boundary mapping.

1.5.2. Research questions

The following are research questions developed corresponding to each of the above specific objectives.

Corresponding to sub-objective 1:

1.1 What are the available automatic feature extraction algorithms?

1.2 Which algorithm is most appropriate for cadastral boundary extraction purpose?

Corresponding to sub-objective 2:

2.1 How the cadastral boundaries can be extracted automatically from the input dataset?

Corresponding to sub-objective 3:

3.1 What is the percentage of correctly extracted cadastral boundaries?

3.2 What is the percentage of completely extracted cadastral boundaries?

3.3 What are the contributions of automatic feature extractions approach for general cadastral boundary mapping in terms of time, cost and labour requirements?

1.6. Scope of the study

The focus of this study is to extract general boundaries from satellite imagery, that is natural or man-made cadastral boundaries, that are visible from imagery. The specific focus is on rural areas, or subsistence agriculture areas, in Amhara Region, Ethiopia. However, these are taken as potentially representative of other smallholder contexts in other parts of Ethiopia and sub-Saharan Africa more generally. Fixed boundary concepts are considered outside the scope of the work. The main focus of the work is on technical procedures relating to boundary identification and extraction: production level issues related to scalability are considered, but, are of secondary concern for this work.

1.7. Research matrix

The following table (Table 1) summarizes research objectives, research questions, required data and software to address objectives/questions, methods to be employed and anticipated results.

Research objectives	Research question	Required data and software[1]	Methods of research	Anticipated results
To review for a suitable feature extraction algorithms for extracting cadastral boundaries from satellite imagery.	What are the available automatic feature extraction algorithms?	Scientific literature, Journal articles, Books, Reports, Expert knowledge	Literature review & Desk study	Criteria to choose appropriate algorithms
	.2 Which algorithm appears most appropriate for cadastral boundary extraction purpose?			Identified appropriate algorithms
To apply feature extracting algorithms on a selected datasets.	How the cadastral boundaries can be extracted automatically from the input dataset?	Orthorectified and pansharpened WorldView-2 image, reference data, Erdas Imagine, ArcGIS, QGIS, MatLab	Image processing & Spatial analysis	Workflow and extracted boundaries
To analyze applicability of automatic feature extraction algorithms for general cadastral boundary mapping.	What is the percentage of correctly extracted cadastral boundaries?	QGIS, Extracted cadastral boundaries, Existing cadastral boundaries	Image processing & Spatial analysis	Identified cadastral features, percentage of completeness and correctness
	What is the percentage of completely extracted cadastral boundaries?			
	What are the contributions of automatic feature extractions approach for general cadastral boundary mapping in terms of time, cost and labour requirements?	Interview data, Scientific literature, Journal articles, Books, Reports, Expert knowledge, and extracted results.	Desk study, Analysis of Interview and extracted boundaries and SWOT analysis.	Contributions of automatic feature extraction approach for general cadastral boundary mapping

Table 1-Research matrix

[1] Intel(R) Core(TM) i7-4700MQ CPU @2.4GHz with RAM 8.00 GB laptop was used to process all the data and software.

1.8. Research approach

To realize the objectives of the study the following procedures are proposed and implemented.

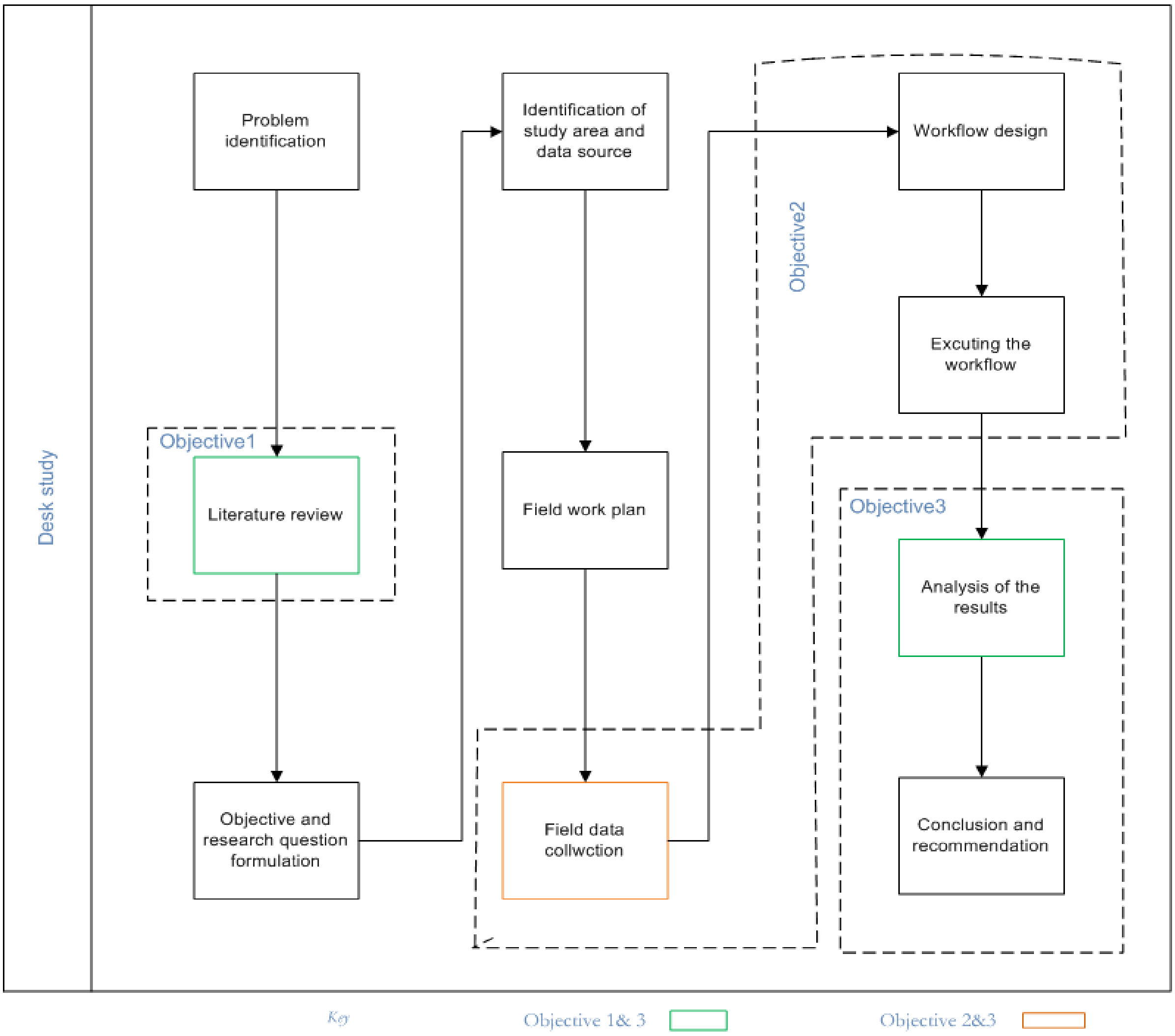


Figure 3 Research design flow

1.9. Thesis structure

This thesis is organized into five chapters as follow:

- Chapter 1: Introduction
  In this chapter the background of the study, research problem, including objectives of the study and questions to be addressed are described.
- Chapter 2: Literature review
  Relevant literature in relation to the cadastral system, cadastral boundaries, the role and practice in using satellite imagery for cadastral boundary mapping, the practice of automated feature extraction algorithms are discussed here. Related background information on feature extraction and quality assessment approaches are also discussed here. Information obtained in this chapter helped to answer the first research objective.
- Chapter 3: Methods and data collection
  Here the types of data collected for the research, the procedures and software used to address the objectives together with the approaches for the validation of results are presented here.

- Chapter 4: Result and discussion
  This chapter presents the main results of the research and with a brief interpretation. Steps used to extract automated cadastral boundaries are developed and implemented here. These will help to address first and second research objective.
- Chapter 5: Conclusion and recommendation
  Concluding remarks of the overall study based on the developed objectives are discussed here. Besides, based on the identified gaps, the scope of the study and/or developed method recommendation of further research areas are made here. By doing this, the third objective is addressed.

1.10. Conclusion

In developing countries, the methods employed by land administration offices to respond to the land related problems in most cases remain as paper value leaving aside the interest of majority of the society. This leads to seventy percent of the population not to guard or formally register their land rights, hence to suffer from results of tenure insecurity. Such issues also hinder the sustainable development of a country. In many cases, financial or human capacities of a country play a crucial role to handle the problems under the required coverage and time constraints. It took many decades to handle such problems by employing for instance, conventional land registration tools. The introduction of HRSI, on the other hand, paved the way to employ fit-for-purpose approaches to respond to the needs of the society in cost effective way. So, this chapter deals with the back ground information behind the research including the research problem, objectives of the research, scope of the study, and the research approach devised to attain the objectives.

2. LITERATURE REVIEW

2.1. Introduction

In this chapter, the concepts of cadastral boundaries, the potential of satellite imageries for cadastral boundary mapping, and automatic feature extraction for different real world applications, as viewed and discussed by different authors is presented. In addition, approaches for evaluating the quality of extracted features are examined. The chapter provides coverage of the essential background concepts needed to undertake the research.

2.2. Cadastral boundary

The International Federation of Surveyors described a cadastre as "a parcel based and up-to-date land information system containing a record of interests in land" - where a parcel, according to Dale and Mclaughlin (1988), is "a continuous area or volume of land within which unique, homogenous interests are recognized". Varieties of cadastres can be identified, usually based on their purpose. The variety of cadastre determines the type of land tenures represented in a cadastre. Establishment of a cadastral system constitutes adjudication, demarcation, surveying and recording as its operational components (Henssen, 2010). Parcel boundaries could be natural or artificial, and can be represented either by visible features on the ground, or by lines on a map, or by coordinate (FIG, 1995). Zevenbergen (2009) described a boundary as a discontinuity line on which the right of one party begins and the other ends. According to (Dale & Mclaughlin, 1988) linear features like fences and hedges served as parcel boundaries in rural areas. They allow the use of cheaper photogrammetric approaches of survey: parcel boundaries are visible from the air. Such visible boundaries are appropriate for many purposes in land management and land information system (Zevenbergen & Bennett, 2015).

Unlike fixed boundaries, the emphasis of general boundary approaches mainly lays on the right of individuals rather than the spatial accuracy of the boundary. The accuracy can actually be modified in future depending on the purposes, but still need to be recognized legally in cadastre (Bennett, Kitchingman, & Leach, 2010). On the issue of using natural boundaries for land administration, the authors identified perception (who perceived its existence?), purpose (what is its purpose?), presence (what is its nature on the ground?), point in time (when does it exist?) and presentation (how is it represented graphically and textually?) as elements to use natural boundaries. It is also stated that the presentation element needs definition of datum, scale, data type, and divide type for better data integration.

In line with vein, (Navratil, 2011) the accuracy which must be applied depends on the purpose, the cost and time of realization of a project or a product. To strengthen this idea, (Bogaerts & Zevenbergen, 2001) noted that as fixed boundaries are costly, introducing general boundaries for the establishing of cadastral system is worthwhile. Particularly, for most rural and semi-urban areas in countries of sub-Saharan Africa, (Enemark et al., 2014) suggested general boundary approach.

2.3. Satellite imagery for cadastral boundary mapping

The idea of using HRSI for the purpose of cadastral boundaries mapping is described by different authors at different times. Among these, the investigation made by (Ali & Ahmed, 2013) on the use of QuickBird satellite images to maintain parcel boundaries and cadastral boundaries in LIS is prominent. Their study was conducted in the Khyber Pakhtunkhwa province of Pakistan by using on-screen digitization techniques. The findings show that costs and times for generating cadastral maps by this method are halved – when compared to conventional cadastral surveying methods.

Rao et al. (2014) underlines the importance of HRSI in cadastral resurvey by comparing the perimeter, area and position of parcel boundaries with the results from GPS/ETS. One of the motivations behind their work was modernization of land records management to improve transparency and minimize land disputes.

The above authors justified how satellite image based mapping (based on manual digitization) is advantageous in terms of cost and time over the conventional cadastral surveying approaches. They describe the significance of HRSI for cadastral boundary maintenance. Thus, exploring the role of automatic feature extraction approach to maximize cost and time benefits is the concern of this research.

2.4. Automated feature extraction

Different authors have used automatic feature extraction algorithms for different purposes. Road network extraction, river coastline extraction, extraction of roofs of residential buildings and valley boundary delineation are among many examples. Here, some of the approaches developed for feature extraction, considered most relevant for the topic at hand, are discussed.

In this regard, the work of Liu and Jezek (2004) showed that automatic feature extraction algorithms are effective and accurate to extract coastlines from satellite imagery by using Canny edge detector and Levenberg-Marquardt methods. The authors employ preprocessing and post processing algorithms to extract 'the coastline'. Image segmentation by the locally adaptive thresholding algorithm was an important step in their work. These segmentation algorithms contribute by partitioning the image into water and land regions. Preprocessing algorithms are used to suppress the effect of image noise and enhance edge. Horkaew et al. (2015) used the SVM method to delineate river boundaries from satellite images. They found an equivalent result with the conventional methods, but the method remains advantageous in terms of time, cost and labour.

Automatic feature extraction algorithms are also used by (Momm, Gunter, & Easson, 2010) to extract roofs of residential housing from IKONOS and QuickBird imagery of the Mississippi Gulf Coast before and immediately after hurricane Katrina.

Qian, Lu, and Chen (2000) also devise a single run-off algorithm by using a 3x3 moving window to automatically demarcate valley boundaries from DEMs. The algorithm detects drainage networks and the valley boundaries in Wangiiagou basin, China.

The contribution of automatic feature extraction algorithms is also tested on road networks. Awad (2013) extracts road networks in Beirut, Lebanon, first by enhancing the satellite image, and then segmentation of the enhanced image, followed by morphological operators. Position wise, compared to conventional urban feature extraction methods, the author obtained a more accurate result with less effort and time. Likewise, for the purpose of road network extraction, from fused images of QuickBird, WorldView 2 and IKONOS 2 images (Kumar et al., 2014) used object oriented segmentation, followed by a soft fuzzy classifier, and morphological operators, to further refine extracted road edges. The correctness and completeness results showed the designed methods were effective.

A closer look at extracting cadastral boundaries from HRSI was done by (Solomon, 2005; Babawuro & Beiji, 2012). Solomon (2005) used ERDAS Image Segmentation Extension and eCognition methods to extract parcel boundaries. The validation of results, which are vector files in both cases, was made based on visual inspection with reference polygons obtained from GPS measurements. The researcher described the result obtained from the former approach as far from acceptable. Even it took considerable time. Though the segmentation by eCognition yields a better result, the visual inspection indicated none of these provisional parcels matched with the reference polygons. Babawuro and Beiji (2012) on the other hand used image processing algorithms to extract farmland boundaries from gray scale HRSI. Canny edge detection, morphological operators, Hough transform and discrete wavelet transform were utilized in the work. They identified some boundaries are not detected by the algorithms, but, that the methods are helpful in achieving cadastral goals by lessening human demerits associated with cadastral surveying. However, the paper failed to explain the quality of detected boundaries and their agreement with cadastral boundary requirements.

2.4.1. Edge detection

Edge detection is one of the basic methods for object detection in image processing. From an image processing point of view, a boundary of an object as described by (Nixon & Aguado, 2012) exists at the position of the edge where a sudden change in the intensity levels appears. To detect edges of an image, first order and second order edge detection methods, based on the concept of differentiation, are among the possible options. Different algorithms for edge detection exist, for example: Sobel, Prewatt, Robert's, Canny's and so on. As justified by many researchers, Canny's algorithm is found to be optimal detector relative to others. For that reason, this algorithm is chosen to be tested in the study.

The Canny edge-detection is a popular edge-detection technique that mainly focuses on reducing the response to noise by using Gaussian filtering to smooth the image, good localization with minimal distance between detected and true edge position, and one response to a single edge. The steps involved in the detection are: Gaussian smoothing, Sobel operator, nonmaximal suppression; and threshold with hysteresis - to connect edge points.

2.4.2. Segmentation

Segmentation as described by (Gonzalez & Woods, 2010) is the division of an image into meaningful structures. It is done by assigning pixels of an image to different partitions called segments. Pixels grouped in one partition are similar to each other in one way (like in their grey value) and different with pixels in other partitions. Segmentation should be done in accordance to our particular interest (Gandhi, Shah, & Kshirsagar, 2014). That is, the process of segmentation should continue only until the object of interest is isolated. Image segmentation algorithms are generally designed to form segments of an image based on abrupt changes in intensity, or based on predefined criteria like thresholding (Gonzalez & Woods, 2010).

Hence, segmentation could be threshold based, edge based or region based. In threshold based segmentation, pixels will be grouped to different categories depending on the given threshold value(s). To identify an object, edge based techniques starting from the boundary and goes inward. Whereas region-based techniques follow the opposite approach by starting from the inside of the object (Gonzalez & Woods, 2010). The issue of over segmentation and under-segmentation is among the concerns of this approach that sometimes leads to imperfect results. In the case of over-segmentation, pixels belonging to the same object are classified as belonging to different segments. On the other hand, pixels from different objects are assigned to the same object in case of under segmentation.

Processing speed and good shape matching are among the advantages of image segmentation (Gandhi et al., 2014). Based on feature space analysis, (Comaniciu & Meer, 1997) proposed an efficient colour image segmentation algorithm that uses the mean-shift algorithm to locate cluster means. For detailed procedures and applications of mean-shift algorithms for edge-preserving smoothing and image segmentation and on how boundaries of smoothed image are formed, please refer (Comaniciu & Meer, 2002) and (Ma & Manjunath, 1997).

Regarding the effectiveness of edge detection algorithms, Katiyar and Arun (2014) compared the most common Gradient and Laplacian based edge detection algorithms. The authors compared Canny, Sobel, Prewitt, Roberts, Laplacian and Zero Crossing edge detection algorithms and finally concluded that the Canny's algorithm is best suited for feature extraction. Unlike other algorithms, more features (roads, lakes and stadium) were distinguished while implementing Canny algorithms within similar manipulation time. It was also described that the reason behind its effectiveness in most contexts is that it yields fewer numbers of false edges.

On the side of those advantages, filtering noise of an image by applying Canny edge detection algorithm affect the edges which sometimes leads to the loss of weak edges. Especially, when the objective is to extract boundaries it is better to use/develop a mechanism that preserves edges as much as possible. In this regard, the work of (Gandhi et al., 2014), depicted that mean shift segmentation is better than canny edge detection algorithm mainly in removing noise and smoothing. The mean shift approach is one of the region-based segmentation methods which allows the formation of segments that maintain discontinuity characteristics (Gandhi et al., 2014).

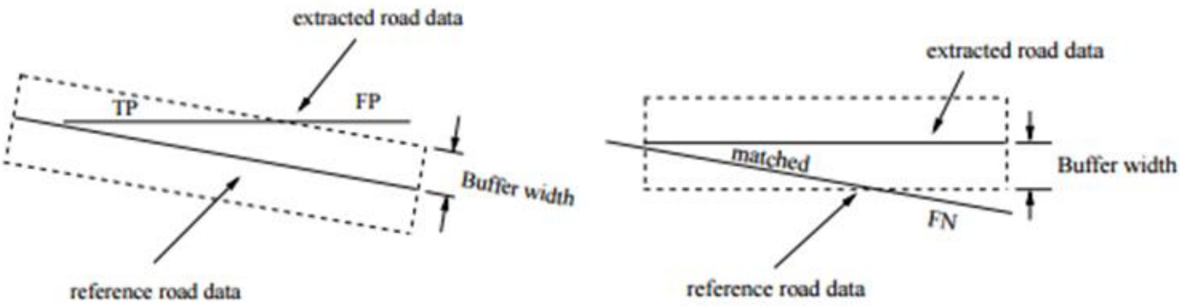
2.5. Geographic data quality measures

Dealing with spatial data quality helps for decision-making purposes. The International Organization for Standadization (2013), in ISO 19157, list completeness, logical consistency, thematic accuracy, positional accuracy, and temporal accuracy as elements to describe the quality of a geographical dataset. Commission, omission, format consistency, topological consistency, and classification of correctness are among the data quality sub-elements.

As stated in the standard (ISO 19157), completeness is related to the presence and absence of features. It is also described as absence of errors of omission. Commission and omission are the two quality sub-elements of completeness. Commission refers to the presence of extra data in the data set while omission refers to the absence of a data. Thematic accuracy as classification correctness is about the comparison of features assigned to class with the reference dataset or ground truth. Topological consistency on the other hand is a sub-element of logical consistency that describes the correctness of clearly encoded topological characteristics. These elements help to evaluate the difference between a reference dataset and an extracted one. This study emphasized on the first three elements.

One way to estimate the qualities of line features quantitatively, according to (Heipke, Mayer, Wiedemann, 1997; Tveite, 1999) is buffer overlay method. Tveite (1999) used the method to determine the completeness and average displacement of a line feature. It is used to estimate the qualities of a dataset of unknown quality relative to a reference data of known quality. The method works by forming buffers of a certain width along a data of unknown quality and its reference.

In the context of this study, TP refers to the length of extracted boundaries/reference boundaries that lie within the buffer, FP refers to unmatched reference boundaries, and FN refers to the length of unmatched extracted boundaries. Matched extracted data and matched reference data based on buffer analysis are described by the figure below. The matched extraction refers to the part of the extracted boundaries that lie within the buffer



a) Matched extraction b) Matched reference

Source: (Heipke, Mayer, Wiedemann, 1997)

Figure 4-Buffer based matched reference and matched extracted data

In the field of feature extraction, it is common to see measures of agreement between reference and extracted data based on correctness, completeness, and quality. Heipke, Mayer, and Wiedemann (1997) evaluated the effectiveness of automatic road extraction algorithms by matching the automatically extracted road networks with a manually digitized one: quality, correctness, completeness, redundancy, RMSE differences and gap statistics were used as a measure of quality in their work. As explained in the paper, the purposes of matching procedures were two-fold. On one hand, it gives parts of the extracted data that are roads. On the other hand, it shows those reference data that are explained by the extracted data. To perform the matching, a buffer was constructed with a predefined width around the reference data and around extracted data. The buffer width, in this case, was chosen to be about half of the road width. Then the decision on the match between the extracted data and the reference data is made depending on whether the extracted data (reference data) lies within the buffer of the reference data (extracted data) or not.

Jin and Davis (2005) used a similar approach to evaluate the performance of the watershed segmentation method in extracting buildings automatically from IKONOS HRSI. By considering manually extracted buildings as reference data they computed the branching factor (FP/TP), miss factor (FN/TP) and detection percentage (100*TP)/ (TP+FP) and quality percentage. According to (Jin & Davis, 2005) detection percentage refers to the percentage of pixels correctly extracted by the algorithm. The branching factor and the miss factor respectively refer to the commission error and the omission error. For instance, in the context of this study, if non-boundary pixels (like a pixel in the middle of a parcel) are incorrectly labeled as boundary pixels it infers an error of commission. Whereas error of omission means the reverse situation has occurred.

2.6. Conclusion

From previous works, satellite images are found to be important for cadastral boundary mapping purposes and proved to be cost effective. Many of the works done so far rely on manual way of extracting information from imageries. They were used for cadastral map updating purposes but much work has not been done on automatic feature extraction from satellite images for cadastral boundary mapping. Automatic boundary extraction from satellite imagery was tested for the purpose of extracting road network extraction, and river boundary delineation. Studies on automatic extraction of cadastral parcel boundaries are few and assessments of these results depend only on visual interpretation. Whereas those studies on automatic road and building extraction, used percentages of completeness, correctness, and quality as accuracy assessment measure.

3. METHODS AND DATA COLLECTION

3.1. Introduction

This chapter discusses the approach followed and the data used (where and how) to address questions of the research. Study area selection and justification is described first. Descriptions of data collection and preparation processes follow, then the procedure to select the appropriate method/algorithm is provided, and finally the assessment approaches for validation and the concluding remarks follow.

3.2. Study area

Ethiopia has nine administrative regions with two charter cities. The Amhara region is the second largest region in Ethiopia covering about 11% of the total area (Adenew & Abdi, 2005). The region constitutes 10 administrative zones, 9 urban and 106 rural woredas, with 2,927 rural kebeles[2]. In the same article, the authors also indicated that about 90% of the people live in the rural areas. Over the past two decades, rural land registration and certification is being conducted focusing on five of the nine regions. Amhara region is one of the nine administrative regions in Ethiopia where a relatively cheap first phase of land certification has been undertaken successfully.

As a continuation of the first phase, the second phase, focussing more on spatial mapping of parcels, is being conducted using orthophoto, total station, and GPS. The wide coverage of rural areas in the region together with other capacity related factors motivates the author of this study to see the impact of automated cadastral boundary mapping from satellite imagery. Due to the availability of high-resolution satellite images and digital parcel boundaries in Angot Yedegera kebele, this case area was chosen as an appropriate test area – however, other areas having such data available, and with similar cadastral mapping challenges, would be equally appropriate. Angot Yedegera covers an approximate area of 42 sq.km and is located 350km north of Addis Ababa and around 200km south of Bahir Dar.

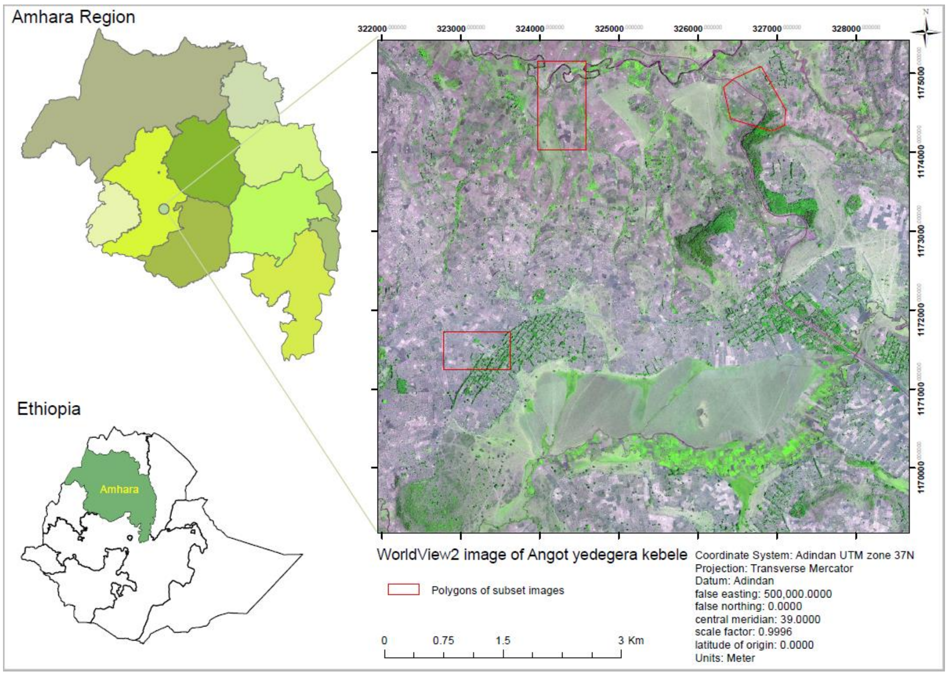


Figure 5-Study area

[2] Kebele is the lowest administrative unit next to woreda

3.3. Data collection activities

To achieve objectives of the study interview data (from key informants) and spatial data (from BoEPLAUA) were collected during field work.

3.3.1. Interviews

To gain background context on the area where the automatic feature extraction processes were to be applied – including understanding the existing cadastral boundary mapping practices, methods used, challenges on the existing approach, and the nature of parcel boundaries in the study area and future directions, semi-structured interview (Appendix 7) with key informants was conducted. This activity would also specifically support achieving the sub-objective 3. A total of nine individuals were interviewed from:

- Bureau of Environmental Protection, Land Administration and Use, Amhara Region (BoEPLAU), one individual;
- National Rural Land Administration and Use Directorate (NLAUD), one individual;
- Responsible and Innovative Land Administration (REILA) project, three individuals;
- Land Investment For Transformation (LIFT) project, two individuals and
- Land Administration Institute, Bahir Dar University, two individuals.

These individuals were selected based on their experience in cadastral boundary mapping projects and their availability.

3.3.2. Spatial data

Both raster and vector data were collected to achieve sub-objective 2 of the study. The raster image, which was later used as input for the automatic extraction, was obtained from BEPLAUA, Amhara Region, Ethiopia. It was taken on 15 February 2010 from the area where the pilot study for the second land registration was conducted. It is a pan sharpened and orthorectified WorldView-2 HRSI with 0.5 m resolution. For the same area parcel boundaries produced from March to June 2013 were received to use them for the purpose of validating extracted results. But, due to lack of vector data corresponding to river and road features, the researcher produced them manually by on-screen digitization. These parcel boundaries were produced from a field map at a scale of 1:2,000.

3.3.3. Spatial data preparation

To make a deep analysis of the existing boundary cases in the rural areas, three subset images that involve boundaries of different features were chosen (Figure 6, 7 & 8). The choice was made systematically so that images would reflect different boundary types in the rural areas. The images were intended to provide information regarding the effectiveness of the application to extract boundaries of different cadastral features. This includes boundaries of parcels, river streams, roads and footpaths. The effect of trees and forests on/near to cadastral boundaries were also considered. The reference boundaries were chosen correspondingly from digital parcel boundaries obtained from BoEPLAUA and from those digitized on screen. Below is a description of subset images with their reference vector data superimposed.

Subset image 1

This subset image (Figure 6) is of area 2212x1004 pixels and mainly contains parcels and river stream. It is intended to see the capability of the mean-shift based segmentation application to extract boundaries of these features. Bushes are also considered here to see their effect on the algorithm.

Figure 6-Subset image1

Subset image 2

Parcels, forest area and road (asphalt) are features considered in this subset image (Figure 7). It covers area of 1516x1565 pixels. This image is mainly included to see how well the intended approach extracts road boundaries and boundaries of forests.

Figure 7-Subset image2

Subset image 3

In this case footpaths and parcels whose boundaries are surrounded by trees (having an approximate height of >1m and approximate crown diameter of >1m) are included. The image contains 849x1326 pixels. Parcels in a relatively open area that have no color difference or visible boundary between them are also part of this subset (Figure 8).

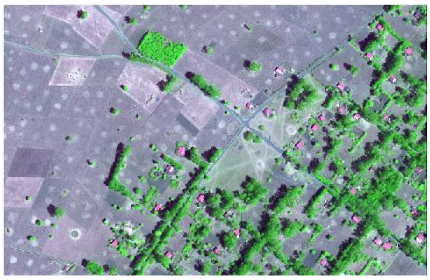


Figure 8-Subset image3

In general, by considering these subset images the capabilities of the mean-shift based segmentation application to extract parcel boundaries under different situations was analysed. These images also provided information to analyse the influence of shadows and colour similarity/difference between neighbouring parcels in extracting cadastral boundaries. Since reference boundaries obtained from BoEPLAUA do not include reference boundaries for the river boundaries in subset image1 and road boundaries in subset image 2- the quantitative assessments for these cases were made separately from the assessment of parcel boundaries.

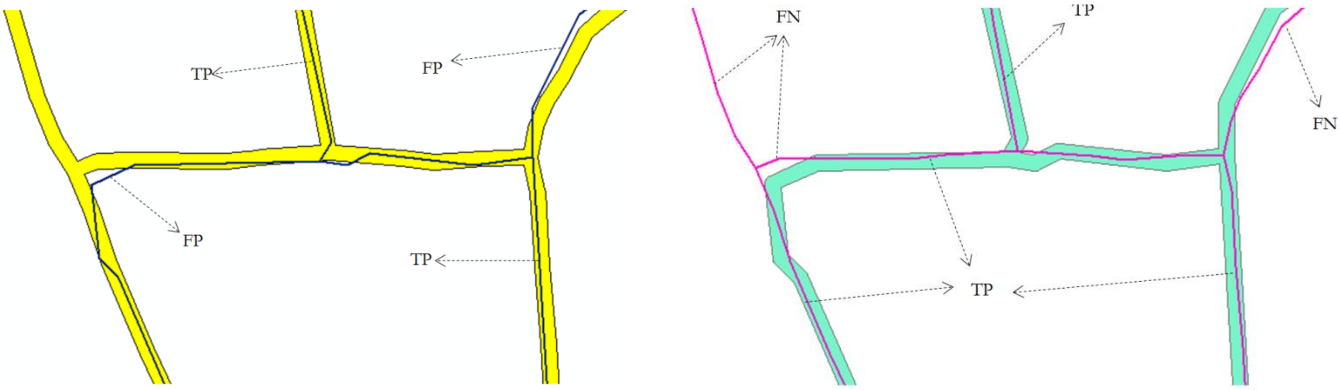
3.4. Process for selecting algorithms

For selecting the appropriate algorithm, information from literature review and experimental results were used. From literature, the Sobel operator, LSD, Hough transform, Canny edge detection, and mean-shift algorithms were found to be among the potential candidates for boundary extraction. By considering previous results of these algorithms, for example, the work of (Katiyar & Arun, 2014) and (Gandhi et al., 2014), canny edge detection, mean shift segmentation algorithms, and LSD were selected for further experimentation. Accessibility of software for implementation, and simplicity of steps involved (to get final output with cadastral boundary requirements) were also taken into consideration to select these algorithms. Then necessary preparation on input image and software for experiment was made. A subset image (Figure 11-a) of size 730x656 pixels was taken from subset image1. Correspondingly, the reference data was taken from the vector file. While the canny edge detection was implemented on Matlab software, QGIS used for both Mean-shift algorithms based segmentation and LSD. These software/applications were chosen based on their availability. The optimal parameter values are adjusted by trial and error. The appropriate algorithm among the three was chosen by taking in consideration observation of experimental results (Figure 11-b, c & d) generated from the testing image and based on the quality of extraction.

3.5. Assessment approaches

The buffer overlay method is a method used to assess the qualities of extracted boundaries. By overlaying the extracted boundaries on the buffer around the reference boundaries, the length of extracted boundaries that are also true boundaries (TP), and the length of extracted boundaries but not in the reference boundaries (FP), are calculated automatically. Similarly, by overlaying the reference boundaries over the buffer along the extracted boundaries, the length of truly detected boundaries that matched with the buffer (TP) and the length of boundaries in the reference data that are not detected by the algorithm (FN), are calculated.

In (Figure 9) below TP, FP and FN are described in more visual way.



a) Extracted boundary overlaid on buffer around the reference data

b) Reference boundary overlaid on buffer around the extracted data

Figure 9-Discription of TP, FP and FN

The workflow used in calculating the TP, FP and FN is described as follow. To calculate TP and FP, the extracted polygon boundaries are converted into line features. Then, by using the spatial analysis tool in QGIS, the line features are overlaid on the buffer along the reference data to get sum of lengths of the line segments that lie within the buffer and those which did not. In a similar way, to determine the value of TP and FN, the reference polygons were converted into line features and the length of those which lie within the buffer around the extracted polygons were measured. The detail procedures used to calculate the value of TP, FP and FN are presented in (Figure 10) below.

The process starts at the left top and right bottom corners as shown by the arrows. Following steps indicated by the blue colored arrows yield the values of TP and FN which are latter used to calculate completeness. Similarly, following steps indicated by the gray colored arrows yield the values of TP and FP which again helps to determine correctness. The output results TP, FP and FP are calculated based on the lengths of matched and unmatched reference (extracted) boundaries obtained from the overlay.

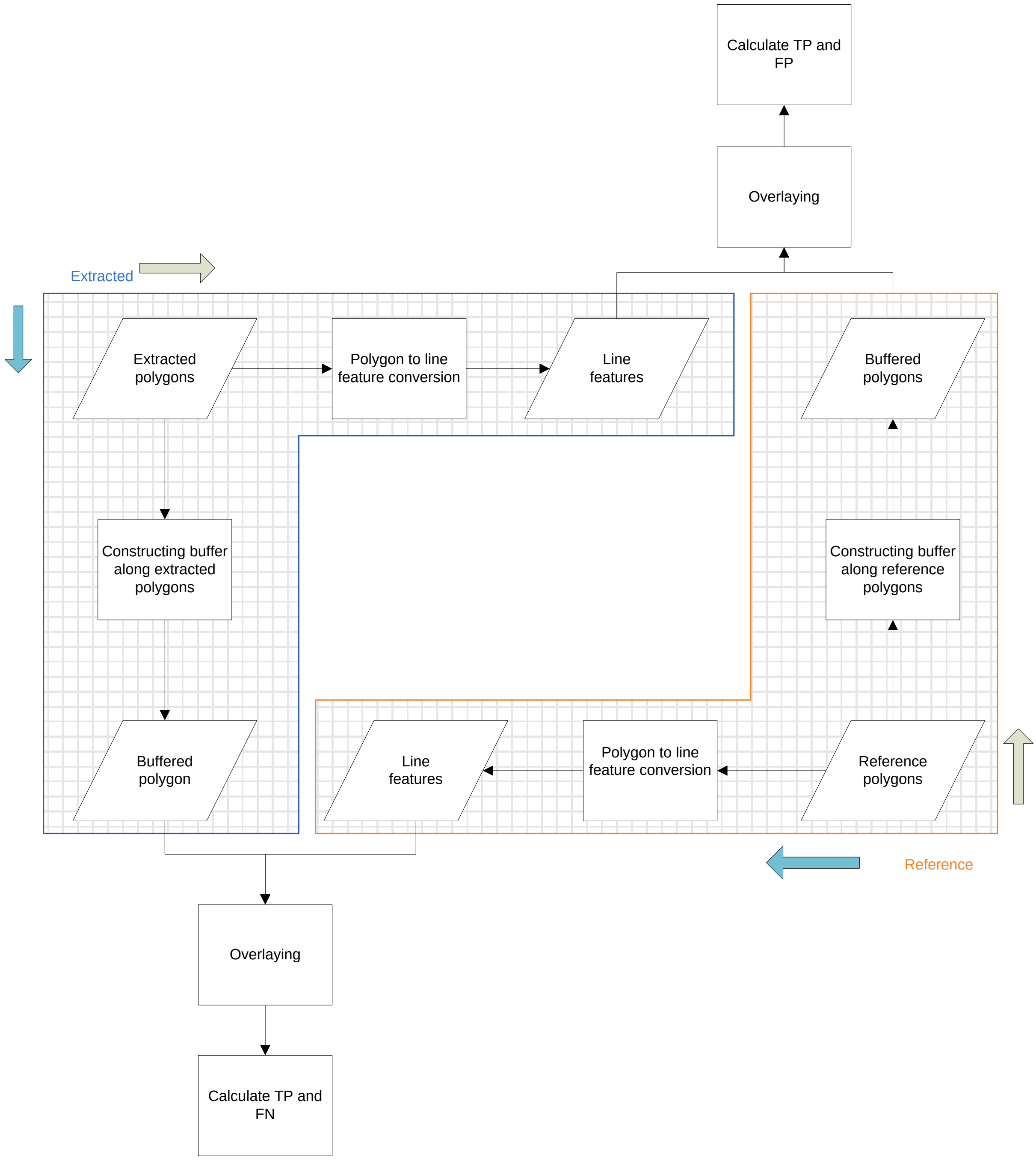


Figure 10-Workflow for calculating TP, FP and FN

In this study, the qualities of extracted boundaries were assessed based on quality measure elements: completeness, correctness and topological consistency discussed in section 2.5. The percentages of completeness, correctness and quality are described and calculated in the following way. The formulas are adapted from the work of (Heipke, Mayer, Wiedemann, 1997) used for automatic road extraction purposes.

- Percentage of completeness is the percentage of the reference boundaries that overlaps with the buffer constructed around the extracted boundaries.

- Percentage of correctness is the percentage of the extracted boundaries that overlaps with the buffer constructed around the reference boundaries.
- Percentage of quality is expressed based on correctness and completeness and it measures the overall goodness of the extraction.

For the sake of convenience, here after the percentages of completeness, percentages of correctness and percentages of quality are respectively written as completeness, correctness and quality.

These can also be described as:

$$Completeness = \frac{length\ of\ the\ matched\ reference}{length\ of\ the\ reference} * 100\% \approx \frac{TP}{TP+FN} * 100\% \quad \text{.........................(1)}$$

$$Correctness = \frac{length\ of\ matched\ extraction}{length\ of\ extraction} * 100\% \quad \approx \frac{TP}{TP+FP} * 100\% \quad \text{....................................(2)}$$

$$Quality = \frac{length\ of\ matched\ extraction}{length\ of\ extracted\ data + length\ of\ unmatched\ reference} * 100\%$$

$$\approx \frac{TP}{TP+FP+FN} * 100\% \quad \text{..(3)}$$

Using the formulas (1, 2 and 3) above, the percentage of completeness, the percentage of correctness and percentages of quality of the extracted boundaries are calculated. This is done by overlaying the extracted boundaries (reference data) over the buffer zone of the reference data (extracted boundaries) respectively.

3.6. Conclusion

The approaches to achieve the objectives of the study are discussed in this chapter. Preparations of required spatial and non-spatial data together with software for analysing results were presented. It is important to see the capabilities of the automatic feature extraction method for different features. As a result, subset images were selected so that they will reflect different cadastral features in rural area. To assess the accuracy of extraction, a reference data which is a cadastral boundary obtained from BoEPLAUA was used as a reference. To analyse results quantitatively buffer overlay methods was used. A workflow to calculate length of matched and unmatched extracted boundaries and reference boundaries was also discussed. In addition to the quantitative results, understanding the nature of boundaries and existing registration process and method in the rural areas is important. Interviews with key informants were used as a means to collect such information and descriptive analysis was used to analyze the result of these interviews.

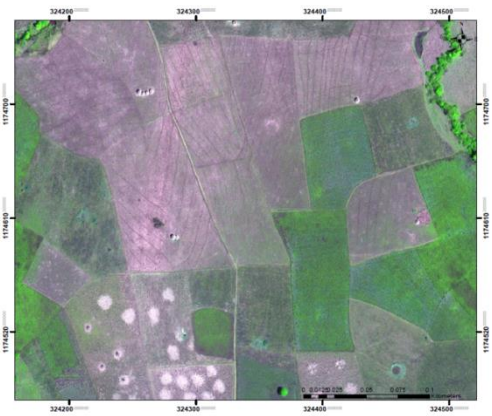
4. RESULTS AND DISCUSSION

4.1. Introduction

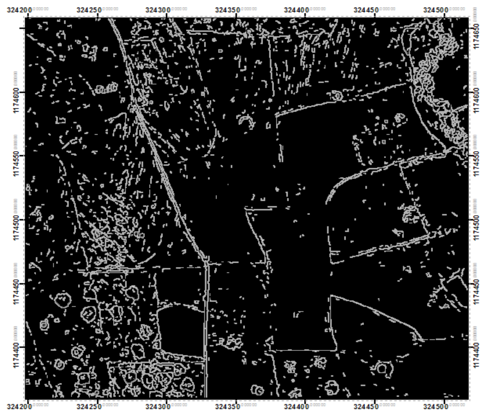
In this chapter, comparative assessment of boundary extraction resulted from the Canny edge detection method, LSD and mean-shift segmentation are presented. This, leads to the choice of the most appropriate algorithm (among the three) for cadastral boundary extraction. Then, a workflow to implement the selected algorithm (mean-shift segmentation) is developed. Latter, automatic mean-shift based segmentation results of the subset images (section 3.3.3) are presented. The results are then assessed both qualitatively and quantitatively. The boundaries of parcels, water bodies, roads - including footpaths - and the effects of shadow due to vegetation are among the foci of the discussion. The contribution of the mean-shift segmentation is also elaborated.

4.2. Comparison of algorithms

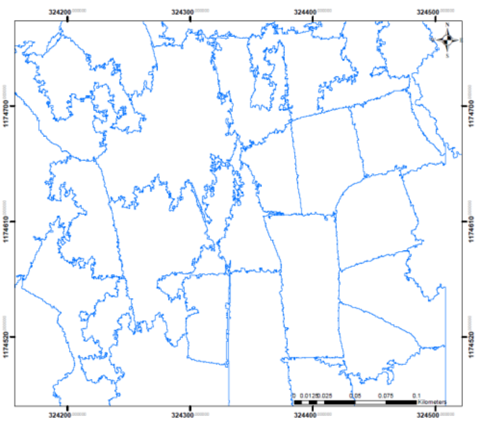
The algorithms were compared by implementing the candidate algorithms/methods on the subset image (Figure 11-a). While the canny edge detector was implemented in MATLAB (Appendix 6-for the code used), both mean-shift segmentation and LSD were implemented in QGIS. For this purpose the subset image was used as an input. Following the results (Figure 11-b, c & d) observation of the methods employed summarized and quality of extraction was also analyzed quantitatively.



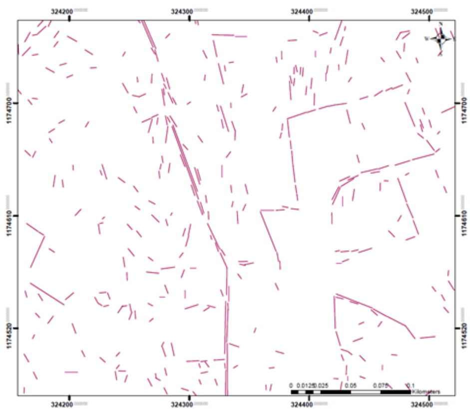
a) Testing image



b) Result by canny edge detector



c) Result by Mean-shift segmentation



d) Result by LSD

Figure 11-Expermental results from a WorldView 2 subset image taken from Angot yedegera kebele, Ethiopia

Based on cadastral boundary requirements the following brief summary of observations are made. Note also that these observations are drawn based only on the above experimental results.

Method	Observation		Remark
Canny edge detection	Pros	• Detect line segments depending on the brightness difference • Faster processing time (it took <1 minutes to process the image)	• With additional steps, it is possible to convert the raster file to vector file. Morphological operators can also be used to close some gaps though it is still difficult to close all polygons.
	Cons	• Captures stripes that result from ploughing as boundaries • Fails to extract curved boundaries • Coordinate transformation required • The format of the output file is not a vector file which needs further processing (even impossible for some cases) to get closed polygons as boundaries.	
Mean-shift segmentation	Pros	• The format of the output file is a polygon feature which agrees with the required final output/reference data. • The output file is in the same reference coordinate system as the input image. • The polygons are closed and there is no overlap between them	• These are ready made products in line with the cadastral parcel boundary requirements. The wiggling effects on the boundaries can be smoothed further.
	Cons	• Relatively took longer time to process (3 minutes to process). • Boundaries showed wiggling nature due to pixels and many nodes produced along the boundaries.	
LSD	Pros	• Detect straight line segments	• Further steps should be employed to close already traced boundaries.
	Cons	• Highly influenced by stripes due to ploughing • Not possible to extract curved boundaries	

Table 2-Comparison of methods based on experimental results

In addition, the results were also analyzed quantitatively by using the same reference data. An overall quality of 19.47%, 22.40%, and 14.25% obtained respectively from the results of canny detector, mean-shift segmentation, and LSD algorithms.

Accordingly, the result of the mean-shift segmentation application is found to be applicable and hence chosen for this study. It is then applied to extract boundaries of parcels from the subset images. It is implemented directly by using the Orfeo image analysis toolbox plugin from the QGIS software. By applying the application in a vector mode, a closed polygon is found as an output vector file. Images of large size can also be processed piece-wisely without overloading the memory. Moreover, simplify geometry option and stitch option respectively allowed to remove nodes in a polygon and to stitch polygons together. The detailed workflow used to extract the boundaries using mean-shift segmentation is presented in the following section.

4.3. Developing the workflow for extraction

Boundaries of cadastral features of the input image are obtained by using the mean-shift segmentation plugin from OTB-5.2. The detail description of the method used for processing the extraction of boundaries is summarized as follow (Figure 12).

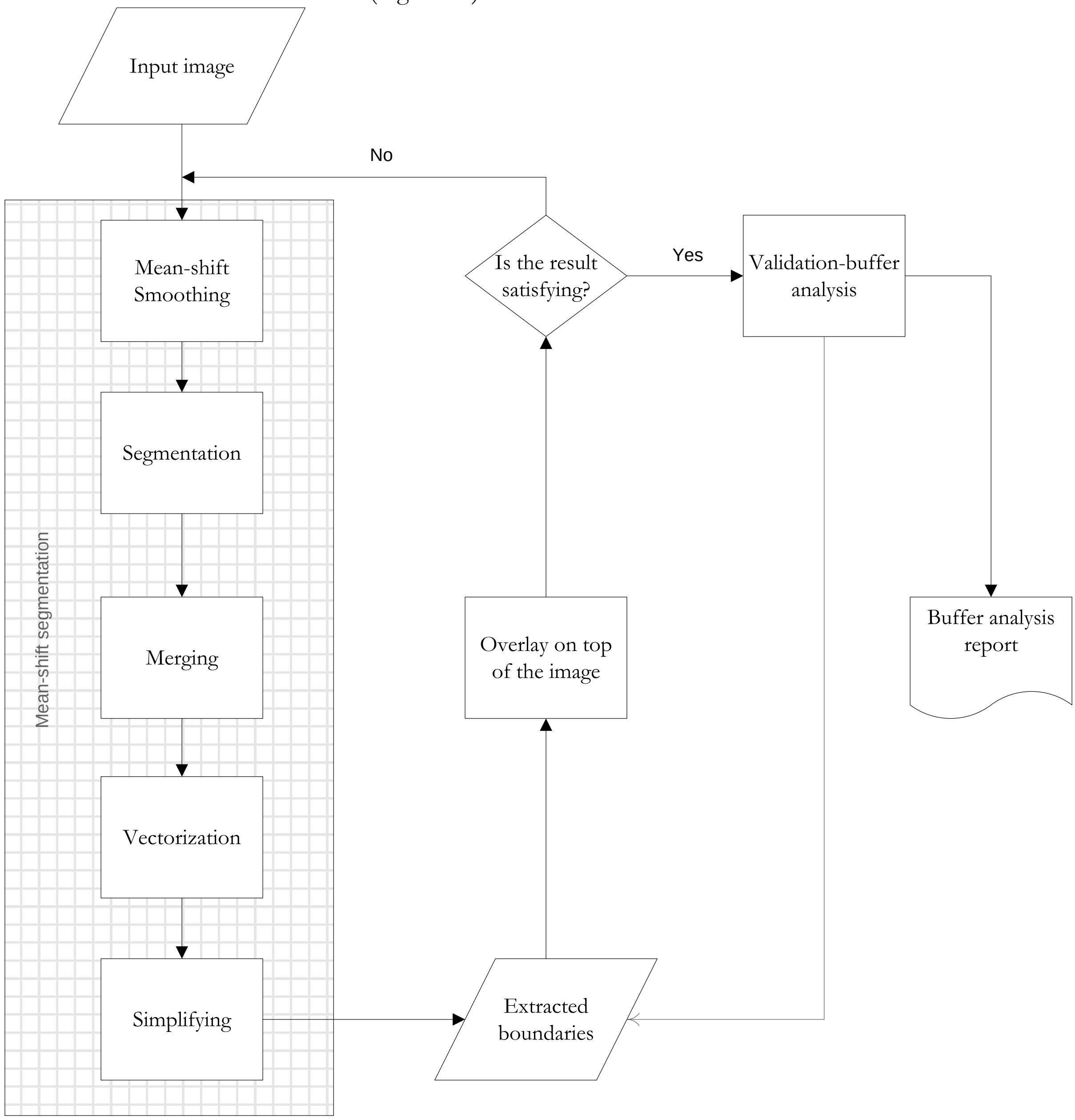


Figure 12-Workflow to extract cadastral boundaries automatically from HRSI

(adapted from (OTB, 2014))

The input image is an orthorectified and pan-sharpened World View-2 image of resolution 0.5m. Based on the radiometric and spatial information of the image, noise filtering is accomplished. It is discontinuity preserving smoothing (Liu, Duan, Shao, & Zhang, 2007). Next adjacent pixels of the smoothed image, whose range distance is below the range parameter, and whose spatial distance is below the spatial parameter, are grouped together. It is done tile-wise. This piecewise nature makes the algorithm an appropriate tool even for images of large size. Then, the segments whose size in pixels is below the minimum region size parameter are deleted (labeled as zero). In addition, segments which are not of the users' interest could also be merged with the adjacent region based on their radiometry values. This is controlled by the minimum object size parameter. In the final step of the processing, by the simplifying tool that depends on some tolerance, the segmented image is changed into a relatively smoothed vector file.

The extracted cadastral boundaries were then overlaid on top of the input image. At this stage, decisions based on the agreement between the extracted boundaries and possible cadastral boundaries from the image were made. The discontinuity in color and intensity of cadastral features in the image were guiding information for this decision. When a satisfactory amount of extracted boundaries looked to agree with the reference cadastral boundaries, the extracted boundaries passed to the next step. Though this step is up to the operator, still algorithms delineate boundaries better than doing it by hand (due to visual subjectivity and susceptibility to an error during manual digitization). Otherwise, the segmentation process is repeated by readjusting the parameters based on results obtained previously. Finally for the validation of results, multi-ring buffers are constructed around the polygons of the reference boundaries and the extracted boundaries.

4.4. Automatically extracted provisional cadastral boundaries

The results obtained by applying the mean-shift algorithm based segmentation are presented below. The algorithm clusters regions based on their color values. In addition, the segmentation parameters, region size and object size, contributed a lot in determining exact boundaries. The values of these parameters are thresholds for those segments that should be ignored or merged with the neighboring segments. When these parameters took lower values, over-segmentation arises. This leads to clustering of haystacks, houses, and tree crowns separately. On the other hand, under-segmentation arose when the values of these parameters are taken too large. Since the focus of this study is to extract possible cadastral boundaries, an effort has been made to get a better result by considering calculated area information of parcels from the reference data.

Figure 13 shows the reference and/or extracted boundaries overlaid on the subset image1. The area considered in this image were characterized by different cadastral features like water bodies, bushes, and parcels covered by bare soil and grasses. The reference shapefile, in this case, contains 53 parcels. The extracted boundaries are obtained by setting region size parameter to 6000 pixels and object size parameter 600 pixels. Spatial radius parameter and range radius parameter are assigned by trial and error and yields a reasonable result. The algorithm set to continues iterating until mean-shift vector is below 0.1 or till the number of iteration reached the maximum value which in this case is 100 iterations.

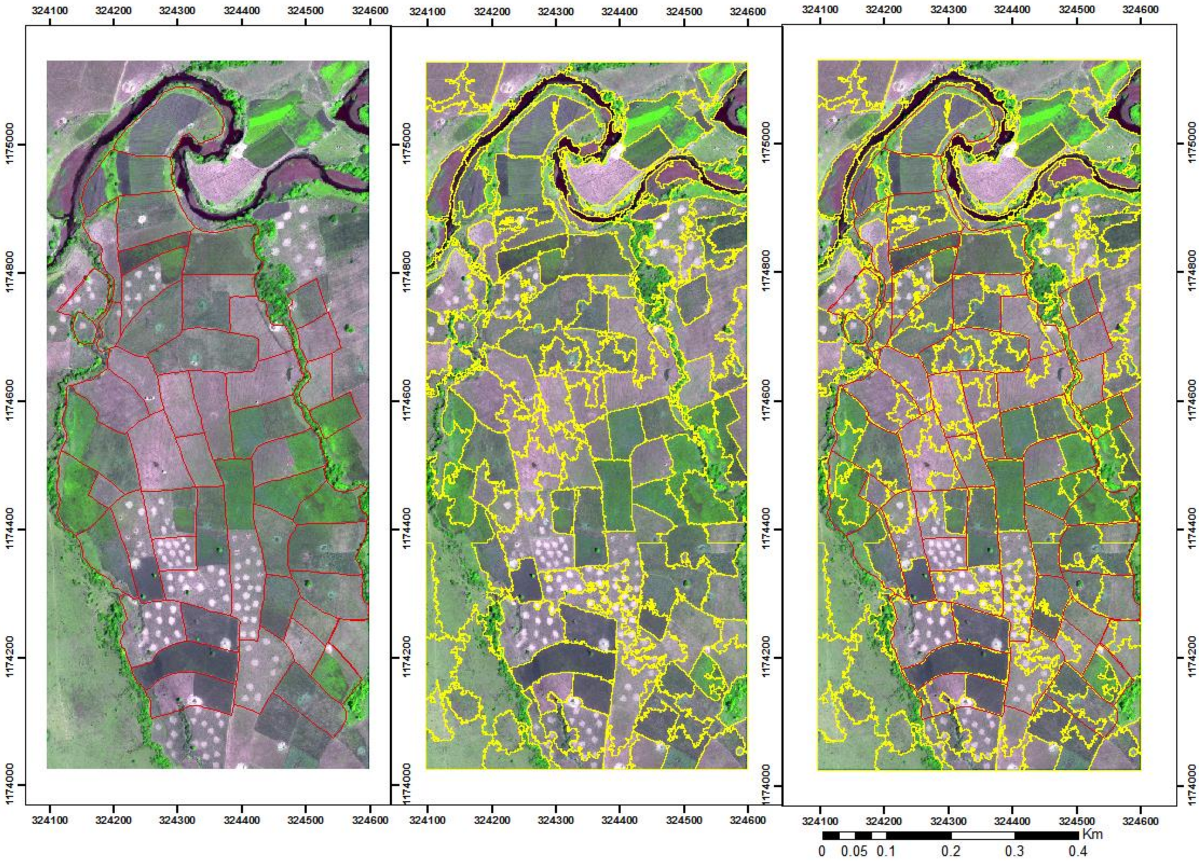


Figure 13-Reference shape file overlaid on subset image1 (left), extracted provisional boundaries overlaid on subset image1(middle) and both reference and extracted shape files overlaid on subset image1(right)

In the left side of (Figure 13), the reference parcel boundaries are overlaid on subset image1. It shows the relation between cadastral boundaries and the ground truth. Though not for all cases, the reference parcel boundaries lay between parcels that have brightness/ color difference. The land covers on the left and right sides of the boundaries in many cases are different in color. On the other hand, parcels containing two different plots between where there is a color difference are also found in the image. For particular cases, refer (Figure 14).

The middle map of (Figure 13) indicates the extracted cadastral boundaries overlaid on the subset image as in the map on the left. When there is a color/ brightness difference between parcels/features, it is highly possible to find a boundary between them. The segments formed in this case are polygons. They are non-overlapping and there is no gap between them. This agreed with the parcel polygon requirements outlined by the (IAAO, 2015). But many nodes due to brightness and/or color difference along pixels and the effect of heystack and bushes on the boundary are also observed here.

In the third case, the map on the right side (Figure 13), both the reference and extracted boundaries are overlaid on subset image1. This image provided more information about the capability of the algorithm to extract cadastral boundaries. Some cadastral boundaries almost perfectly overlapped with the extracted boundaries.

When the color of the land covers near the boundaries is different, the extracted boundaries matched with reference boundaries (Figure 14) (arrow 1). The result also depicted the power of the segmentation to identify boundaries even when land covers near the boundaries of neighbouring parcels looks similar (visually) in color (Figure 14)(arrow 2). As the reference boundaries are ownership based while extracted boundaries are not, the extracted boundaries did not always match with the reference boundaries. The result also assured that the existence of brightness/color difference does not necessarily imply there is a parcel boundary as the boundary indicated by (arrow 3) in (Figure 14) shows. Extracted boundaries of type indicated by (arrow3) are examples of commission errors. The quantitative analysis of such results is presented in section 4.5.

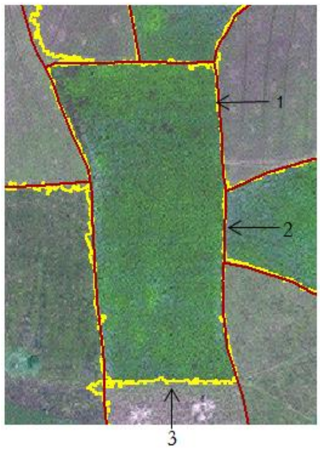


Figure 14-Reference and extracted boundaries overlaid together

When there is a clear color/intensity difference between parcels/features the algorithm delineates a boundary between them. Specifically, this worked well in delineating river (Figure 15) and road (Figure 16) features boundaries. In the following figures, the yellow lines refer the extracted boundaries and the dark umber color lines refer parcel boundaries.

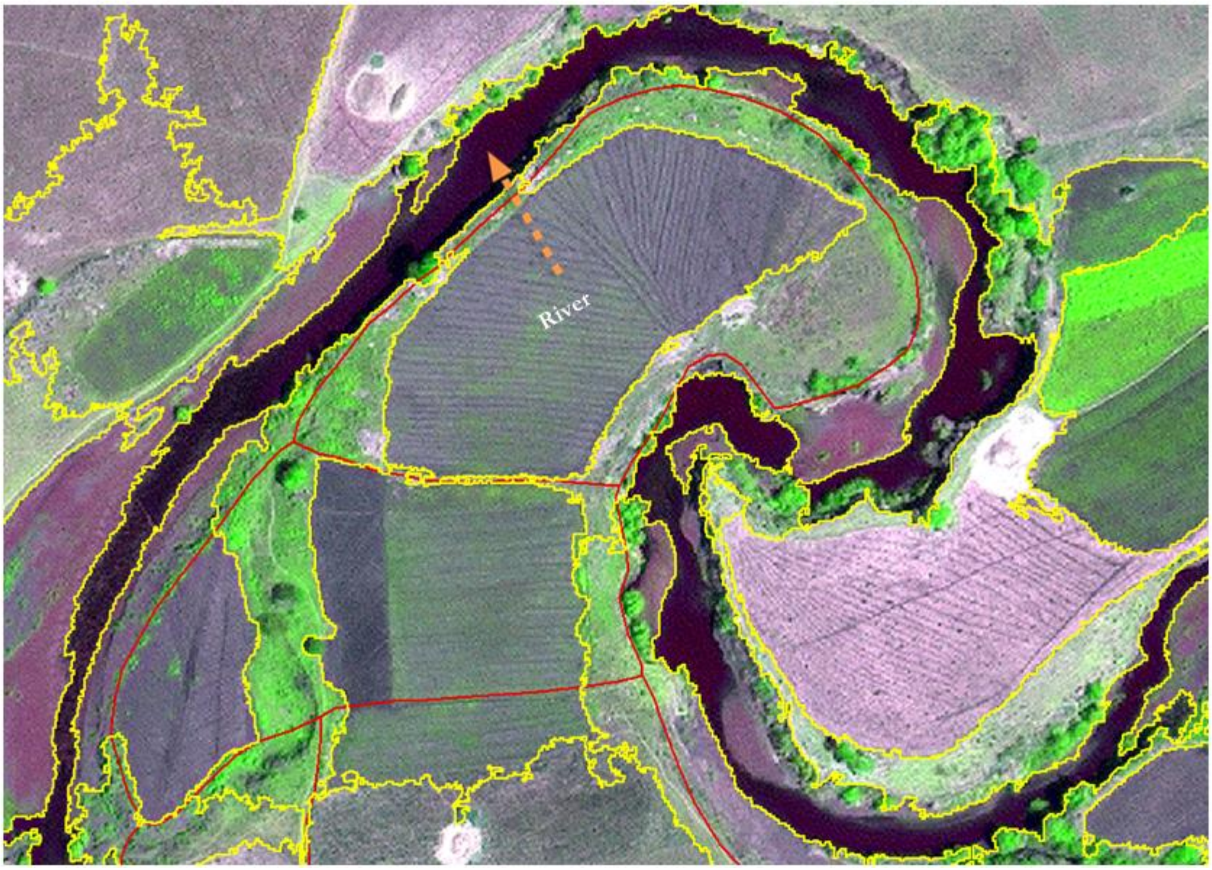


Figure 15-Extracted boundaries overlaid on magnified portion of the image around a river feature

Referring to (Figure 16), the boundaries of the road feature are extracted almost perfectly. On the other hand, a gap that approximately ranges from 5m-6m observed between the extracted road boundary and the reference parcel boundaries near roads. This is not surprising: it is common to leave such a gap purposely by the responsible bodies. To see the actual gap on the ground between the road and the parcel boundaries please refer Appendix 12(e).

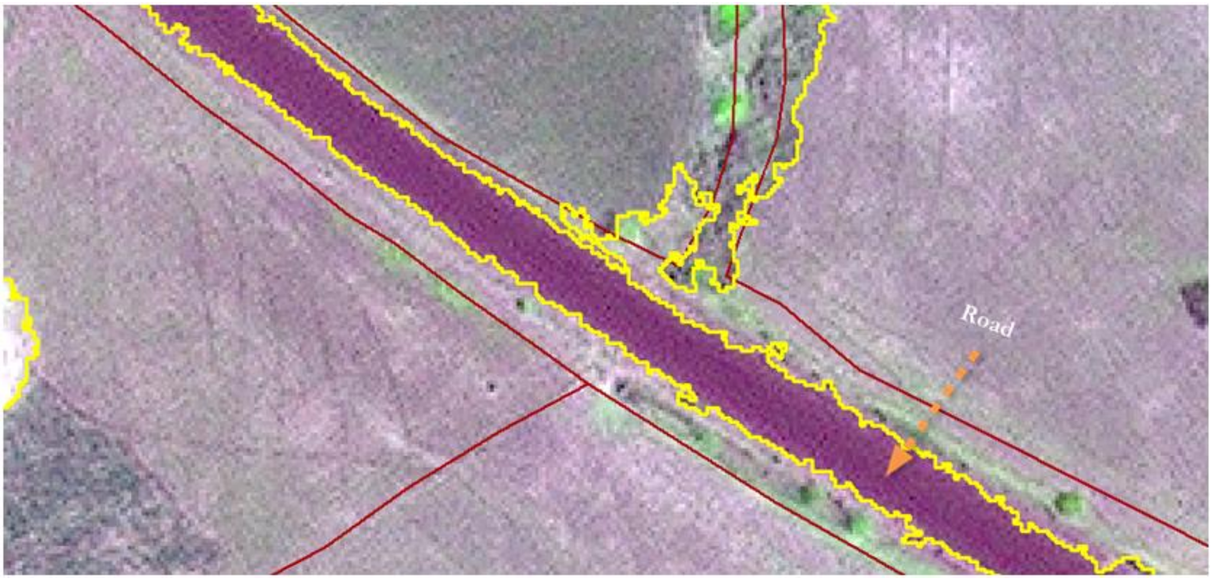


Figure 16-Extracted boundaries overlaid on magnified portion of the image around a road feature

From the result it was also found that trees and/or vegetated areas have numerous effects on the algorithm. Unwanted boundaries due to the effect of shadow observed. In some cases, though the true boundary lies inside the vegetated area, the algorithm delineates the boundaries around the shadow. Due to the color similarity with the neighbouring parcels (particularly in this image), only small part of the footpath is extracted well (top right corner of Figure 17). Figure 17 clearly depicts the effect.

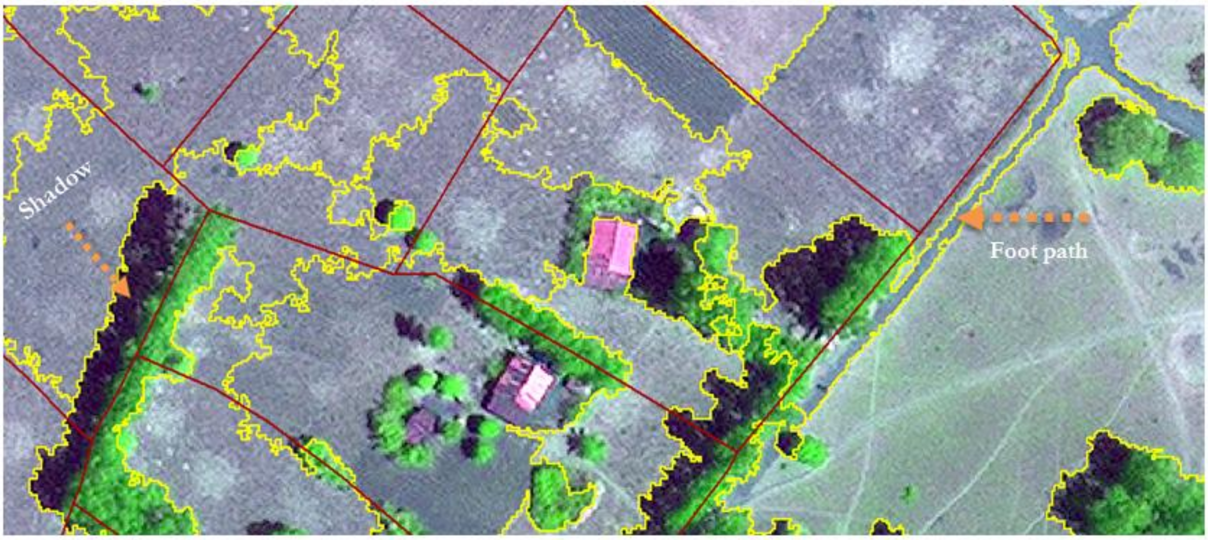


Figure 17- The effect of shadow in automatically extracting parcel boundaries

Unlike the work of (Solomon, 2005) and (Babawuro & Beiji, 2012), the qualities of extracted boundaries are assessed both qualitatively and quantitatively. Both studies described results based only on visual comparisons but in this study, in addition to visual interpretations the conclusions are drawn quantitatively based on buffer analysis. By the mean-shift segmentation, the boundaries of some parcels matched even with legal parcel boundaries (for instance with in a buffer of width 2m). Whereas (Solomon, 2005) based on the visual comparisons with the reference boundaries concluded as none of the parcels matched with legal parcels. Though the studies implemented in different areas, the approach followed and the nature of boundaries obtained in both studies were similar to some extent. For instance, boundaries found in both cases are vector files ready to be processed in a GIS environment, however, the effect of shadow on the extraction are still found to be there as per the work of (Horkaew et al., 2015).

The results could be improved when there is a color/intensity difference between parcels around the boundaries and/or when the area is flat and free from vegetation (or when the trees are dispersed and less in number). To justify this idea, a QuickBird image (0.5m resolution) from Meshenti, Amhara region was tested (Appendix 11). Its being free from vegetation makes it different than previous subset images. At least, it minimizes the effect of shadows.

4.5. Validation

For validating the extracted boundaries, both visual interpretations and quantitative assessments were used. Completeness and correctness were described quantitatively, whereas, topological consistency and the cases like effects of shadow due to vegetation and that of footpaths, were explained based on visual interpretation. The extracted parcel boundaries were assessed against the reference cadastral boundaries obtained from BoEPLAUA.

Calculated values of TP, FP, and FN (together with Equation 1, 2 and 3 in section 3.5) were used to determine the data quality measures: completeness, correctness and quality[3] of the extracted boundaries quantitatively. The buffer widths considered in this study are 0.5m, 1m, and 2m, all of which are within the limit of 2.4m: the sufficient accuracy level for rural boundaries according to (IAAO, 2015). That means, for each buffer width, boundaries are assumed to be matched when they lie within or on 0.5m, 1m and 2m distance from the axis of the buffer formed.

For the analysis, buffer widths of 0.5m, 1m and 2m were considered. These buffer widths are considered to give an overview of effects of the buffer width on the extracted results. Moreover, this is in line with the acceptable rural boundary accuracy suggested by the (IAAO, 2015). The results obtained from the extraction are summarized and presented as follow.

	Length of reference boundaries in meter		
Buffer width	Matched(TP)	Unmatched(FN)	Total length in meter
0.5m	9877.65	7955.97	17833.62
1m	12744.44	5089.17	17833.61
2m	14757.62	3076	17833.62

Table 3-Lengths of matched and unmatched reference boundaries

[3] The quality in this case is as defined in section 3.5.

	Length of extracted boundaries in meter		
Buffer width	Matched(TP)	Unmatched(FN)	Total length in meter
0.5m	11746.35	60504.74	72251.09
1m	17842.2	54408.89	72251.09
2m	24774.42	47476.67	72251.09

Table 4-Lengths of matched and unmatched extracted boundaries

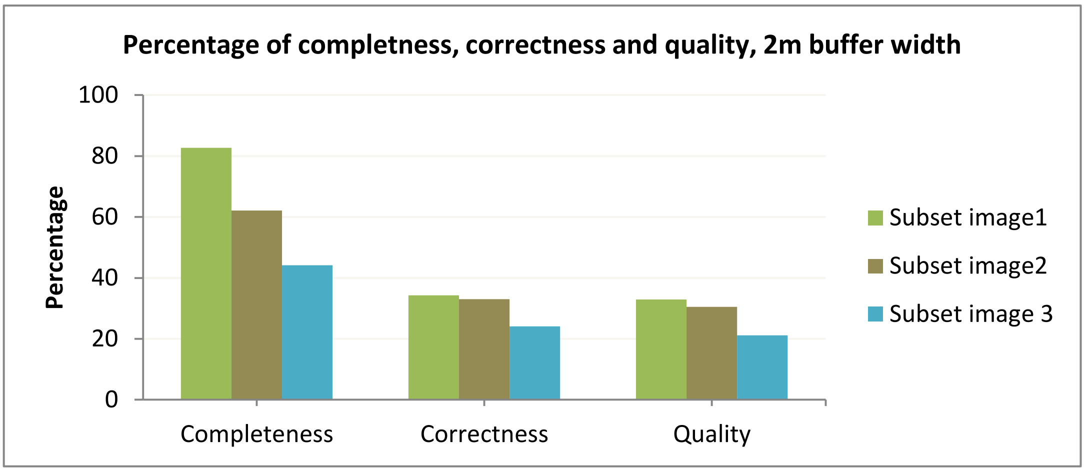
The results from Tables 3 and Table 4 above indicated that the buffer width is directly related to the length of matched boundaries and inversely to the length of unmatched boundaries. Likewise, in Table 5 below the completeness, correctness and quality of the extracted data increases as the buffer width goes from 0.5m to 2m.

Buffer width	Completeness	Correctness	Quality
0.5m	55.39	16.26	14.65
1m	71.46	24.69	23.07
2m	82.75	34.29	32.89

Table 5-Percentages of completeness, correctness, and quality of parcel boundaries

As the buffer width increases, the length of unmatched boundaries will decrease as more boundaries are going to be incorporated with in the buffer. This, on the contrary, leads to the increase of values of matched boundaries and hence percentages of completeness, correctness and quality. Moreover, the more quality the less post processing work on extracted boundaries.

The graphical representation of these results is presented as follow.



Graph 1-Percentage of completeness, correctness, and quality per subset images

As depicted in Graph1 above, subset image 1 and subset image2 had closer values of correctness than completeness. It means the extracted boundaries explained the reference boundaries more in subset image

1 than subset image 2. But in both cases a randomly chosen extracted boundary to be a true boundary is almost the same. The boundaries extracted due to the brightness difference around haystack and bushes (in subset image1) and boundaries due to crowns of trees and different land covers in a parcel (in subset image2) contributed to commission errors. Mainly invisible boundaries and shadows resulting from trees caused the high rate of commission and omission errors in subset image 3 that leads to the lower values of completeness, correctness and hence quality of the extraction. In all cases the assessments are restricted to the extents of the reference boundaries and effect of clipping around the outer extent of extracted boundaries is assumed negligible.

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Moreover, the quality of extraction of boundaries of river and road was also assessed. Like the case of parcel boundaries, the completeness, correctness and qualities of extracted boundaries found to be directly proportional to the buffer width. For instance, for a buffer width of 2m, overall qualities of 45.06% and 64.51% were found respectively for the road and the river. This implies that, for the particular image considered in this study, the method is found to be more effective for extracting river boundaries than road and parcel boundaries. This happened due to the similarity in spectral reflectance value of water pixels among themselves and being different from pixels of other features around the boundaries. The percentages of completeness, correctness and quality of road boundaries and river boundaries are presented in the following tables (Table 6 and 7).

Buffer width	Completeness	Correctness	Quality
1m	41.88	28.04	21.40
2m	69.10	52.51	45.06

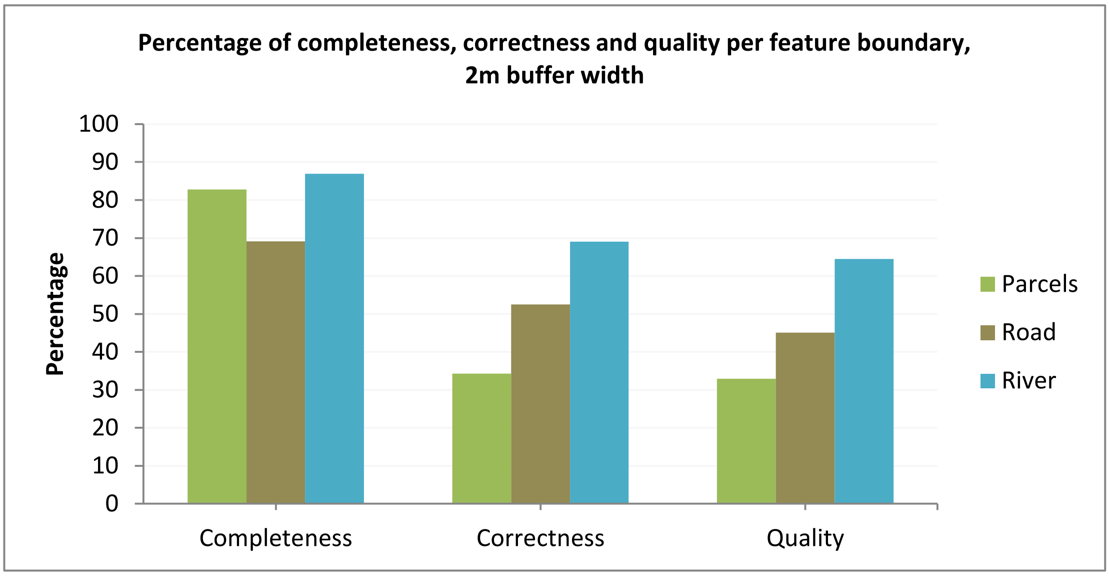
Table 6-Percentage of completeness, correctness, and quality for road boundaries

Buffer width	Completeness	Correctness	Quality
1m	72.66	50.45	44.04
2m	86.94	68.99	64.51

Table 7- Percentage of completeness, correctness, and quality for river boundaries

The results obtained here are better, though of different image, than what (Heipke, Mayer, Wiedemann, 1997) found using lines algorithm for automatic extraction of road segments. On three different test images, with a buffer width of 3m, they found a quality of 36%, 34% and 26%. On the other hand, for the same purpose with a buffer width of 4m, Kumar et al. (2014) achieved 72.36%, 87.98% and 79.90% respectively for the overall quality, completeness and correctness. Comparing the complexity of steps, the format of the output file and the buffer width considered, the result obtained by mean-shift segmentation still remain promising.

Finally to have a comparative view of qualities over cadastral feature boundaries the percentage of completeness, correctness and qualities of parcel boundaries, road boundary and river boundary put together as shown in the following figure. For this comparison results of parcel boundaries from subset image1 were used.



Graph 2- Percentage of completeness, correctness, and quality per cadastral feature boundaries

As clearly depicted in (Graph2) above, the method is found to be more effective in extracting river boundaries than road boundaries and parcel boundaries. The quality of extracted road boundaries exceeds that of parcel boundaries. It also showed that the reference data of parcels explained better than the reference data of roads. The color difference along the boundaries and effects of other features around the boundaries of these features contributes for the difference in the results. But, the effects due to the difference in production time and method for reference boundaries of the above features are considered negligible. Note also that though the order in percentage of quality still remains the same, it would have been a different result for parcels if all the parcels from the three subset images were considered.

The other important point to note is effectiveness of the algorithm was affected a lot by tree crowns and shadows around parcel boundaries. These lead to higher commission error and omission errors. As a result, the boundaries of footpaths near vegetated areas were not identified to the required extent. These results match with what (Kumar et al., 2014) identified. The authors indicated that tree lines on road segments and shadows of high buildings that fall on roads were among the factors hindering road network extraction.

Regarding topological issues, the (IAAO, 2015) described that parcel polygons in a cadastral map should neither overlap, nor should there exist a gap between them. Responding to this, automatically extracted results from this study showed that; parcel polygons are closed, there was no gap between parcel polygons, there was no overshoots/ undershoots and the output file is a vector file. These characteristics suggest close alignment with such cadastral boundaries requirements. It is possible to edit the boundaries and to insert attribute information, too. In the study such issues were checked visually and validated by using QGIS topology checker tool by configuring the topological rules. The report results to no gaps and overlaps between parcel polygons in the extracted boundaries. In addition, the average distance of extracted line segments from the reference boundaries, which is the relative positional accuracy, is less than the buffer width.

In practice, by the existing approach, for instance in Ethiopia, a digitizer can digitize around 40 parcels/day. That means on average for a digitizer it took around 20 minutes to digitize one parcel manually. And it took around 3 months to digitize one kebele [4] by four digitizers (Personal

[4] On average, around 6000 parcels found in a kebele (Personal communication, October 14, 2015) in Amhara region.

communication, interview, 14 October 2015). On the other hand, by applying the mean-shift segmentation application on the subset image (of size 2012 pixels by 1024 pixels) on average, it took 20 minutes to extract around 50 parcels. Actually, the amount of commission and omission errors affects the post processing time. This means, by extracting 32%, of total parcels it will be possible to extract around 384 parcels per day. By considering other factors in mind it is possible to minimize the amount of digitization time that took in the existing practice at least by one-third. The ideal benefit of this approach will be achieved when each parcel has different color/brightness around the boundaries from its neighboring parcels.

As far as the knowledge of the author of this study is concerned, this is the first study that applied the mean-shift segmentation approach for cadastral parcel boundary extraction, or alternatively no previous works on automatic cadastral parcel extraction using an approach has been assessed quantitatively. Hence, for this particular work, there are no previous results to compare with. Bearing this in mind, this work is about extracting cadastral boundaries from satellite images-which is like estimating the legal boundaries based on land cover boundaries. So achieving such results, which could possibly be improved, will still lift the current cadastral boundary mapping substantially.

In addition to the quantitative results above, the applicability of this segmentation approach is measured by understanding the existing boundary mapping methods and processes obtained from key informants, and by analyzing SWOT of the proposed methods. These information latter used to propose a cadastral boundary mapping approach that could possibly support the existing approaches. All these issues are presented in the following sections.

4.6. Views of land administration professionals

The second registration in Amhara region is part of the first registration. The map produced during second registration will be attached with the book of holding provided during first level registration. In Amhara region orthophoto, total station and GPS are being used for land registration (some regions are using satellite images in addition). Errors from the first registration, cost issues, and lack of trained human power are among the challenges.

Land administration professionals, during the interview, shared their experience on the current land registration approach employed in the country and on the nature of cadastral boundaries in rural areas. Their views and reaction to the proposed automatic cadastral boundary mapping approach is summarized and presented as follow:

On the visibility of cadastral boundaries from HRSI, they explained different characteristics of boundaries depending on their previous field experience in the rural area. Except for few cases, rural boundaries in general are visible from HRSI. The issue of invisible boundaries, which is not the concern of this study, was one of their concerns. But they all underlined the importance of field verification to successfully implement the automatic approach. Below are their views on the visibility of cadastral boundaries in rural areas.

- *"…no doubt…it is possible to see and demarcate the boundaries easily -no problem at all in the rural area to see boundaries from high-resolution satellite imagery, our main problem during the pilot project was related to orthorectification issues not about visibility of boundaries from the image…"* from BoEPLAUA.

- *"…one parcel out of five on average will have a problem in visibility…"* from REILA project.

- *"…mostly, the boundaries are not visible in densely populated areas… In such cases it is difficult to identify the boundaries"* from LIFT.

- *"…there are difficulties unless you go out in the field and verify …in some cases what you think is a boundary may not be a boundary…* " from NLAUD.

In addition they were also asked for the benefit of automatic boundary extraction from HRSI. All of them agree on the benefit of the approach, they mentioned that the time of editing automatically extracted boundaries will be much shorter than digitizing from the scratch. Even they mentioned the automatic boundary extraction implemented in this study as a modification of what they are doing from orthophoto, by emphasizing the main differences. The direct speech of some of the key informants on the benefit of automatic boundary extraction is presented below.

- *"…if we could get a system that automatically draw borders, the time of editing these borders is much shorter than editing from the scratch…it would help a lot."* from REILA.

- "*…If you achieved 70% or 80% and if 30% or 20% of the boundaries are missed or misplaced boundaries still it is good to reduce the time and is cost effective…"* from NLAUD.

- *…The point is the segmentation obtained by the algorithms should be supported by field work. If it is possible to achieve 40% or 50% it will help a lot-other parts will be covered by using other methods. Your idea is like a modification of what we are doing here. We use orthophoto and we delineate those boundaries which are visible on the map by going to the field. For those which are not visible we use other methods. But in your case the visible boundaries are managed in the office without going to the field. It will be a matter of confirming the correctness of the extracted boundaries on the field. We didn't try it but I totally agree with the contribution of your idea to the system provided it should be supported by the field survey…* from *LIFT.*

The interviewees' also mentioned the benefit of automatic boundary extraction approach in response to difficult weather conditions in the field which is one of the hindrances in the current approach. They also suggested the value of field survey as an integral component of this approach.

From the field visit and discussion with key informants, the overall nature of rural cadastral boundaries and the progress of land registration in the study area, and the country in general are pictured. It is observed that some cadastral boundaries might be invisible from the image because of land covers having identical reflectance values on adjacent parcels. This also leads to thinking about the effect of the season of image acquisition on cadastral boundary extraction algorithms. On the other hand, a cadastral feature like terrace looks cadastral boundaries though it is not always true. The discussion also fills the gap happening due to scarcity of literature on the process and status of land registration in Ethiopia.

The quantitative results and feedbacks from key informants, who are also possibly future users, encouraged the researcher to think about future implementation strategies of the mean-shift segmentation. Below, the SWOT analysis followed by possible ways of integrating the positive parts of mean-shit segmentation with existing cadastral boundary approaches is presented.

4.7. SWOT analysis

As mean-shift segmentation based cadastral boundary mapping is a new approach that has not been implemented yet. Looking at the strength and weakness of the approach together with the opportunities for the approach and threats it will face, is important. The information from the SWOT analysis facilitates comparison with other related approaches and support future decision making on using mean-shift segmentation approach. The strength, weakness, opportunity and threats of the developed approach are presented below.

Strength	Weakness
• gives vector data/ ready-made output file for further GIS analysis. • can be applied in both multispectral as well as panchromatic images. • the result is a non-overlapping closed polygon. The simplifying parameter used to minimize the wiggling nature of boundaries. • can capture arbitrary shape of boundaries. • minimize human demerits and cost of surveying • possible to get vector data for large areas within a a short period of time. • it provides promising result for sparsely vegetated areas and flat terrain.	• yield false boundaries like boundaries due to shadow near forests, or as a result of the terrace or due to color difference/similarities between neighboring plots within a parcel. • produce many number of nodes.
Opportunities	**Threats**
• availability of HRSI on the market. • the plugin used to implement mean-shift segmentation is available in an open software like QGIS. This can be accessed offline. • support of government officials for cost-effective approaches and willingness of some LA officials • the shift from conventional surveying approach. • research interests are growing on improving mean-shift algorithm and on using automatic approaches for cadastral boundary mapping. • the algorithm can be implemented in parallel with other approaches. • the process can be implemented any time(regardless of weather conditions) once the required data are at hand.	• on field boundary drawing on top of orthophoto. • focus on accuracy by some professionals/resistance to new approach.

Table 8- SWOT matrix

The SWOT matrix above shows that the mean-shift segmentation takes both multispectral and panchromatic images as an input and produce vector files ready to be used in a GIS environment. The method can also capture arbitrary shaped boundaries and produce closed polygons. These strengths together with the opportunities to find the algorithm freely available and offline make it cost effective and worthwhile to use for cadastral boundary mapping.

Based on the SWOT analysis the following strategies are suggested to better implement this approach for cadastral boundary mapping:

- The potential of the approach to yield closed polygons of arbitrary shape boundaries, together with its being timely and cost effective especially for non-vegetated and flat terrain makes the approach worthwhile. The simplifying parameter can be used to minimize the number of nodes and hence to smooth the boundaries.

- The availability of HRSI with a reasonable revisit time is a good opportunity to get a cloud-free image. Hence, would be possible to use it in place of relatively costly orthophotos.
- The growing interest of researchers to work in the field of (semi)automatic feature extraction is encouraging to discover ways of handling false boundaries. Till then, for cases of vegetated areas and terraces which lead to false boundaries, other methods like boundary drawing on top of HRSI could be integrated with this approach. Moreover, outputs of research works will provide good opportunities to show the applicability of the approach for stakeholders. Thus, focus on research should continue.

Thus, integrating automatic boundary extraction approaches with simple boundary mapping approaches is a task whose feasibility is to be tested in future works. Probable workflows are designed below, to see how the automatic boundary extraction approach could support the existing boundary mapping approaches. This helped to anticipate the process in practice and provide additional information to answer objective3.

4.8. Workflow for cadastral boundary mapping

By considering its benefits, suggesting a workflow for cadastral boundary mapping based on automatic boundary extraction approach from a high-resolution remote sensing imagery is found to be important.
The automated feature extraction could be integrated with cadastral data collection in different ways. Lemmen et al. (2015) suggested undertaking the automated feature extraction in office parallel to field data collection. The detail procedures are illustrated in (Figure 18) below.

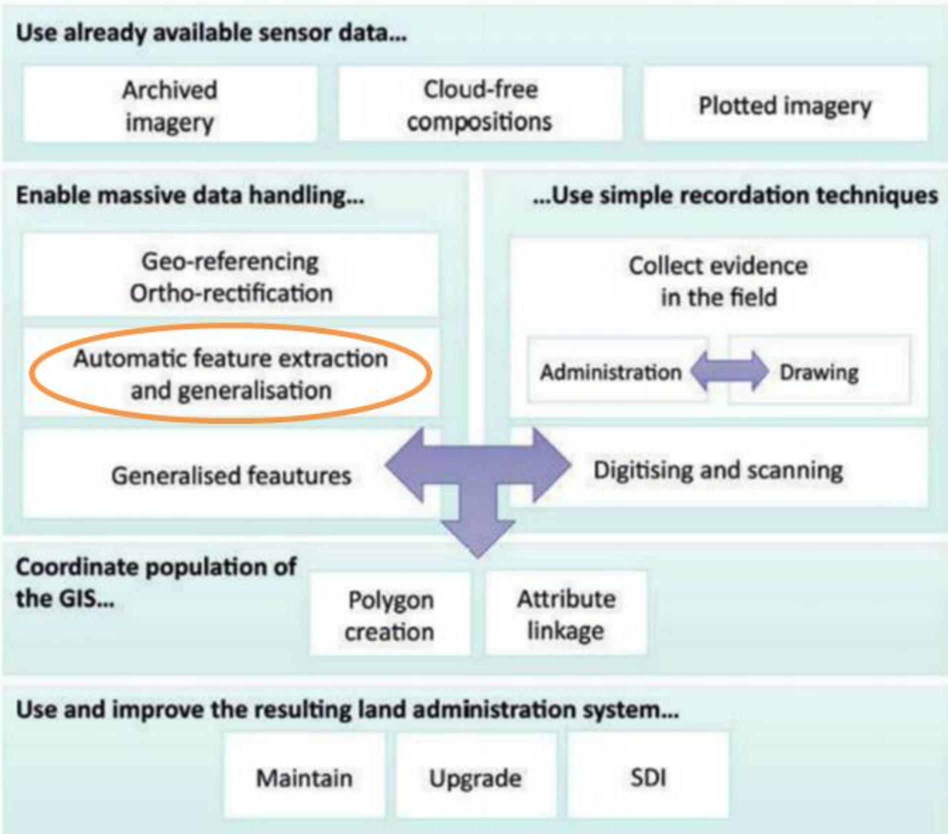


Figure 18- Data acquisition and handling

Source: (Lemmen et al., 2015)

The automatic feature extraction, particularly the mean-shift segmentation approaches could be used to support cadastral boundary mapping in the following way. In this case, automatically extracted boundaries will be overlaid on top of the image and verified on the field.

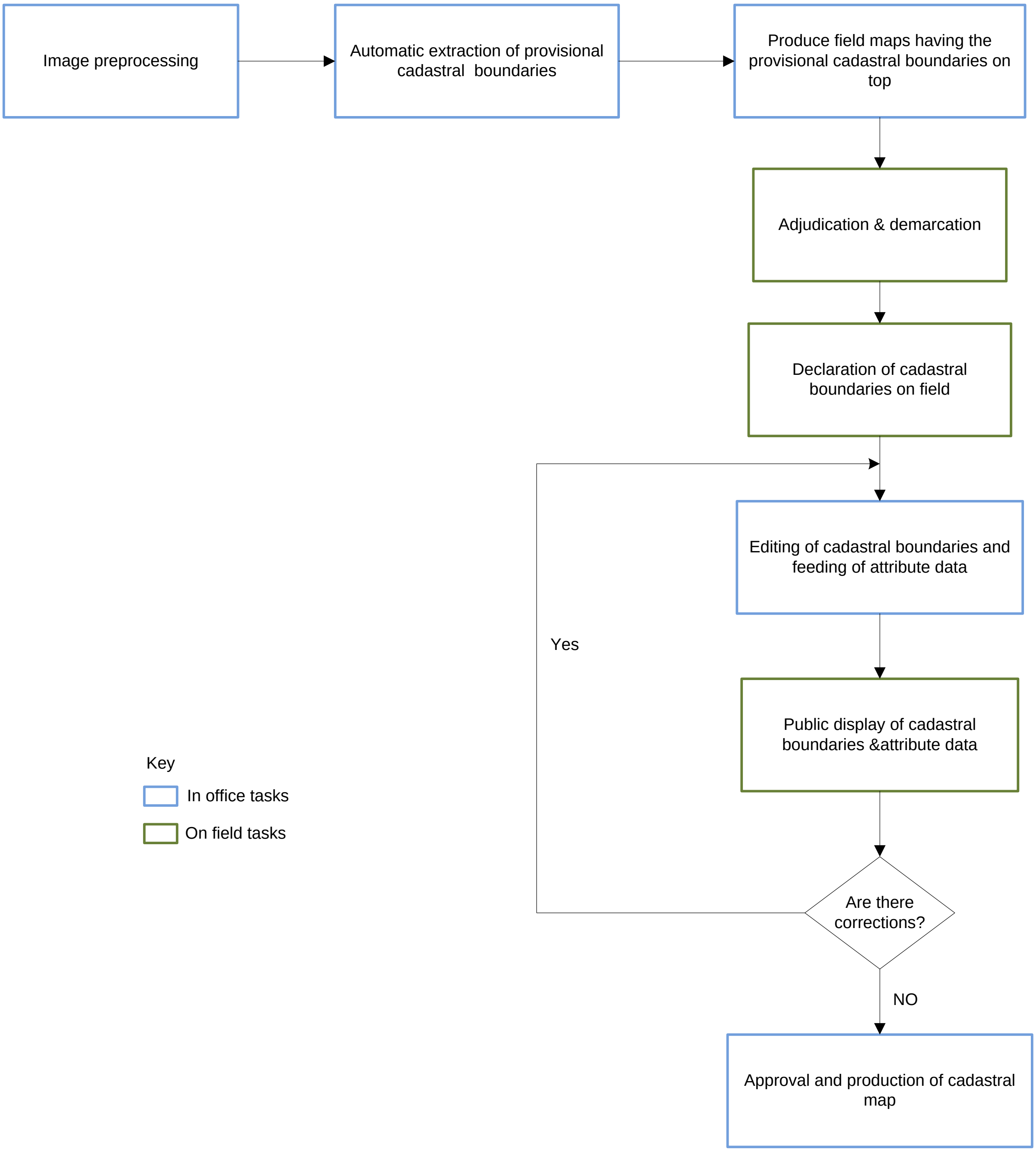


Figure 19-Workflow for automatic cadastral boundary mapping from HRSI

Once the remote sensing imagery is acquired it passes through pre-processing stages. This stage includes orthorectification and other image enhancement techniques like radiometric corrections. If necessary, pan sharpening is also part of this step. Next automatic extraction (in the case of this study Mean-shift algorithm based segmentation) should be applied. The quality of extracted boundaries should be checked first by observation and then by checking against a reference data. The reference data, in this case, could be parcels' boundaries obtained by surveying in sample areas. The extracted boundaries should be overlaid on the image and field maps should be produced.

Next using these field maps declarations of provisional boundaries should be conducted on the field. Unlike the procedures currently employed in Ethiopia, the surveying could be done immediately after the adjudication and demarcation. Boundaries that are extracted incorrectly and those that are not tracked by the algorithm will be modified by pencil on the field map. Measuring tape with a ruler or other surveying instruments may also be used to determine exact boundaries. Then based on the actual parcel information gathered on the field, parcel boundaries will be modified in office. In addition, the attribute data will be inserted to the corresponding polygons at this stage. The attribute data and corrected parcel boundaries on the top of the image should be displayed for the public. Finally, based on the feedback from citizens the final corrections are made and digital cadastral boundaries will be produced.

Hence, by integrating the automatic boundaries mapping approach the amount of boundaries to be digitized, the time required to stay on field (for experts and para surveyors), expected to be minimal. But the time needed for the post-processing work on refining extracted boundaries will still be there though could be minimized by improving the quality of extracted boundaries. Note that the workflow is not tested yet.

4.9. Conclusion

In this chapter, the capabilities of the mean-shift segmentation approach were tested. The results were analyzed both qualitatively and quantitatively. The percentages of completeness, correctness, and quality of extraction were calculated by the buffer analysis method. Relative to other cadastral features, the extraction of river boundaries, road boundaries, and parcel boundaries in a flat non-vegetated terrain was found to be effective. From visual interpretation of the results, it was observed that shadows due to trees having wider crowns and bushes affect the segmentation from extracting cadastral boundaries correctly. It was also noted that some cadastral boundaries might be invisible from the image because of land covers having identical reflectance on adjacent parcels. On the other hand, a cadastral feature like terrace looks cadastral boundaries though it is not always true. The strength, weakness, opportunities and threats in implementing the mean-shift segmentation method was analyzed by SWOT analysis. By considering the results of the SWOT analysis and views of land administration professionals, a workflow for cadastral boundary mapping based on automatic feature extraction algorithms is developed.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

This chapter summarizes the key outputs from each chapter and synthesizes them into a set of concluding remarks that relate directly to the objectives and questions outlined in section 1.5. In addition, possible recommendations for future research and practical implementation of automated cadastral mapping approach are provided.

5.2. Conclusions

The main objective of this study was to test the applicability of automatic feature extraction algorithms for cadastral boundary mapping from satellite imagery based on a general boundary approach. This objective was achieved by addressing the specific objectives;

1. review of a suitable feature extraction algorithms to extract cadastral boundaries from satellite imagery,
2. apply feature extracting algorithms on a selected datasets, and
3. analyze applicability of automatic feature extraction algorithms for general cadastral boundary mapping based on the results.

These objectives are achieved by answering the corresponding research questions stated on section 1.5.2. The results corresponding to the objectives are summarized and presented in the following sections.

5.2.1. The appropriate boundary extracting algorithm

To identify the appropriate boundary extracting algorithm a literature review focused on different feature extraction algorithms and visualization of experimental results, with quantitative analysis, was undertaken. Accordingly, the Sobel operator, LSD, Hough transform, Canny edge detection, and mean-shift based segmentation algorithms are found as possible candidate algorithms for the purpose. By considering previous results on these algorithms for a similar context, for example, the work of (Katiyar & Arun, 2014) and (Gandhi et al., 2014), canny edge detection and mean shift algorithms and LSD were selected for further experimentation. For this, accessibility of software, and simplicity of steps involved (to get final output with cadastral boundary requirements) were taken as criteria to select the algorithms. Experimental results showed that the mean-shift segmentation approach is most appropriate among the three: the output file in this case is a closed vector file (particularly, closed polygons with no gaps or overlaps) that is in the same format as the reference data. Moreover, with this segmentation it is possible to extract boundaries of any shape unlike the other two.

5.2.2. The workflow to apply the selected approach

The procedure used to extract cadastral boundaries is best summarized in (Figure 12). The mean-shift segmentation method in Orfeo image analysis toolbox, a plugin in QGIS, was used for implementing the workflow. It took raster images as input and gave a vector file as an output. The region size and object size parameters with spatial and range radious parameters play a great role to optimize the effect of over segmentation and under segmentation.

5.2.3. The results and their implications

The percentages of completely extracted and correctly extracted boundaries including contributions of automatic boundary extraction to the existing cadastral boundary mapping are discussed. Besides, the percentages of quality of extraction, that takes in to account both completeness and correctness, are also described.

The IAAO (2015) put 2.4 meters as an acceptable limit of accuracy for cadastral boundaries in rural areas. Based on this, buffer widths 0.5m, 1m and 2m, all of which are within the specified limit, were considered to determine the percentage of completeness and correctness.

The results showed that with buffer width equals to 2m, 82.75 % of the parcel boundaries are extracted completely, 34.29% of the parcel boundaries are extracted correctly and the overall quality of extracted parcel boundaries is 32.89%. Likewise, for buffer width equals to 1m, 71.46% of the parcel boundaries are extracted completely, 24.69% of the parcel boundaries are extracted correctly and the overall quality of extraction is 23.07%. Relatively lowest results obtained corresponding to the buffer width of 0.5m, it yields percentage of completeness equals to 55.39%, percentage of correctness equals to 16.26%, and an overall quality of 14.65%.

For the cases of boundaries of rivers and roads better results are recorded. For instance by constructing buffer width of 2m, respectively 69.10% and 52.51% of the road boundaries are extracted completely and correctly. The overall quality percentage in this case was 45.06%. With the same buffer width, 86.94% of river boundaries extracted completely, 68.99% of them extracted correctly and 64.51% overall quality achieved.

The overall results suggested that the approach is more effective in extracting boundaries of cadastral features situated in a relatively open terrain and having land covers of different reflectance near boundaries. Road and river boundaries were extracted effectively and a promising result found for parcel boundaries. On the contrary, the effectiveness of the segmentation is affected a lot by forests and trees around parcel boundaries. As a result, the boundaries of footpaths near vegetated areas were not identified to the required extent.

In automatic boundary extraction approach, a digitizer is supposed to work on those already extracted boundaries which need modification. That means the digitization will not start from the scratch and it will not be done for all the boundaries. Due to this the impact of the automatic extraction approach on time, cost and a human power requirement becomes considerable. The digitization can be accomplished in a short period of time, with less number of employers for the digitization, hence less cost, compared to fully manual based digitization approaches. This effect is mainly noticed for images of larger size. For smaller images, the advantages of the automatic approach may be negligible or less compared to manual digitization.

Implementing the automatic boundary extraction on a flat and relatively open terrain is expected to improve the time of digitization at least by one-third. It has also benefits in minimizing the waiting time and cost of sophisticated surveying materials (including the cost of labor) that has been used in the field during conventional surveying. Moreover, it gives the opportunity to undertake the adjudication, demarcation and boundary confirmation on the field map at the same time. This is not the case, for instance, in Ethiopia where adjudication and demarcation had been conducted during the first phase of registration and field survey is being conducted in the second phase.

In general, the automated feature extraction approach, particularly using mean-shift algorithm based segmentation application, is proved as an effective approach to supporting the current cadastral boundary mapping. The method can be implemented in an integrated way with existing boundary mapping approaches. The possible work flow (which can be customized depending on contexts) is presented in section 4.8. It is also proved to be a perfect alternative for extracting boundaries of water bodies and roads automatically. But, due to the effect of shadow and tree crowns, its effectiveness in extracting parcel boundaries around vegetated areas is found to be minimal.

5.3. Recommendation for further research

This study was intended to test the role of automated feature extraction for the purpose of cadastral boundary mapping. Already existing algorithms proved to work for other contexts were checked and promising results were found. Especially for river boundary extraction, road boundary extraction and for boundaries of parcels in a relatively open and flat terrain, the results suggested it worked well. Though these results are reflections of the study area, the researcher also believes that these results could be extended to similar contexts. As far as the issue of cadastral boundary mapping is concerned, more issues need also be considered.

So, further investigation on the following issues could give a better sight on the applicability of the approach for large-scale cadastral boundary mapping in rural areas.

- The effect of time of image acquisition should be tested from a time series data.
- The effect of landscape could be addressed by testing the approach on mountainous areas.
- Sometimes accuracy demands vary per holding type even with in rural areas. For such cases, for instance, subset images could be taken from individual holdings, common lands and/or state lands.
- Integrating this approach with other sources of geospatial information, like LIDAR data may help to minimize the effect of shadow in vegetated areas.

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APPENDICIES

Appendix 1-Table of results of TP, FP, FN and quality assessment for subset image 2.

Buffer width	Length of reference boundaries in meter		
	Matched(TP)	Unmatched(FN)	Total length in meter
0.5m	3879.35	9970.79	13850.14
1m	6114.03	7736.10	13850.13
2m	8605.13	5245.00	13850.13

Table 1a-Reference boundaries overlaid on the buffer around the extracted boundaries

Buffer width	Length of extracted boundaries in meter		
	Matched(TP)	Unmatched(FN)	Total length in meter
0.5m	10129.33	53710.03	63839.36
1m	14317.68	49521.67	63839.35
2m	21056.73	42782.62	63839.35

Table 1b-Extracted boundaries overlaid on the buffer around the reference boundaries

Buffer width	Completeness	Correctness	Quality
0.5m	28.01	15.87	5.74
1m	44.14	22.43	9.65
2m	62.13	32.98	15.19

Table 1c-Percentages of quality measures per buffer widths

Appendix 2-Table of results of TP, FP, FN and quality assessment for subset image 3.

Buffer width	Length of reference boundaries in meter		
	Matched(TP)	Unmatched(FN)	Total length in meter
0.5m	3020.23	12992.35	16012.58
1m	4849.54	11163.04	16012.58
2m	7071.9	8940.68	16012.58

Table 2a- Reference boundaries overlaid on the buffer around the extracted boundaries

Buffer width	Length of extracted boundaries in meter		
	Matched(TP)	Unmatched(FN)	Total length in meter
0.5m	4697.4	60317.6	65015.00
1m	8875.41	56139.59	65015.00
2m	15666.95	49348.05	65015.00

Table 2b-Extracted boundaries overlaid on the buffer around the reference boundaries

Buffer width	Completeness	Correctness	Quality
0.5m	18.86	7.23	6.02
1m	30.29	13.65	11.65
2m	44.16	24.10	21.18

Table 2c-Percentages of quality measures per buffer widths

Appendix 3-Table of results of TP, FP and FN for road boundaries

Buffer width	Length of extracted boundaries in meter		
	Matched(TP)	Unmatched(FN)	Total length in meter
1m	850.03	2180.97	3031
2m	1591.47	1439.53	3031

Table 3a-Extracted boundaries overlaid on the buffer around the reference boundaries

Buffer width	Length of reference boundaries in meter		
	Matched(TP)	Unmatched(FN)	Total length in meter
1m	678.34	941.55	1619.89
2m	1119.39	500.5	1619.89

Table 3b-Reference boundaries overlaid on the buffer around the extracted boundaries

Appendix 4-Table of results of TP, FP and FN for river boundaries

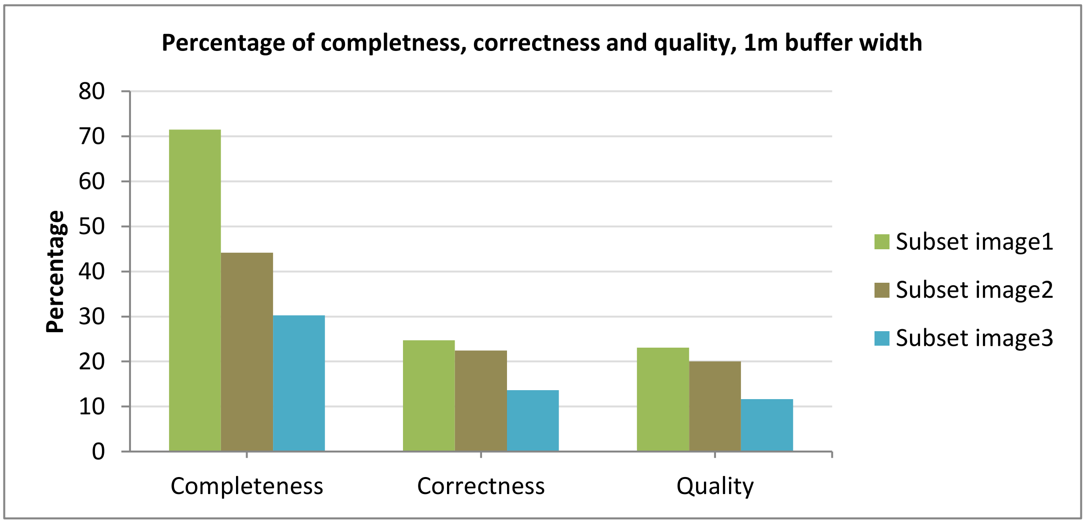
Buffer width	Length of extracted boundaries in meter		
	Matched(TP)	Unmatched(FN)	Total length in meter
1m	2428.86	2385.14	4814
2m	3321.26	1492.74	4814

Table 4a-Extracted boundaries overlaid on the buffer around the extracted boundaries

Buffer width	Length of reference boundaries in meter		
	Matched(TP)	Unmatched(FN)	Total length in meter
1m	1861.62	700.62	2562.24
2m	2227.72	334.52	2562.24

Table 4b-Reference boundaries overlaid on the buffer around the reference boundaries

Appendix 5-Graphs showing the percentage of completeness, correctness and quality per subset image



Graph 5a- Percentage of quality measures for each subset images when buffer width equals 1m

Graph 5b- Percentage of quality measures for each subset images when buffer width equals 0.5 m

Appendix 6-MATLAB code used for Canny Edge Detection

(Source: Rachmawan Atmaji Perdana: (c) 2014. http://nl.mathworks.com/matlabcentral/fileexchange/46859-canny-edge-detection)

```
%Input image
img = imread ('yis_subset.tif');
%Show input image
figure, imshow(img);
img = rgb2gray(img);
img = double (img);

%Value for Thresholding
%highThresh = find(cumsum(counts) > PercentOfPixelsNotEdges*m*n,1,'first') / 64;
%highThresh = find(cumsum(counts) > 0.7*m*n,1,'first') / 64;
%T_High=find(cumsum(counts) > 0.7*m*n,1,'first') / 64;
%T_low=4*(T_High);

T_Low = 1.0015;
T_High = 2.0850;

%Gaussian Filter Coefficient
B = [2, 4, 5, 4, 2; 4, 9, 12, 9, 4;5, 12, 15, 12, 5;4, 9, 12, 9, 4;2, 4, 5, 4, 2 ];
B = 1/129.* B;

%Convolution of image by Gaussian Coefficient
A=conv2(img, B, 'same');

%Filter for horizontal and vertical direction
KGx = [-1, 0, 1; -2, 0, 2; -1, 0, 1];
KGy = [1, 2, 1; 0, 0, 0; -1, -2, -1];

%Convolution by image by horizontal and vertical filter
Filtered_X = conv2(A, KGx, 'same');
Filtered_Y = conv2(A, KGy, 'same');

%Calculate directions/orientations
arah = atan2 (Filtered_Y, Filtered_X);
arah = arah*180/pi;
```

```
pan=size(A,1);
leb=size(A,2);

%Adjustment for negative directions, making all directions positive
for i=1:pan
    for j=1:leb
        if (arah(i,j)<0)
            arah(i,j)=360+arah(i,j);
        end;
    end;
end;

arah2=zeros(pan, leb);

%Adjusting directions to nearest 0, 45, 90, or 135 degree
for i = 1  : pan
    for j = 1 : leb
        if ((arah(i, j) >= 0 ) && (arah(i, j) < 22.5) || (arah(i, j) >= 157.5) && (arah(i, j) < 202.5) || (arah(i, j) >= 337.5)
&& (arah(i, j) <= 360))
            arah2(i, j) = 0;
        elseif ((arah(i, j) >= 22.5) && (arah(i, j) < 67.5) || (arah(i, j) >= 202.5) && (arah(i, j) < 247.5))
            arah2(i, j) = 45;
        elseif ((arah(i, j) >= 67.5 && arah(i, j) < 112.5) || (arah(i, j) >= 247.5 && arah(i, j) < 292.5))
            arah2(i, j) = 90;
        elseif ((arah(i, j) >= 112.5 && arah(i, j) < 157.5) || (arah(i, j) >= 292.5 && arah(i, j) < 337.5))
            arah2(i, j) = 135;
        end;
    end;
end;

figure, imagesc(arah2); colorbar;

%Calculate magnitude
magnitude = (Filtered_X.^2) + (Filtered_Y.^2);
magnitude2 = sqrt(magnitude);

BW = zeros (pan, leb);

%Non-Maximum Supression
for i=2:pan-1
    for j=2:leb-1
        if (arah2(i,j)==0)
            BW(i,j) = (magnitude2(i,j) == max([magnitude2(i,j), magnitude2(i,j+1), magnitude2(i,j-1)]));
        elseif (arah2(i,j)==45)
            BW(i,j) = (magnitude2(i,j) == max([magnitude2(i,j), magnitude2(i+1,j-1), magnitude2(i-1,j+1)]));
        elseif (arah2(i,j)==90)
            BW(i,j) = (magnitude2(i,j) == max([magnitude2(i,j), magnitude2(i+1,j), magnitude2(i-1,j)]));
        elseif (arah2(i,j)==135)
            BW(i,j) = (magnitude2(i,j) == max([magnitude2(i,j), magnitude2(i+1,j+1), magnitude2(i-1,j-1)]));
        end;
    end;
end;

BW = BW.*magnitude2;
figure, imshow(BW);

%Hysteresis Thresholding
T_Low = T_Low * max(max(BW));
T_High = T_High * max(max(BW));
```

```
T_res = zeros (pan, leb);

for i = 1  : pan
   for j = 1 : leb
       if (BW(i, j) < T_Low)
           T_res(i, j) = 0;
       elseif (BW(i, j) > T_High)
           T_res(i, j) = 1;
       %Using 8-connected components
       elseif ( BW(i+1,j)>T_High || BW(i-1,j)>T_High || BW(i,j+1)>T_High || BW(i,j-1)>T_High || BW(i-1, j-1)>T_High || BW(i-1, j+1)>T_High || BW(i+1, j+1)>T_High || BW(i+1, j-1)>T_High)
           T_res(i,j) = 1;
       end;
   end;
end;

edge_final1 = uint8(T_res.*255);
%Show final edge detection result
figure, imshow(edge_final1);
```

Appendix 7-Interview questions

Semi structured interview questions used to collect data from key informants in the field.

1. Can you please explain about the second land registration process and its progress in rural area of the Amhara region/Ethiopia?
    - *what approach followed, spatial accuracy*
    - *techniques and tools used*
    - *time it takes, cost, labor*
    - *the result in terms of its coverage*
2. What are the main challenges during the registration process?

3. What are the strengths, weaknesses, opportunities, and threats of the second registration process in Amhara region?

4. In your opinion, to what extent cadastral boundaries in the rural area are visible from high-resolution (< 1m) satellite imagery?
    - *Please roughly estimate in percentage.*

5. In your opinion, do you think automatic feature extraction will support cadastral boundary mapping in the region/Ethiopia? How?

6. Do you think the procedures and methods employed in the current land registration process will respond well to address the issue of cost, time, and involvement of human power?

Appendix 8-Reference parcel boundaries and extracted boundaries overlaid on subset images

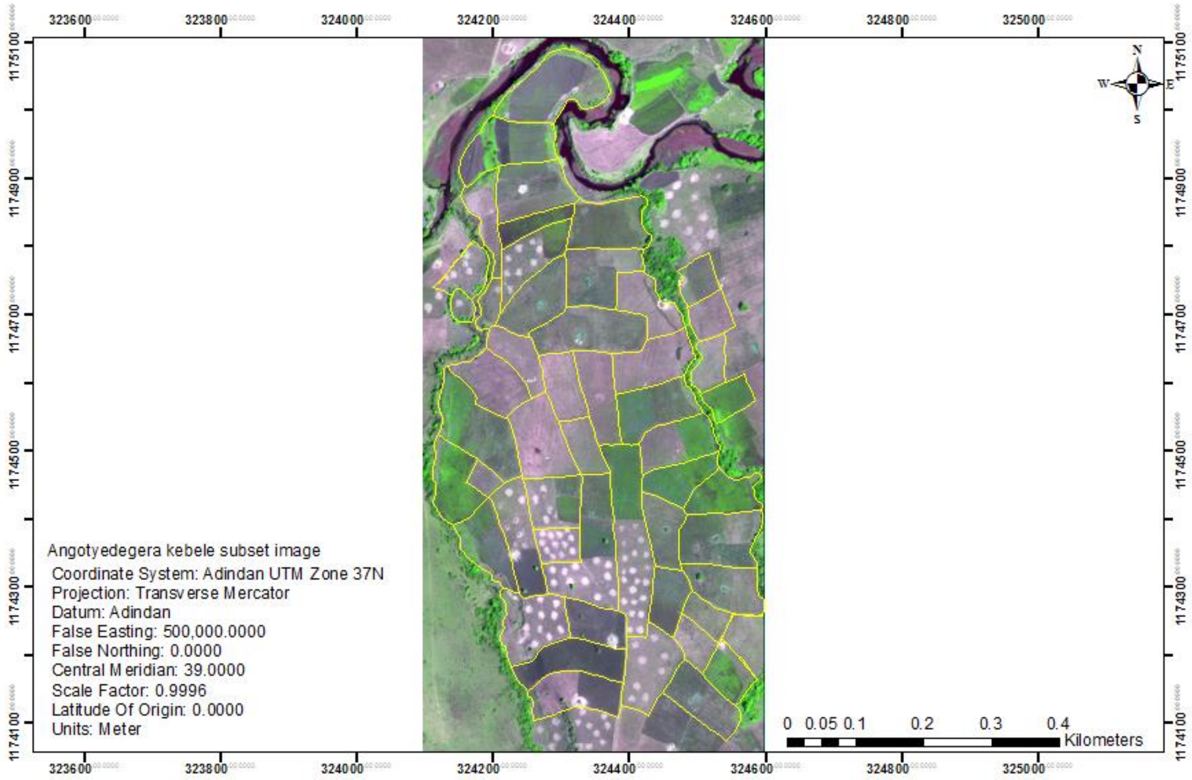


Figure 8a- Reference image overlaid on subset image 1

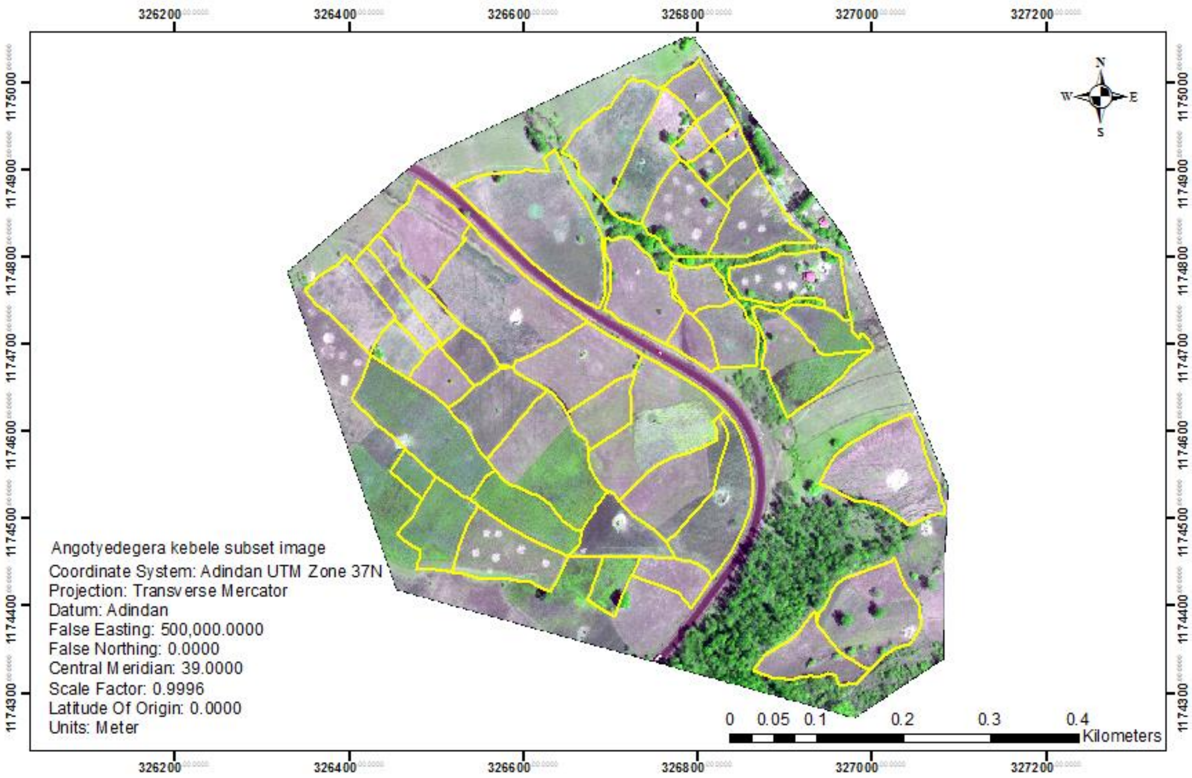


Figure 8b- Reference boundary overlaid on subset image 2

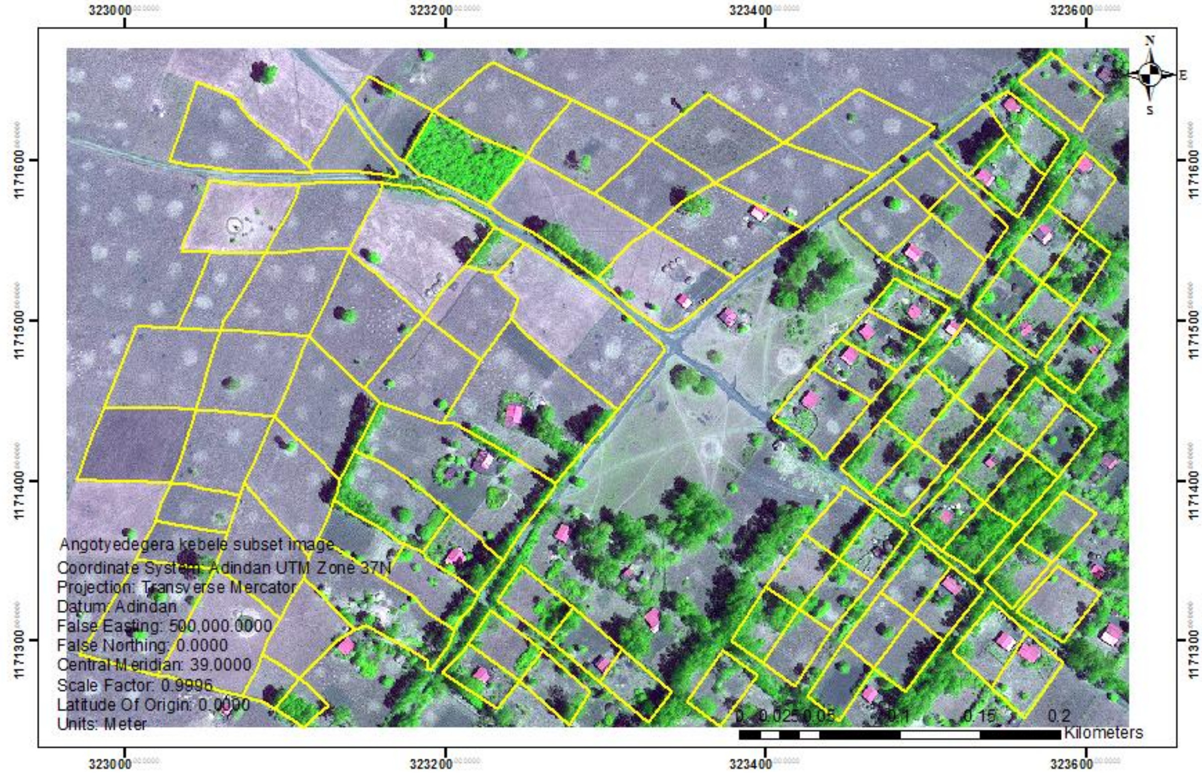


Figure 8c-Reference boundaries overlaid on subset image 3

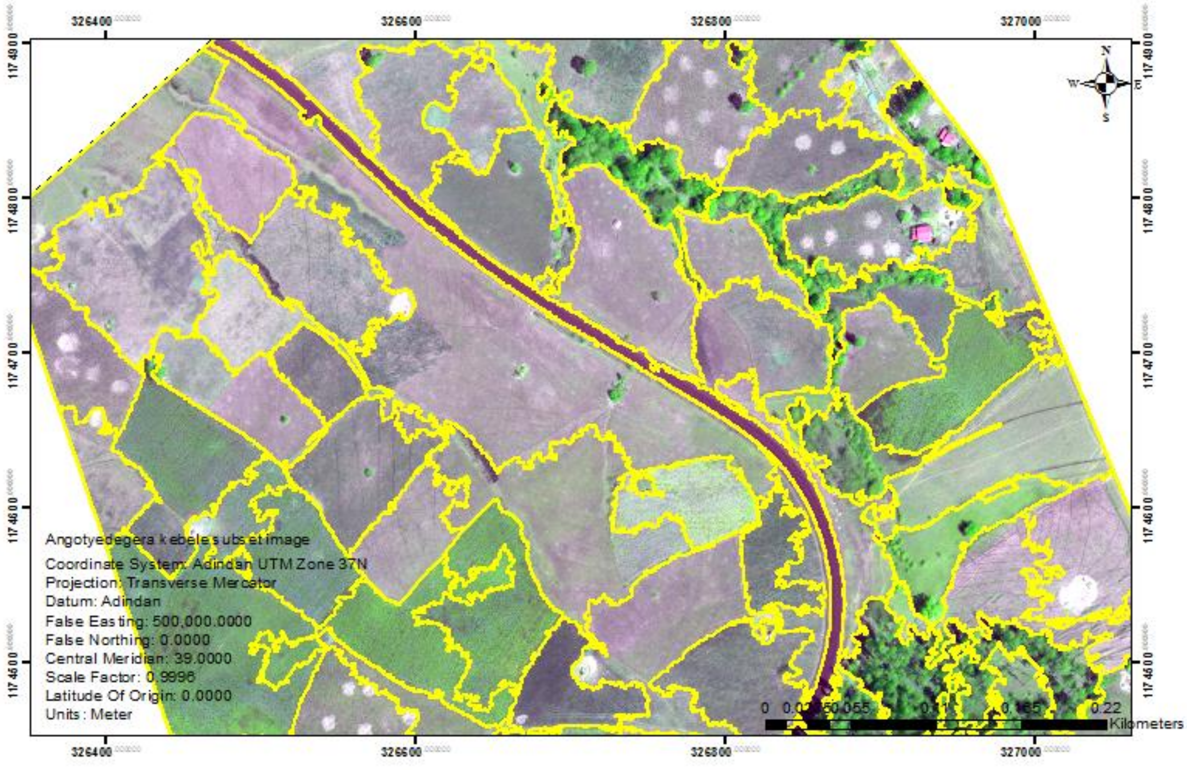


Figure 8d-Extracted boundaries overlaid on subset image 2

Appendix 9-Buffer along the reference and extracted boundaries

Figure 9a-Buffer along the reference boundaries

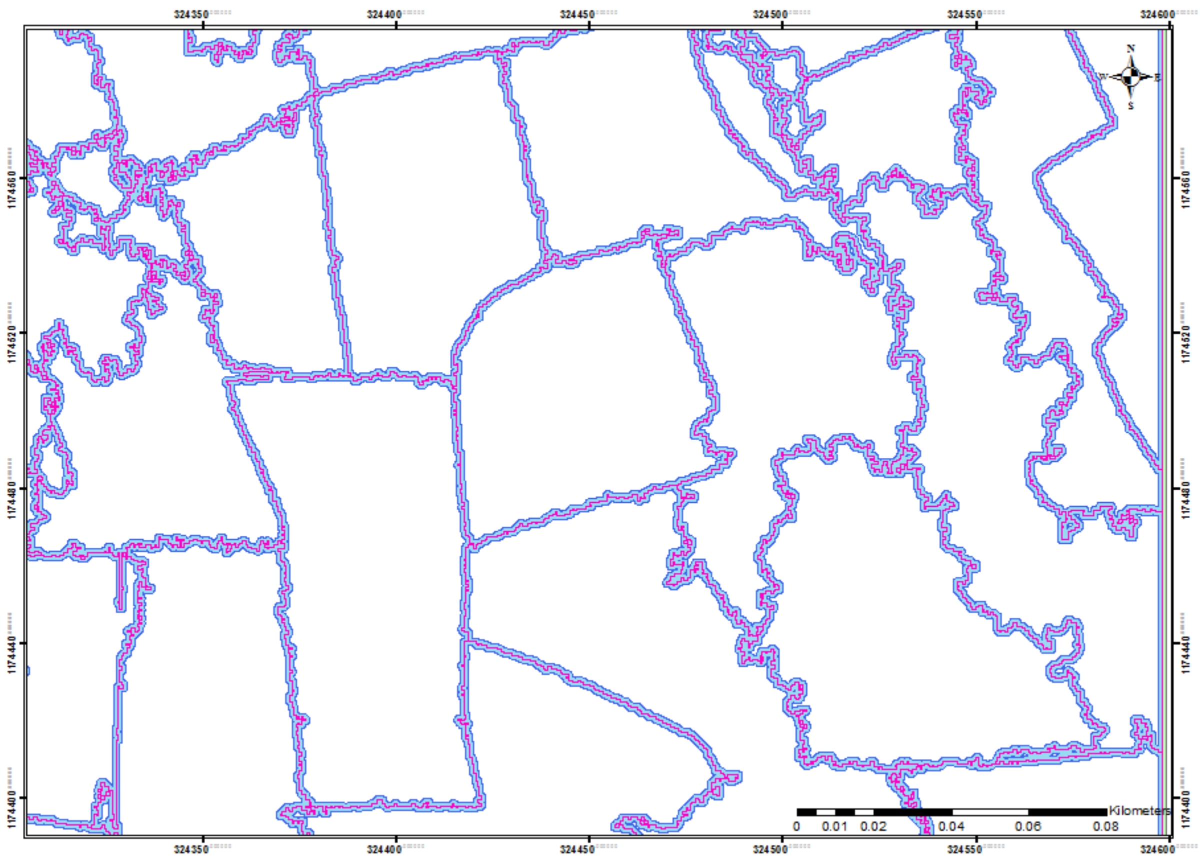
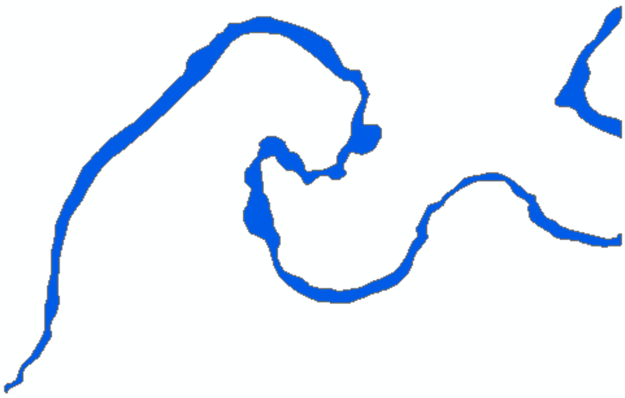


Figure 9b- Buffer along the extracted boundaries

Appendix 10-Manually digitized river and road reference boundaries



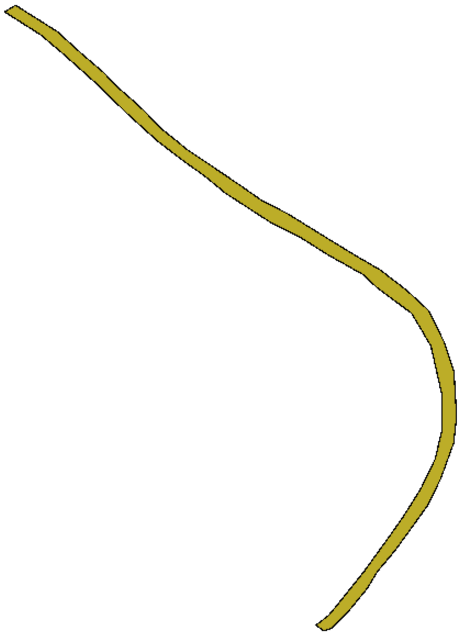


Figure 10a-River reference boundary

Figure 10b- Road reference boundary

Appendix 11-Extracted boundaries (from an image taken from non-vegetated area) overlaid on the image

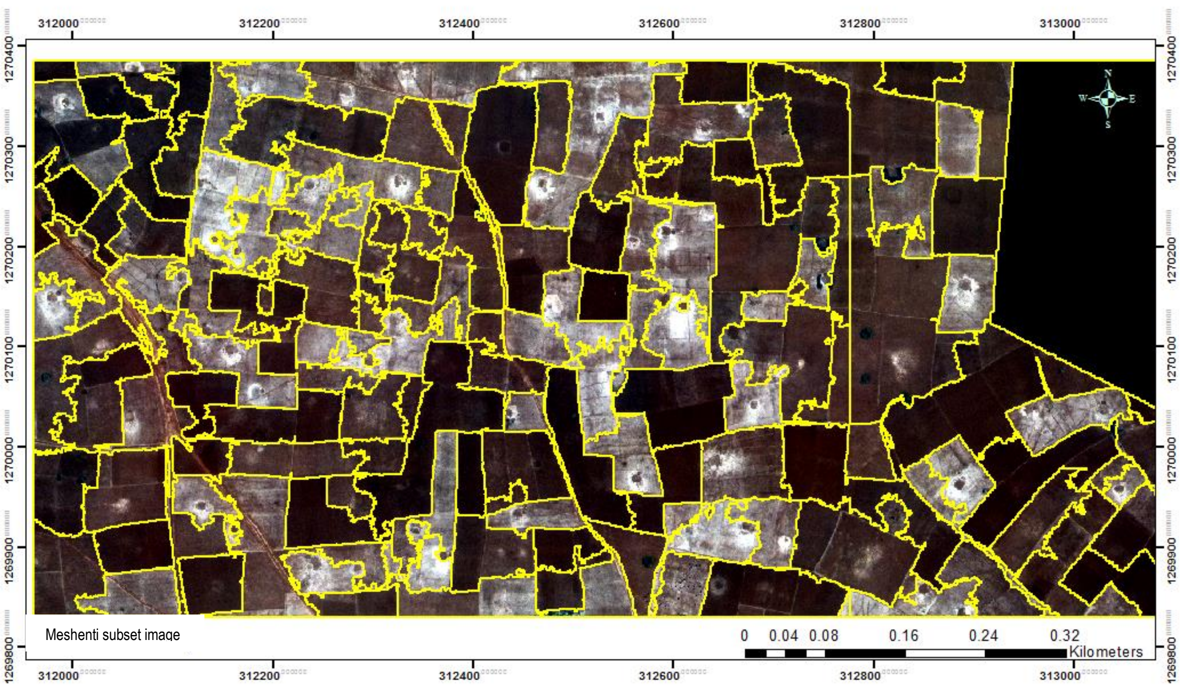


Figure 11(a)-Extracted boundaries overlaid on non-vegetated area

Appendix 12- Pictures showing different boundary types in the study area immediately after rainy season

a) Fences as boundaries

b) Similar color/reflectance on neighboring parcels

c) Different color/reflectance on neighbouring parcels

d) Walkway between parcels

e) Picture showing gaps between parcel boundaries and road feature