EVALUATION OF DIGITAL PEN IN DATA CAPTURING FOR LAND ADMINISTRATION PURPOSES IN RWANDA

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February, 2011

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Specialization: Land Administration

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ABSTRACT

The implementation of land administration is being taken in Rwanda. This includes spatial data (boundaries of parcels) and related legal administrative data. There are approximately 8 million parcels. Efficient data acquisition methods are needed. Existing land rights are determined in an adjudication process supported by a participatory mapping (P-mapping) process. Digital orthophotos are available.
For spatial data acquisition in the field the orthophotos are first plotted, then the boundaries of parcels are drawn and the parcels IDs written on field sheets with pencil on site. Post-processing has to be performed in the office. This concerns redrawing and rewriting over the pencil marks by using normal pen on field sheets, the scanning and geo-referencing of the field sheets, and the vectorisation of parcels boundaries. This process implicates different sources of errors because of many process steps. It is double work in terms of time. It requires a lot space for archiving. This implies a complex information management.
The focus of this research is on spatial data acquisition by using a digital pen. It compares the existing method and the digital pen method by qualitative and quantitative methods on the basis of four criteria: quality of data, time used, P-mapping, and process.
It is concluded that a digital pen can be used to draw lines on map as normal, but the plotted map has patterns printed on it. This allows for storage of spatial data directly into georeferenced digital format into the pen. This addresses the sources of errors which are in the existing method, saving of time, saving the space for archiving, and keeping the promotion of P-mapping. The digital pen method would be more practical by improving some related functionalities. Proposals are made for that.

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LIST OF ABBREVIATIONS

AC:	Adjudication Committee
DEM:	Digital Elevation Model
DTM:	Digital Terrain Model
DGPS:	Differential GPS
EDM:	Electronic Distance Meter
ESRI:	Environmental Systems Research Institute
GCP:	Ground Control Point
GIS:	Geographic Information System
GPS:	Global Positioning System
ITRF:	International Terrestrial Reference Frame
LIS:	Land Information System
LSK:	Local Spatial Knowledge
LTR:	Land Tenure Regularisation
LUP:	Land Use Plan
NLC:	National Land Centre
OLL:	Organic Land Law
P-mapping:	Participatory mapping
PGIS:	Participatory GIS

1. INTRODUCTION

This research presents the use of digital pen in land adjudication[1] process for land administration purposes in Rwanda. The focus of this research is on spatial data acquisition and mapping cadastral information. The use of the digital pen method is assessed by using the digital pen for orthophoto based boundaries demarcation. In the existing method, data collected from the field are in analogue format, and post-processing has to be performed in the office. This research assesses the use of the digital pen method compared to the existing method.

1.1. Background of the study

Access to reliable information on the ownership, value, and use of land helps to further social and political objectives. The most common form of a land information system is the cadastre through land registration (McLaughlin, 1999).

Land registration in Rwanda is being undertaken under the systematic land registration, and this will provide a nation wide parcels boundaries index map for each location. With the 2005 organic land law (OLL) determining the use and management of land in Rwanda, all land must be formally registered (Official Gazette of the Republic of Rwanda, 2005). There are approximately 8 million parcels (MINIRENA, 2009). Compared to the colonial period, the situation has not changed much after independence. As a matter of fact, 90% of the country's arable land was still governed by customary law. The written land law was still applied to a small number of persons and religious congregations. It was applying more often in urban areas and business communities (Official Gazette of the Republic of Rwanda, 2007).

At the moment, the process of land registration is taken under land tenure regularisation for all land in the country using orthophoto based land adjudication. Land Tenure Regularisation (LTR) is a set of administrative procedures undertaken for the purpose of recognising and securing existing rights that people and organisations other than the State have to, in or over land, including individual land, State private land, private district land, and City of Kigali land. It is designed to clarify the rights of the existing owners and occupants of land and, where necessary and desirable, to convert those rights into a legally recognised form that will allow people to legally transact their interests in land, and use their titles for mortgaging and credit purposes (National Land Centre, 2009). The goal of this process is land tenure security which leads to avoidance of land disputes, economic development, investments in different aspects, etc. According to (Dale, 1993), land registration and cadastral systems are part of the infrastructure that is needed to minimise the waste and to maximize the effectiveness of land development programmes.

In a land administration system, various technologies are used for cadastral data acquisition. Spatial data and related non spatial data (legal administrative attributes) are required as a basis for land registration and for the establishment of a sustainable land administration system. Before the innovative system of orthophoto based land adjudication, the techniques for spatial data acquisition were to use theodolite, GPS and total station for fixed boundaries survey. This was done on a demand led basis (sporadic land registration), in rural and mainly in urban areas. At the moment, the aim is to register systematically all land (parcels). In this process, Quickbird satellite imagery (0.60m resolution) has been used for LTR trials in 2007, and at the moment aerial photographs (0.25m resolution) are used for the on-going process at national level. The government facilitates local people to do the work by themselves. Participatory

[1] Land adjudication is the initial data collection for cadastre, it concerns the identification of existing rights.

mapping (P-mapping) is adopted for field data collection using plotted orthophotos for parcels boundaries demarcation, and register books for recording related legal administrative attributes. The analogue collected data from the field are post-processed in the office for digitisation.
Politics and policy can happen only in communities. Public policy is about communities trying to achieve something as communities (Stone, 2002). In land administration, a participatory approach is useful to get information related to people's lands; the starting point is local people.

1.2. Research problem

With the implementation of land administration in Rwanda, the aim is to have nation wide coverage as soon as possible. Efficient data acquisition methods are needed. In the existing orthophoto based land adjudication, the pencil is used on plotted maps for demarcating parcels boundaries and writing parcels IDs for data collection in the field. After field work, the post-processing is to redraw and rewrite the pencil marks on field sheets by using normal pen to make boundaries and parcels IDs more visible on the field sheets. Then scanning field sheets, georeferencing them, and digitising (vectorising) parcels boundaries is by redrawing them. This process implicates different sources of errors because of many process steps. It is double work in terms of time, but also it implicates a lot space for archiving.
The existing method has as advantage to facilitate P-mapping; this doesn't require a high educational level; it requires anyone who is able to interpret the image, and is able to read and write. The tools are familiar and easy to use, suitable for field conditions and facilitate collaboration in the field. Printed field sheets are on large or small scale, they are lightweight, portable, reliable, and other advantages for field work.
Despite these advantages, there is a need to investigate data acquisition techniques to use in order to prevent the sources of errors which are in the existing method and improve efficiency.
The digital pen captures what is drawn and written on digital paper[2], and it stores the drawn and written data to its internal memory and the operator can transfer the collected data to the computer by connecting the pen via USB[3] adapter.

1.3. Research objectives

The research assesses whether the use of digital pen can improve the efficiency for spatial data acquisition for general boundaries survey in Rwanda.

1.3.1. Specific objectives

To compare the existing method of spatial cadastral data acquisition (general boundaries) and the digital pen method by:

- Assessing sources of errors in the existing method that can be addressed by the digital pen method
- Identifying the time that the existing method takes compared to the time that the digital pen method would take for spatial data capturing
- Assessing the process used for each method, the existing method and the digital pen method, in terms of the space for archiving
- Identifying practical field operations in P-mapping when using the digital pen method compared to the existing method.

[2] Digital paper is patterned paper used in conjunction with a digital pen to create the records digital. The digital paper is an ordinary paper. During the process the application software converts the paper to a digital paper by printing patterns of tiny black dots, and these dots are printed in a carbon black ink that reflects infrared light, and so the camera in the pen records the dots. Digital pen records the position (XY geographic coordinates) of the pen as it moves across the paper. The digital records stored into the pen can be uploaded to a computer.
[3] USB stands for Universal Serial Bus which is one of the most prevalent connection ports on today's computers and peripheral devices.

1.4. Research questions

To meet the research objectives, the research responds to the following questions:

1.4.1. Main question

Compared to the existing method of spatial cadastral data acquisition (general boundaries survey), what degree of efficiency is the digital pen method?

1.4.2. Sub-questions

- Which sources of errors in the existing method can be addressed by the digital pen method?
- What time does it take for data collection in the field and the office workload when using the digital pen method compared to the existing method?
- What the digital pen method can change in the process used in terms of the space for archiving compared to the existing method?
- What is the level of practicability of the digital pen method for field operations in P-mapping compared to the existing method?

1.5. Research methodology

To meet the research objectives and to answer to the research questions, the methods were:

- Literature review. This concerns land administration and participatory mapping and a brief analysis focusing on the goals of this research. The review is presented in chapter 2.
- Direct observation. This concerns an overview of the existing method for data collection during the field adjudication using orthophotos in the field, and in the office workload for mapping the collected data. This overview is needed for comparison of an alternative method for data acquisition using digital pen. The overview of the existing method is presented in chapter 3.
- Data collection. The organisation of the field work and other work done in this research for data collection is presented in chapter 4.
- Experiments in relation to the use of the digital pen are presented in chapter 5. This includes assessments for efficient data collection when using the digital pen. Further the qualitative and quantitative comparison of the existing pencil based data acquisition with the alternative digital pen based data acquisition is presented here.

According to (Corne´ P. J. M. van Elzakker, 2008), *"the combination of quantitative and qualitative research is a common characteristic of the user centred design process, whereby qualitative research is implemented to test the first prototype designs and more quantitative research to evaluate the final designs. To help understand this, we first of all require more qualitative user research. But, on the other hand, we also want to have quantitative measures telling us, for instance, how long it takes for a subject to execute a particular use task."*

For quantitative method, there was to assess how long the use of the digital pen method takes to accomplish a certain task compared to the existing method. This was quantified in terms of number of parcels demarcated in certain range of time until getting the final digital outputs, and number of people to accomplish the task.

For qualitative method, after uploading data from digital pen to the computer, in ArcGIS, there was to assess the quality of parcels boundaries visualised by assessing whether they are true to the original parcels boundaries drawn on printed map (digital paper). This was assessed by overlaying uploaded data to the original orthophoto and check if the visualised boundaries reflect the ones drawn on digital paper. The quality of data in the existing method was assessed compared to the digital pen method. For quality assessment of outputs, there was to assess the degree of keeping original collected data in each of both methods in minimising sources of errors. There was also to assess the practicability of the process used for each method in terms of archiving, and the level of practicability of each method in P-mapping.

The research compares the existing method and the digital pen method in order to assess whether the digital pen method can improve the efficiency of spatial data acquisition. In the context of this research,

the state or quality of being efficient is the competency in performance, ability to accomplish a task with a minimum expenditure of time and effort, and with a good quality of outputs.

1.6. Thesis outline

Chapter 1. Introduction

This chapter consists of the background of the study, the research problem, the research objectives, the research questions, the research methodology, and the thesis outline.

Chapter 2. Land administration and participatory mapping

This chapter analyses the key concepts, land administration and P-mapping, related to this research for understanding how they are related each other. This analysis concerns commenting and linking existing knowledge on P-mapping and land administration. This existing knowledge has been collected based on a literature review.

Chapter 3. Cadastral survey process and data acquisition techniques in Rwanda

This chapter describes in short the existing data acquisition techniques in Rwanda, and the focus on orthophoto based land adjudication in P-mapping in general boundaries survey. This description is needed to compare the existing method of data acquisition with the digital pen based method in chapter 5.

Chapter 4. Data collection methods

This chapter presents the pre-field work activities, it gives an overview of the field work, further tests for para-surveyors in the use of the digital pen method, the selected sites for data collection, further tests for other approaches in the use of the digital pen method, and materials used in data collection.

Chapter 5. Comparison of the existing method with the digital pen method

This chapter presents the results of different tests done for the use of digital pen in spatial data capturing, and it compares the existing method used in Rwanda for general boundaries survey and the digital pen method. The comparison is done by qualitative and quantitative methods.

Chapter 6. Discussion on the digital pen method for cadastral survey

This chapter discusses the results presented in chapter 5. The discussion is based on the four criteria used in this research (P-mapping, quality, time, and process). The research questions are focus of attention in this discussion.

Chapter 7. Conclusions and recommendations

This chapter presents the conclusions of this research. It also presents the recommendations related to this work and suggestion for further research.

2. LAND ADMINISTRATION AND PARTICIPATORY MAPPING

This chapter analyses the key concepts, land administration and P-mapping, related to this research for understanding how they are related each other. This analysis concerns commenting and linking existing knowledge on P-mapping and land administration. This existing knowledge has been collected based on a literature review.

2.1. Land administration

Land information system is the basis of facilitating land administration. "*A land information system is defined as a GIS which utilizes land parcels as the link to the non-graphic database attribute*"(Bishop, et al., 2000). According to these authors, land information, in urban area, is buildings and the name of the owners of land parcels. According to (Heo, Kim, & Kang, 2006) "*Land Information System (LIS) is a subset of GIS with a focus on data concerning land records*".

In the context of this research, land information is the information for all land parcels, in urban and rural areas. According to (Lemmen & Oosterom, 2002) "*A cadastral system covers both land registration (the administrative/legal component) and the cadastral map (the spatial component). The combined process is called land administration and a cadastral system is the environment in which this process takes place*". According to (UN/ECE, 1996) "*Land administration is the processes of recording and disseminating information about the ownership, value and use of land and its associated resources*". According to (M.-P. Törhönen, 2004) "*land administration is one, if not the main land policy instrument. Land policy is a governmental instrument that states the strategy and objectives for the social, economic and environmental use of the land and natural resources of a country. It includes the regulations and measures of the rights to land (land tenure), the use of land and the valuation of land*".

In land administration system there is relation between people and land, it is important to keep updating information, for both spatial data and related legal administrative data. According to (Deininger, Ali, Holden, & Zevenbergen, 2008) lack of updating could quickly undermine the reliability of the system, especially in areas with higher transaction frequencies, thus undermining its overall reliability and trustworthiness. According to (Heo, et al., 2006) spatial data changes in a parcel-based LIS mean changes of parcel boundaries. Legal and administrative actions on parcels result in changes of the attributes in a cadastre. According to (Williamson & Ting, 2001) "*Cadastre is normally a parcel based and up-to-date land information system containing a record of interests in land (e.g. rights, restrictions and responsibilities). It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, and ownership or control of those interests, and often the value of the parcel and its improvements.*" Land tenure system or a land register is sustainable if it manages to administer land effectively and to reflect the actual relationships between people and land (M.-P. Törhönen, 2004).

The way to get land information is through land registration, and one of the ways of registering land is the involvement of local people in the process of land registration through P-mapping. This research studies land registration with application of surveying general boundaries in P-mapping. According to (Bogaerts & Zevenbergen, 2001), under general boundaries, the emphasis is on the visible features on the ground. In general, these features are supposed to coincide with the approximate position of the boundaries. These features can be mapped relatively easily; creating a cadastral index map, with a graphical representation of the boundaries. However, these boundaries although clearly visible in the terrain (walls, hedges, ditches, etc.) do not indicate the exact location of the legal boundaries, but they are very easy to measure with land surveying or with aerial photogrammetry.

2.2. Participatory mapping

In the context of this research, the use of the terminology of participatory geographic information system (PGIS) for land administration activities is under participatory mapping (P-mapping). This means that in P-mapping it doesn't mean to take necessary a GIS to the field or in another way, it is the use of local spatial knowledge for mapping spatial information, whatever techniques used.

2.2.1. Participatory mapping techniques

In participatory method people intimate knowledge of their own space in collectively interpreting aerial-photographs and satellite images. The development of GIS helps to develop local knowledge processes (e.g. constructing knowledge, discovering relationships in space, learning from each other, and building a common view) (Gonzalez, 2002).

Participatory mapping based on orthophoto is a precise, cost-effective and participatory tool for land use planning, resource assessment, impact monitoring, and conflict mediation. Participants in mapping exercises typically show high level of participation and engagement, most likely due to the authentic nature of the data. In addition, data input into a GIS program enables post-processing, permits enhanced cadastral activities, better land use statistics and computer-based monitoring of land use changes (Müller, Wode, & Wehr, 2003).

Participatory mapping can also be done in mobile GIS[4]. This is done for example by uploading orthophotos into the mobile devices, such as PDA[5], to take in the field for data collection. According to (Verplanke, 2004) "*local communities can learn without much difficulty to use mobile GIS to make inventories of their natural resources*." But on the other hand, this author argues challenges in the use of mobile GIS for ordinary community. According to this author, it is challenge in the use of mobile GIS to explain the basic functions and features of a computer to people that are unfamiliar to the concept of computers. A lot of button pressing is necessary to get to the starting point of the GPS exercise, which is difficult to achieve for someone unfamiliar with the equipment.

2.2.2. Participatory mapping in the context of land tenure

The community involvement in land tenure regularization activities is seen as an instrument for engendering social capital and a strategy for resource mobilization towards securing tenure (Magigi & Majani, 2006). In South Africa, in the Mpumalanga Province, local people traced their views on paper maps by using pencils and colored markers on how land reform would be done in their area(Weiner & Harris, 1999). The value of participation in land registration is the information agreed upon by local people. For this reason, the first phase is the public information. In Cambodia, registering land systematically by using orthophotos printed maps, the participation of local people is to provide information over their parcels, and the adjudication officer and the demarcation officer literally go together to the parcel in question on the agreed date. During land adjudication, the existing rights in parcels are ascertained, not altering the existing rights or creating new ones. In demarcation of parcels, boundaries are delineated and agreed upon with the adjoining owners or other interest parties (Törhönen, 2001).

"*PGIS is the relationship between the use of geo-information and governance to foster accountability, transparency, legitimacy and other dimensions of governance, to facilitate systematically identifying and representing the spatial rights of people to their land and land resources, in terms of ownership, access, use and management*" (McCall, 2003). This author argues the expectation of P-mapping to be implemented in a participative manner and make use of local information within which local spatial knowledge (LSK) is a special category. Untrained people, with LSK, can work effectively, easily and happily interpreting aerial photos.

[4] Mobile GIS is the combination of GIS software, GPS, and mobile computing device. Mobile GIS fundamentally changes the way information is collected. A mobile GIS allows to visualize information in a digital map.

[5] PDA stands for a personal digital assistant. It is an electronic handheld information device.

During land registration process local people should be involved in land adjudication and demarcation process using understandable mapping tools in applying LSK. According to(Lemmen and Zevenbergen, 2010), in Ethiopia, in 2008, a team conducted a simple field test using Quickbird satellite imagery in the programme of rural land certification. The results showed that high resolution imagery based in land adjudication is useful in P-mapping. The data collection in the field was done with the help of land rights holders and local officials. The image quality of the plots at a scale of 1:2000 was sufficiently high to allow the parties to easily understand the images and contribute input, making the process very participatory.

2.2.3. Ethics and participatory mapping

The ethics in participatory mapping is necessary in the whole process of land registration. It would be in preparation of field work, during the field activities, and after data collection. This motivates local people to participate by using their LSK. Before starting land registration in a certain area, local people should be well informed about which purpose and whose purpose. The facilitators/planners should make clear the objectives of the activity and why the involvement of local people. "*If carefully considered, the 'Who?'/'whose?' questions may induce appropriate attitudes and behaviours in the broader context of good practice*" (Rambaldi, Chambers, McCall, & Fox, 2006). These authors describe guiding principles which should be taken into consideration for PGIS, such as to be considerate in taking people's time, to be careful in avoid causing tensions or violence in a community, put local values, needs and concerns first, to make participation be informed consent, not to raise expectations to the community, etc. According to (Wang, Yu, Cinderby, & Forrester, 2008), the design of PGIS process is mainly based on participants abilities and needs, for example, lower education of villagers and high aspirations amongst local communities for expressing their perspectives in planning process. PGIS attempts to mobilize the inherent intelligence of local people, involving them in actions rather than providing training in how to drive a GIS.

During P-mapping the planner/facilitator should not rush the process. The community needs to learn how to use the equipments and how to proceed the work. Regarding this, the planner should choose spatial information technology appropriate to the activity but also which local people would understand without difficulties.

The transparency is important in P-mapping to protect rights of all parties. According to (Weiner, Harris, & Craig, 2002) "*Community-based GIS projects simultaneously promote the empowerment and marginalization of socially differentiated communities. As a result, the nature of the participatory process itself is critical for understanding who benefits from access to GIS and why*." According to (Törhönen, 2001) *"Special attention has to be paid to the weak groups. Women are often potentially weaker than men, in terms of securing their land rights. Other vulnerable groups might be the poor, disabled, illiterate, etc. In the worst case, an ignorant registration procedure could enable the powerful people to take advantage of the weak and formalise land grabbing. Prevention comes in the form of publicity, leaving little space for corruption and other violations".*

2.3. Concluding remarks

It has been shown from a literature review on a related analysis that P-mapping, land administration and ethics are related to each other. In land registration process land owners show their parcels boundaries agreed upon by their neighbours who are also present in the field to show their respective parcels boundaries. P-mapping is useful in land registration to involve local people in this process for better land administration. The ethics in P-mapping are also necessary to make the participation useful.

The next chapter presents data acquisition techniques existing in Rwanda, and the focus on orthophoto based land adjudication in P-mapping.

3. CADASTRAL SURVEY PROCESS AND DATA ACQUISITION TECHNIQUES IN RWANDA

In Rwanda, there exists too types of cadastral survey process, these are fixed boundaries survey and general boundaries survey. This chapter describes in short the existing data acquisition techniques in Rwanda, and the focus on orthophoto based land adjudication in P-mapping in general boundaries survey. This description is needed to compare the existing method of data acquisition with the digital pen based method in chapter 5.

3.1. Process of cadastre

Before the organic law n° 08/2005 of 14/07/2005 determining the use and management of land in Rwanda, cadastral survey in Rwanda was a centralised system on a demand led basis in rural and mainly in urban areas. This process was done under fixed boundaries. According to (Bogaerts & Zevenbergen, 2001) *"Under fixed boundaries, all parties concerned have to fully agree on the exact position of each boundary point. This means that once such a position is agreed upon, it is marked in the terrain with high precision. The demarcation, measuring and registration of fixed boundaries ask for more time and effort. General boundaries would be a good alternative, and owners can then, later, when they feel the need, apply for having their boundaries converted to fixed ones at their own expense"*.

Currently in Rwanda, with the land reform policy, all land in country is being registered systematically. This will improve land tenure security to anyone who has right to a certain land in the country. To achieve this, P-mapping is adopted, and this process is based on the use of high resolution orthophotos for general boundaries survey.

3.2. Techniques of cadastral survey

Survey techniques used in Rwanda are of the following categories: terrestrial based techniques, airborne and space techniques. Terrestrial based techniques consist of optical theodolite, total station and global positioning system (GPS). Airborne and space techniques consist of aerial photographs and satellite images.

Since long time, theodolite was used for fixed boundaries survey, with establishment of monuments, in rural areas and mainly in urban areas. This instrument is still used but it is now less used because of the acquired advanced survey technologies in the country. According to (Österberg, 2006), since 2002 GPS is used in land survey in Rwanda. At the beginning, it was limited in Kigali City for establishment of cadastral database using GIS/ArcCadastre.

At the moment, GPS and total station are used by National Land Centre (NLC) and private surveying companies for surveying fixed boundaries, with the establishment of monuments for showing the boundary of each corner point surveyed. *"GPS-surveying requires less technical expertise than traditional surveying. The software guides the user; understanding the underlying measuring principle is not necessary. The surveyor only has to take care of his own roving receiver (data-terminal)"* (Salzmann, 2002).

Although, there are some challenges. The modern accurate GPS is not extended in land surveying departments; the equipments of this kind of GPS are still very few for the reason of expensive costs. In Rwanda, district land bureaus use navigation GPS, it is not surveying GPS.

Orthophotos with high resolution are used in systematic cadastral survey process in country; they are used in P-mapping. General boundaries are identified on the image and agreed upon by all parties concerned,

then marked, no establishment of monuments. After field work, the parcels boundaries are digitised using GIS software packages.

3.3. Human resources in surveying

Every district land bureau has a surveyor. The human resources working in land surveying in district land bureaus have their background in domains which provide some training in surveying such as geography, and civil engineering.

In parcels boundaries demarcation using orthophotos, the human resources required are local people in their respective areas; they are trained as para-surveyors on how to use the orthophoto map. The training is undertaken when doing the parcels boundaries demarcation work in the field, and after three to four weeks they get familiar with the work, and they can work by themselves. After they finish covering their area, they train also other para-surveyors in other areas as the systematic land registration is progressing, thus they become also the trainers of others.

3.4. Technological bottlenecks in carrying out the survey

Among the bottlenecks in carrying out the survey, there is a lack of surveying law in the country determining for example the accuracy tolerance, etc. The lack of this legal framework affects techniques of data acquisition. Beside this, one of the bottlenecks in carrying out the survey is the lack of the appropriate surveying equipments.

3.5. Participatory mapping in data acquisition for land tenure regularisation

LTR formalises land tenure by establishing how people came by their land, they make a claim, they show what evidence/documents they have to support their claim, they define their parcels boundaries, and this brings to legal first registration of their lands legal titles.

3.5.1. Main activities of land tenure regularisation in Rwanda

The main activities and actors in LTR from preparatory work to field work, and titling are:

- Notification of LTR area
- Local information campaign to sensitise local people to participate in land adjudication process
- Land adjudication and demarcation of parcels boundaries
- Objections and corrections
- Disagreement resolution (in case of disagreement)
- Final registration and titling

Regarding the period for objections and corrections, this is done after the digitisation of parcels boundaries and data entry of related legal administrative data (attributes). After this, the digitised data (boundaries of parcels and related attributes) are printed and taken back with the original field sheets to the concerned administrative cell for the feedback of local people. The following figure presents the main activities in LTR and actors.

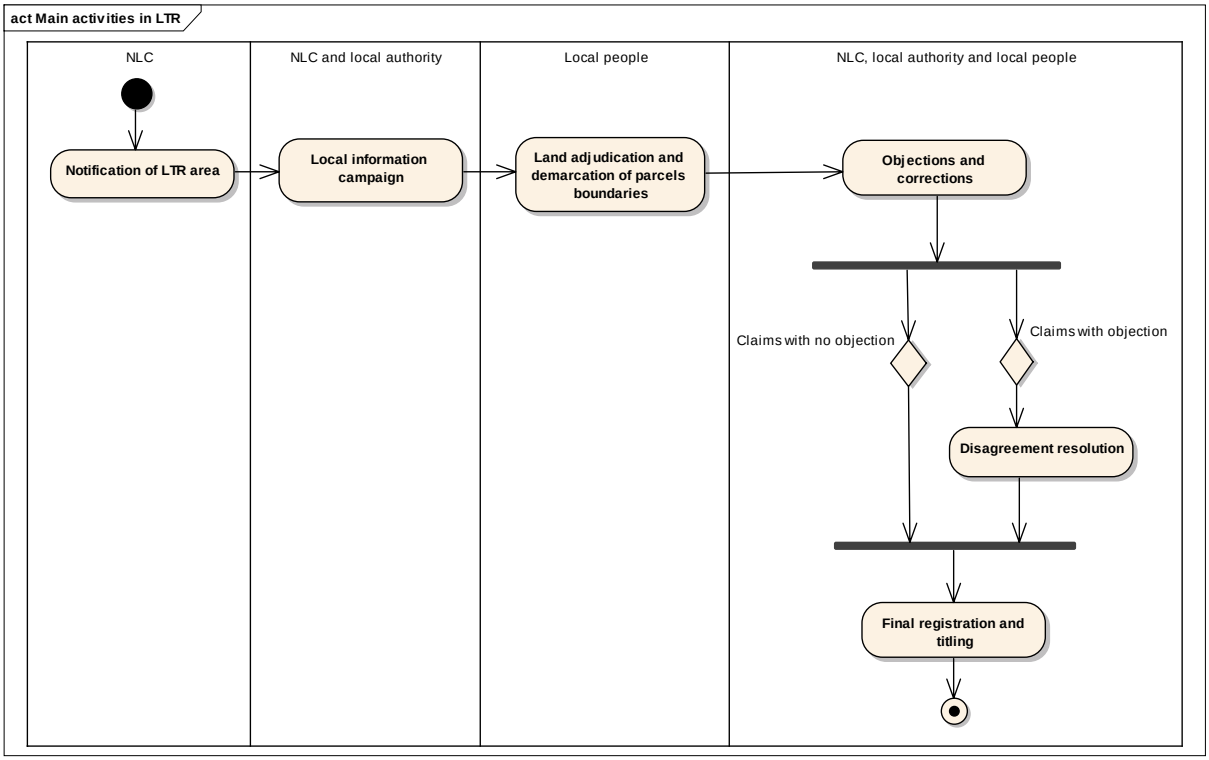

Figure 1. Main activities in LTR

According to (de Vries, 2004) one of the key common elements of progressive titling is gradual upgrade of land rights formalisation, in order to improve the level of tenure security, and to provide additional means of land management.

One district curried out systematic land registration in 2003. This was in former Itabire District, and the main objective was to reduce land disputes (MINITERE, 2007).

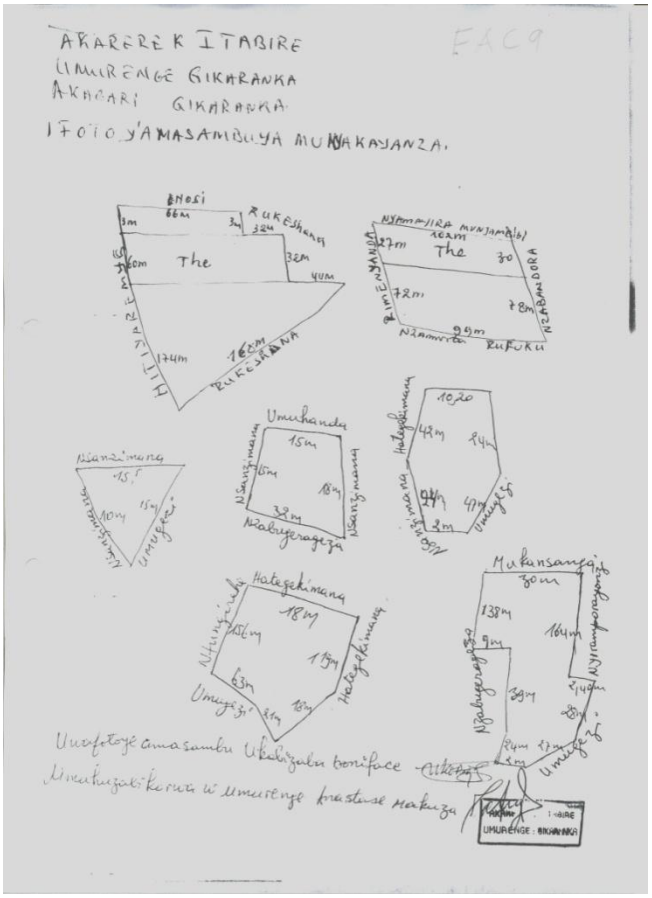

Figure 2. Parcel sketches in former Itabire District

Source: MINITERE[6], 2007

As shown in the figure 2, the land registration was done by using the traditional measurements, this was done by tape measure.

3.5.2. Orthophoto based in applying participatory mapping

During LTR trials, in 2007, the high resolution (0.60m resolution) Quickbird satellite imagery which date of 2006 was used. The image resolution describes the detail an image holds; resolution quantifies how close lines can be to each other and still to be visibly resolved. Higher resolution means more image detail. Quickbird satellite imagery used in LTR trials provided an easily understandable basis for the identification and demarcation of land parcels as part of the LTR. Four districts were selected for LTR trials (Karongi, Musanze, Gasabo and Kirehe districts). In each district, the LTR process was done in one cell administrative boundary.

The Quickbird satellite imagery used in LTR trials was orthorectified. Orthorectification is the process of geometrically adjusting a perspective image to an orthogonal image by transforming coordinates from the image space to the ground space and removing tilt and relief displacement. A perspective image, camera or sensor calibration information, ground control points[7] and a digital elevation model[8] are the main inputs

[6] MINITERE is former Ministry of Lands, Environment, Forest, Water and Mines. Later it changed to MINIRENA (Ministry of Natural Resources). At the moment the land sector and environmental sector are in MINELA (Ministry of Environment and lands).

[7] Ground control point (GCP) is a point on the surface of the earth of known location, fixed within an established co-ordinate system, which is used to geo-reference image data sources, such as remotely sensed images or scanned maps.

[8] Digital elevation model (DEM) is a digital representation of ground surface topography or terrain. It is also widely known as a digital terrain model (DTM).

for orthorectification processing. The absolute accuracy of orthoimages is largely dependent on the quality and the distribution of the ground control points used to orient the image to the ground space. The role of the DEM is to eliminate the effects of terrain relief displacement (Liu, Zhang, Peterson, & Chandra, 2007).

After LTR trials, land registration process is extended to other areas using high resolution orthophotos produced from aerial photographs. Quickbird satellite imagery used in LTR trials and aerial photographs used for now are both orthorectified, they can be used to measure distances because they are an accurate representation of the Earth's surface.

The orthophotos produced from aerial photographs were produced for Project Rwanda National Land Use and Development Master Plan; they date of 2008 and 2009. These orthophotos have 0.25m image pixel resolution, and they are geo-referenced and projected in Rwanda geodetic system; the spatial referenced system is ITRF 2005 (Swedesurvey, 2010). These orthophotos are now also used in land registration process.

3.5.3. Production of field sheets

Different map scales are used for preparing field sheets, and this is related to the size of parcels and land management in different areas. 1:500 scale is used in Kigali City, part of spontaneous areas where the plots are dense and without any planning, and 1:1000 scale in other areas in Kigali City and other urban areas of the country. 1:1500 scale is used in North, West and South parts of the country, and 1:2000 scale is used in East part and in rural part of Kigali City. For every scale used in a certain area, there is an overlap between 2 consecutive field sheets, thus they have same features between their overlap, so this allows demarcating a parcel which has boundaries on more than 1 field sheet. The field sheets are printed on A2 size. After the preparatory work, parcels boundaries demarcation and land registration start.

3.5.4. Field work for parcels boundaries demarcation and registration

In one cell[9], four teams process/do the work. Each team is composed by adjudication committee (two members of cell land committee and three members of umudugudu[10] committee) and two para-surveyors.

In field, the following materials are used:

For parcels boundaries demarcation, the materials are:

- Orthophoto maps/field sheets printed on A2 size.
- Clip board, pencil, rubber, pencil sharpener, ruler, form with official stamp, and tape measure. A tape measure is used when it is difficult to find features on map like in forest; it helps by using the measurements of tape measure on the ground, and then based on these measurements demarcation of parcel boundaries on map is done by using the scale.

For land registration the materials are claim receipts and objection receipts, registers books, pens, tampon and its liquid.

The following figure presents the procedures applied in parcels boundaries demarcation and registration in the field:

[9] A cell is administrative boundary which is land registration base unit. It is composed by more than 1 umudugudu.

[10] Umudugudu is the last smallest administrative boundary.

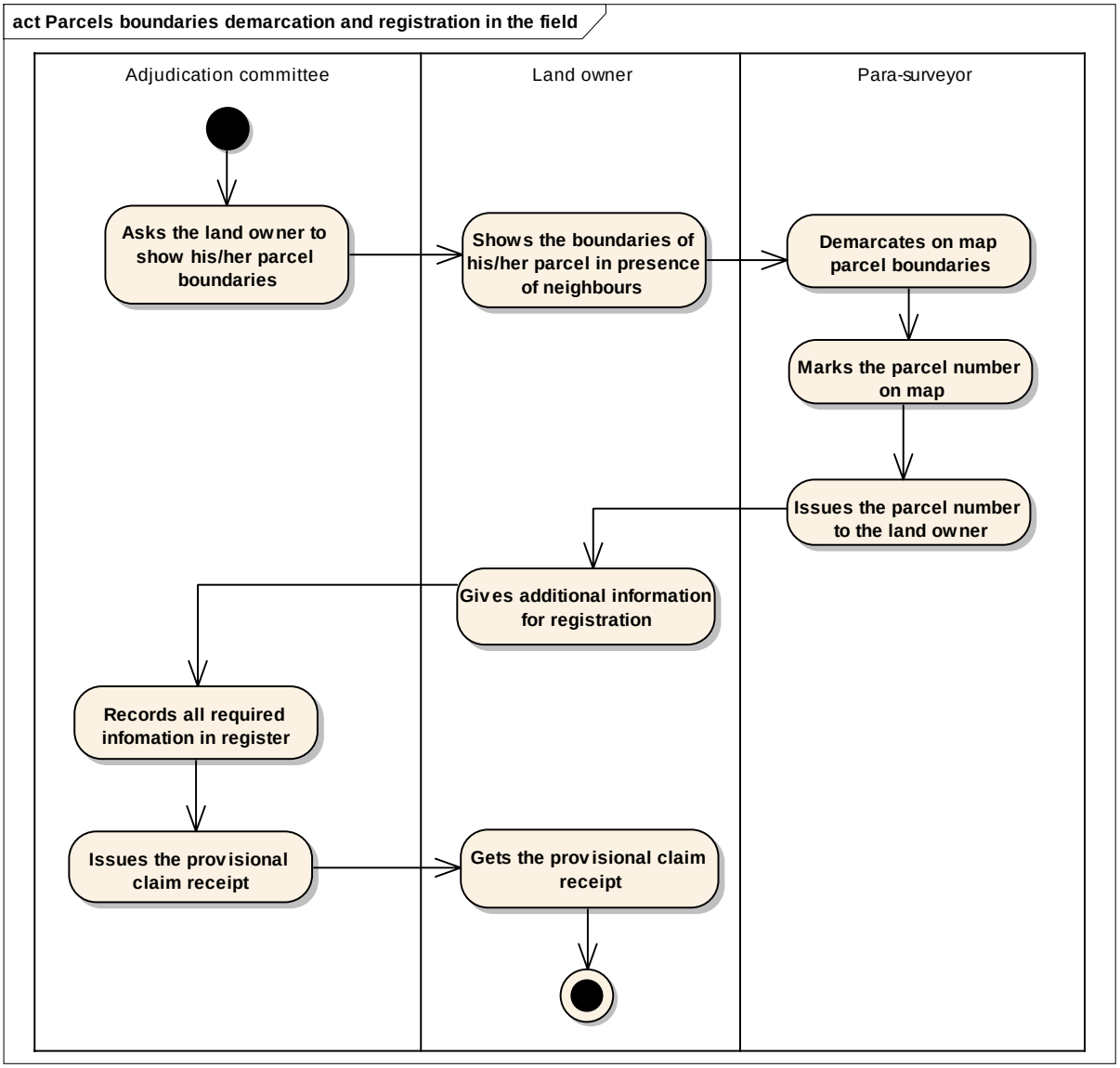

Figure 3. Procedures applied in parcels boundaries demarcation and registration in the field

As shown in the figure 3, the following steps are done in the field when doing LTR:
1. The adjudication committee, accompanied by a para-surveyor, requests the land owner to point out the existing physical boundaries of his/her parcel in the presence of land owners of neighbouring parcels.
2. The para-surveyor identifies parcel boundaries on the orthophoto map and marks the boundaries features shown on actual ground as they appear on the orthophoto.
3. On completion of the whole accepted perimeter of the parcel as it exists, the para-surveyor then issues a unique consecutive number for that parcel.
4. The unique number is then marked on the orthophoto map. The para-surveyor marks the parcel ID inside the parcel to the map, or besides by using the arrow if the parcel is too small. S(H)e writes also, on the form which has the official stamp, the parcel ID, the land claimant names, parcels IDs of neighbouring parcels, whether there is servitude on that parcel or whether not, the existing land use, remark, names of para-surveyor and his/her signature, administrative location of that parcel (sector, cell, and umudugudu), and date of parcel boundaries demarcation. The land holder takes this form to the adjudication committee (AC), and the AC fills the detailed information in a register book.
The information filled in lands claims register book is the administrative location of the parcel (province, district, sector, cell and umudugudu), identification of the parcel (date of registration, parcel number), identification of provisional landowners (names of land claimants, their personal IDs), relationship of land

claimants, whether there is case of orphans or widow, names of persons representing orphans under 18 years old, their relationship with those orphans, personal IDs of those orphans' representatives, names of other persons who have interests/right on that parcel, their personal IDs, and the relationship they have with landowners. The administrative location of landowner's residence is also recorded in register. Other information is land acquisition type, existing documents proving the ownership on that land, what land is supposed to be used for, existing land use, whether servitude on that land, and whether disagreement on the parcel. After the AC to fill the detailed information in the lands claims register, the AC gives land claim receipt to the land claimant.

Regarding the disagreement on parcel, in that case the parcel is recorded both in lands claims register book, and there is another register book filled with information on disagreement (lands disagreements register). The information[11] filled is almost similar to the one filled in lands claims register book, and with additional information on disagreement. After the AC to fill the detailed information in the register of lands disagreements, the person(s) who disagree the information provided on that parcel gets land disagreement receipt.

There are 4 teams working in 1 cell, and in order to avoid that 1 parcel is demarcated and registered by more than 1 team, thus to be demarcated and registered twice or more, the 4 teams are deployed in a way that every team has a delimitation of the area to demarcate within a cell administrative boundaries, they are divided referring to the common references such as roads, rivers, and other natural or physical features. During parcels boundaries demarcation, for a parcel which has boundaries in more than 1 cell administrative boundaries area, every piece of land is demarcated and registered in a cell that it is located. But for a piece of land which is less than 5m of distance from cell boundary, this piece of land is demarcated and registered in a cell that has the biggest part of that parcel. This case happens on parcels which are in line of division between 2 neighbouring cells, and that line of division is neither natural nor physical feature, for example neither river nor road such as in forests, farms, even in some marshlands. Demarcation of land is completed at the same time as adjudication and recording of administrative information. In case of disagreement of the information provided on parcel in the field, the AC resolves. And if it is not resolved, the parcel is registered as the parcel with disagreement, and the disagreement is taken to mediation committee (Abunzi) before final registration and titling.

The orthophoto based method for parcels boundaries demarcation is suitable for the progress of cadastral surveying in the country, all parcels are demarcated and registered by local people, they understand orthophoto map; this requires simple field work training.

3.5.5. Spatial analysis of cadastral information

After field work, the paper based data is taken to NLC office for digitisation (data entry of legal administrative information and digitisation of parcels boundaries). After digitization of spatial data and non-spatial data, these data are linked by using parcels IDs for spatial analysis, land ownership analysis, land disagreement analysis and other analysis can be done spatially.

[11] The information filled in the lands disagreements register is administrative location of that parcel (province, district, sector, cell and umudugudu), identification of the parcel (date of registration, parcel number), identification of persons who disagree the information provided on that parcel (their names, their personal IDs, their relationship, names of persons representing orphans under 18 years old, their relationship with those orphans, personal IDs of those orphans' representatives, names of other persons who have interests/right on that parcel, their personal IDs, and relationship they have with persons who disagree the information provided on that parcel, relationship that persons who disagree the information provided on that parcel have with land claimants). The administrative location of residence of the person(s) who disagree the information provided on that parcel is also recorded. Other information recorded is the type of disagreement, and existing documents proving the ownership on that land.

3.5.6. Status of parcels boundaries demarcation and post-processing digitisation

The speed of parcels boundaries demarcation in the field and post-processing digitisation in the office depends on the land management, land cover, shapes and sizes of parcels.

In residential areas like in urban areas and agglomerations in rural areas, the number of parcels boundaries demarcated in the field is high because of buildings on small sized parcels. It's easy to identify a building plot on the image compared to a parcel in the forest. This is the same when doing post-processing digitisation in the office.

In Eastern zone, parcels boundaries demarcation and post-processing digitisation is fast, parcels boundaries are clear because of land management in this zone. The parcels have regular shape (rectangular), they have been subdivided and allocated by the State, agricultural land is separated from residential land. In this area, the demarcation of parcel boundaries takes time because parcels are big from farms, and it takes time to cover the entire perimeter but the total area covered is big. This is the same for post-processing digitisation in the office, it is relatively fast.

In West, North and South zones, parcels boundaries demarcation and post-processing digitisation is less fast compared to the other mentioned areas. Parcels in these areas are in most cases inherited land, and/or purchased lands, they are scattered with irregular shapes; but also agriculture land is mixed with residential land.

Rwanda has 2148 administrative cells. As mentioned in introduction, systematic land registration started in 2007, and 4 cells for LTR trials were covered in this year (2007) and before extending the programme at national level all parcels boundaries of these 4 cells were digitised. Since June 2009 LTR programme is extended to national level, and at the end of august 2010, other 399 cells were adjudicated and demarcated. Among these cells, 55 cells were digitised at the end of August 2010. The following table shows the progress between end June 2009 to end August 2010.

Adjudicated and demarcated parcels (cells covered)	Adjudicated and demarcated parcels (cells in progress)	Digitised parcels (cells covered)	Digitised parcels (cells in progress)
399	164	55	17

Table 1. Progress of field work and post-processing digitisation

At the beginning of October 2010, LTR was taking place in different zones in country at the same time (Kigali City: 15 cells, North Zone: 22 cells, West Zone: 22 cells, East Zone: 20 cells and South Zone: 12 cells).

As long as the number of adjudicated and demarcated parcels in the field increases, the number of staff to post-digitise these parcels is also required to recover the gap between the work done in the field and the workload in the office.

Period	June to September 2009	September to November 2009	November 2009 to April 2010	May to July 2010	August to September 2010
Number of human resources	1	2	2	7	17

Table 2. Human resources evolution for digitisation

At the end of August 2010, apart from 17 human resources who were working in post-processing digitisation, the total number of human resources who were working in GIS Unit was 19; there is 1 working for mapping and printing field sheets and 1 coordinating activities and working on other tasks in

relation with GIS for LTR, and other services in relation with national spatial information. In addition to this staff, there are other more 30 staff who started since October 2010 for post-processing digitisation work.

Post-processing digitisation of parcels boundaries is done by using ArcGIS software. The polygon feature class is created in the geodatabase. After digitising 1 complete parcel boundary, the entire parcel perimeter is a polygon, and the neighbouring parcels boundaries are digitised by using auto-complete polygon option, and other editing options. Post-processing digitisation of parcels boundaries is done at 1:500 scale. After polygonising parcel boundaries, the consecutive parcel ID is recorded in attribute table. As mentioned, the speed of post-processing digitisation depends on different aspects in the area digitised.

Area (Location)	Residential area (urban area and agglomeration): small parcels	Agriculture land mixed with residences (parcels of medium size)	Grazing land (parcels of big size)
Average of number of parcels digitised by 1 person per day/9hours	250	180	60

Table 3. Average of parcels digitised per day

When digitising parcels boundaries and recording parcels IDs, errors are corrected. During post-processing digitisation, overlaps[12] and gaps[13], happen when digitisation is not done properly and carefully. These errors are checked automatically by using ArcGIS topology error inspector, and then errors are corrected manually. For attributes, the errors happen during recording parcels IDs, and these errors concern duplications of parcels numbers and missing parcels numbers. These errors are also checked automatically and they are corrected manually by rechecking on field sheets used during post-processing digitisation, and then recording them correctly.

For the case of errors which the source is from the field, are corrected by field work rechecking. When doing post-processing digitisation in the office, GIS staff finds parcels IDs which are duplicated on field sheets, parcels IDs not assigned to any parcel, demarcated parcels but without IDs, parcels with unclear boundaries, issues between parcels bordering 2 neighbouring cells such as overlaps between parcels boundaries, and parcels not demarcated. The correction of these errors is to go to the location in the field and work with para-surveyors for field checking and correction.

In the pilot phase of LTR, the post-processing digitisation was done in Kenya/Nairobi from traced maps sent from Rwanda. These traced maps were drawn manually by para-surveyors by looking at field sheets they used in the field for parcels boundaries demarcation, and redraw the same parcels boundaries and rewrite the parcels IDs on transparent paper or tracing paper overlaid on A0 imagery maps. These traced maps were the ones sent to Nairobi, and then they were scanned and georeferenced for post-processing vectorisation of parcels boundaries.

After the pilot phase, the post-processing of demarcated parcels boundaries is done in Rwanda, at NLC office. For a while, post-processing digitisation was to vectorise parcels boundaries directly to the original orthophotos, and this method was the one which was used since June 2009 until end October 2010. At the beginning, the post-processing digitisation was done by referring to the pencil marks on field sheets as collected from the field, thus the concentration to the field sheet, then to the computer screen, and so on. But because of the way the pencil marks were not easily visible/readable for GIS operators during post-

[12] Overlap is when 2 neighbouring parcels have double boundary between them, thus their interiors intersect, and the interior of the one intersects with exterior of the other, both ways.

[13] Gap is when 2 neighbouring parcels are disjoint, thus their interiors do not intersect, their boundaries do not intersect, and interior of one doesn't intersect with boundary of the other, both ways.

processing digitisation, this approach changed, and in the post-processing, the first step was to redraw parcels boundaries and rewrite parcels IDs over the pencil marks to make pencil marks more visible on field sheets. This was done by the para-surveyors by using normal pen after land adjudication process of the administrative cell they covered, and it was done in that cell before sending the field sheets at NLC office. The vectorisation process was the same as the previous one, to look at parcels boundaries as they appear on field sheets and to redraw the same parcels boundaries on the original image/orthophoto in ArcGIS, thus the concentration to the field sheet, then to the computer screen, and so on, the same for recording parcels IDs in the related attributes table.
Since November 2010, the post-processing work for para-surveyors is still to redraw parcels boundaries and rewrite parcels IDs over the pencil marks to make pencil marks more visible on field sheets, and this is done by using normal pen after land adjudication process of the administrative cell they covered, and it is done in that cell before sending the field sheets at NLC office. The post-processing for GIS staff at NLC office is to scan the field sheets, georeference those field sheets, and digitise (vectorise) parcels boundaries by redrawing them following the ones which are on those scanned georeferenced field sheets, and to record parcels IDs in the related attributes table. The field sheets are kept, and also the scans of those field sheets.

3.6. Concluding remarks

The orthophoto based method by using the pencil for drawing parcels boundaries on the plotted map is useful for general boundaries survey in Rwanda, and it promotes P-mapping. This method has advantages of making the progress of land registration, and it provides also land information. On the other hand, this method of analogue data from the field and many process steps for post-processing implicates the risks of different sources of errors, it is time consuming, and it implicates a lot space for archiving. Digital pen is the alternative method which can be assessed for orthophoto based land adjudication for spatial data capturing. The overview of the existing method as presented in this chapter is the basis for comparison between this existing method (pencil based P-mapping) and the alternative method (digital pen based P-mapping). The next chapter presents the methods used in this research to compare the existing method and the digital pen method.

4. DATA COLLECTION METHODS

This chapter presents the pre-field work activities, it gives an overview of the field work, further tests for para-surveyors in the use of the digital pen method, the selected sites for data collection, further tests for other approaches in the use of the digital pen method, and materials used in data collection. The figure 4 presents the steps used in this research for data collection.

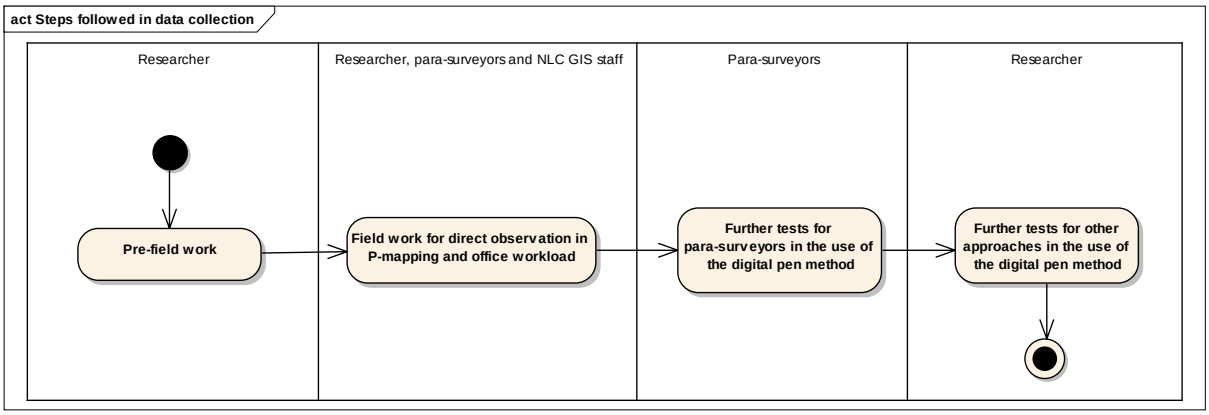

Figure 4. Steps followed in data collection

4.1. Pre-field work

Before field work, there was to do the tests to identify which approach to use for data collection, the polygon feature based was compared to the line feature based. These tests were done by the researcher. The results of these tests showed that line feature based is the one practical for parcels boundaries demarcation, and this approach was the one adopted for data collection in the field. For production of field sheets, the parcel boundary layer for legend was line feature class created in geodatabase.

4.2. Field work

During field work, there was to test the use of digital pen in P-mapping for land adjudication process. This was to work together with local people in the field where LTR was taking place, and test the practicability of digital pen for data capturing in P-mapping. There was direct observations on how this technique can be used in P-mapping by looking at the time it can take to train local people on how to use it and get familiar with it. But also during the exercise there was to ask the operators (local people) how they feel this method easier or difficult for them compared to the existing method (their acceptability). According to (Corne´ P. J. M. van Elzakker, 2008) observation in the field is the promising methodology to be used for the evaluation of the first mobile geo-application prototype. The observer would have to stay very close to the user during testing.

In P-mapping, a part from the users of digital pen (para-surveyors), there was also to see the attitude of local people (land holders) towards digital pen, thus their reactions when the pen is introduced to the site. In addition to this, there was also to assess the usability of the digital pen method in terms of reliability for field work operations. This was to identify how long the battery can last in the field before recharging it. Another test was to check what happens to data stored in digital pen when the battery is discharged, thus to check whether digital pen can still keep data which were collected before the battery getting discharged. There was also to assess reliability of the digital pen method for climate conditions. There was also to assess any issue which can occur in the field for technical matters for this electronic tool (digital pen).

In terms of time, there was to identify the speed in the use of the digital pen method compared to the existing method, both in P-mapping in the field and the office workload. There was also to check the outputs in terms of quality of data for the both methods. Beside this, there was also direct observations of the process done in the existing method, both in the field and in the office.

4.3. Further tests for para-surveyors in the use of the digital pen method

Other tests were done in the field work location area (Rwanda) to assess whether local people who were trained to collect spatial data by using the digital pen method during the field work in September 2010 could still remember how to operate in this method without anyone to show them again. These further tests were done in December 2010 by sending the equipments to Rwanda. The parcels boundaries reconstruction was done by the para-surveyors, and this was done at the NLC office. The task for these para-surveyors was to redraw the same parcels boundaries demarcated during the field work of September 2010, and rewrite the parcels IDs on digital paper. This reconstruction was done because of the technical issues which happened during the field work of September 2010 (see appendix 2). A part from the reconstruction of parcels boundaries, another field work for para-surveyors was also done in another new area where LTR was taking place, and these para-surveyors did parcels boundaries demarcation in P-mapping using the digital pen method.

For both cases of P-mapping in the field, the one of September 2010 and the one of December 2010, it was where LTR was taking place, the spatial units (parcels boundaries) collected in the existing method were also collected in the digital pen method, thus the spatial units were the same. With the 4 teams working in 1 administrative cell for LTR field work, they were rotating on the use of the digital pen method. This means that there were 2 teams working in parallel, 1 team continuing the daily work as usual using the existing method and another team using the digital pen method.

4.4. The selected sites for data collection

The field work of September 2010 was in one cell within Kigali City with urban and peri-urban characteristics. Normally, before field work, the plan was to work in 2 cells in Kigali City. One cell in peri-urban area with rural characteristics and one cell in urban area with urban characteristics. The purpose was to work together with para-surveyors of those 2 different areas. For urban area the reason was also that parcels are most of time small in Kigali City, part of urban area, but also big number of plots to demarcate and digitise compared to rural areas. This is in relation of errors which can happen when the parcels to work on are many and small.

In the period of field work (September 2010), LTR in Kigali City was taking place only in areas which are urban, and the choice for research field work was Musezero Cell, in Gisozi Sector, Gasabo District. With 4 teams which were working in this cell, a part from para-surveyors of Musezero Cell, their trainers, who are also para-surveyors, were from urban and most from peri-urban areas (1 from Gasabo Cell in Rutunga Sector, 1 from Nyagasozi Cell in Bumbogo Sector, 1 from Ngara Cell in Bumbogo Sector, and 1 from Gasharu Cell in Kinyinya Sector). After finishing LTR in their areas, these para-surveyors trainers went to Musezero Cell to train new para-surveyors of this cell.

Regarding further tests for these para-surveyors in December 2010, parcels boundaries reconstruction was done at NLC office, and the area of parcels boundaries reconstructed was Musezero cell. Another field work for para-surveyors was done in another new area where land adjudication process was taking place, this was in Kibenga Cell, in Ndera Sector, Gasabo District, in Kigali City, and this area has rural characteristics, with parcels of quite big size.

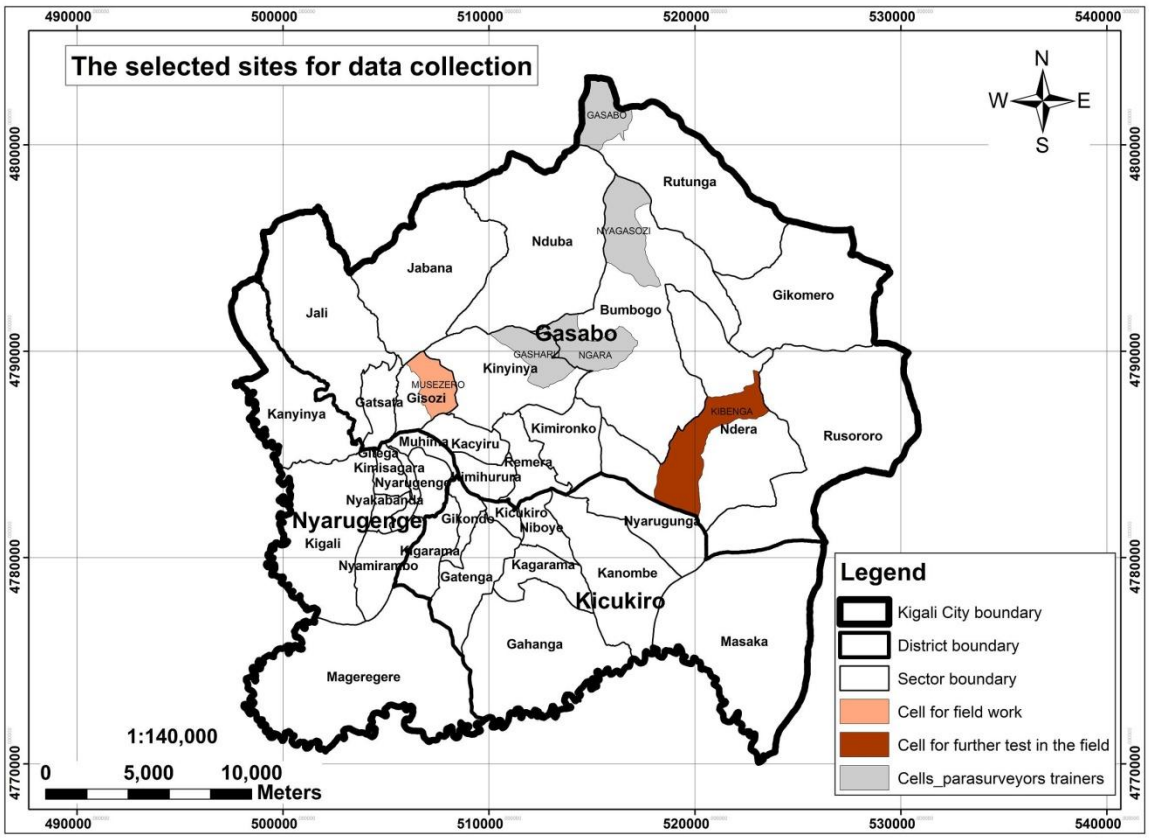

Figure 5. Location of the selected sites for data collection

4.5. Further tests for other approaches in the use of the digital pen method

After field work and further tests for para-surveyors, there were other further tests, and this was to look for the approach to use in order to improve the quality of outputs and to save time when using the digital pen method for spatial data capturing. This was desk work done by the researcher. One of the other approaches tested was the use of point feature based compared to the line feature based. But also another approach for line feature based was also tested compared to the one used in the field work, and this was to assess the use of line feature based by overlapping the lines when doing parcels boundaries demarcation in order to avoid the gaps, and so to facilitate the post-processing editing after uploading data from digital pen to the computer. For both tests of other approaches, point feature based and line feature based, the tests were done by redrawing the same parcels boundaries demarcated during the field work of September 2010, and rewriting the related parcels IDs.

4.6. Materials used in data collection

The following materials are the ones used during this research:

- Computer with installation of ArcGIS and Capturx for ArcGIS softwares for producing and printing maps from ArcGIS as digital paper
- Quick bird satellite imagery (0.60m resolution). This was used in pre-field work test. This image is the one covering Nyamugali Cell, in Gatsata Sector/Kigali City, which is one of the LTR trial areas. The plotted maps for this pre-field work test were printed at A3 paper size, and the map scale was 1:1000
- Orthorectified aerial photos/orthophotos (0.25m resolution). These orthophotos are the ones used in the existing method for the land adjudication process at national level. These orthophotos were used for the rest of the research (research field work, further tests for para-surveyors, and further tests done by the researcher)

- Plotted orthophotos printed at A3 paper size. The maps scales were 1:1000 and 1:1500, respectively for Musezero Cell and Kibenga Cell where the research work took place. These scales were the same as the ones which were used for field sheets of the existing method for LTR in these 2 areas
- Clip board to put the maps on in the field (plastic protection)
- Digital pen for drawing parcels boundaries and record their attributes (parcels IDs) on map
- USB adapter to transfer data from digital pen to the computer into ArcGIS, and also for charging the battery of digital pen to the computer.

The research assessed the digital pen method only for spatial data capturing because of the limitations of application software (Capturx for ArcGIS). With the discussions and demonstrations with Vicrea[14], by their application software (GOLDliner), it can be possible to use digital pen in data capturing for both spatial data and related administrative data. But this was not assessed during this research because of the limitation of time.

[14] Vicrea is Dutch company which has developed application software for the use of digital pen in data capturing for both spatial and administrative data.

5. COMPARISON OF THE EXISTING METHOD WITH THE DIGITAL PEN METHOD

This chapter presents the results of different tests done for the use of the digital pen in spatial data capturing, and it compares the existing method used in Rwanda for general boundaries survey with the digital pen method. The comparison is done by qualitative and quantitative methods.

5.1. The use of digital pen and digital paper in parcels boundaries demarcation

The tests were done to know which approach to apply for the use of the digital pen method in parcels boundaries demarcation in the field. For the map legend, two tests were done, spatial unit based on polygon feature, and spatial unit based on line feature.

5.1.1. Spatial unit based on polygon feature

If boundaries are drawn in polygon mode, each lift of the pen implicates the start of inserting a new polygon. This creates a series of polygons as can be seen in the figure 6. The lines in red are as drawn on digital paper. In yellow are series of polygons calculated by the application software; this includes polygons because of lifting the pen.

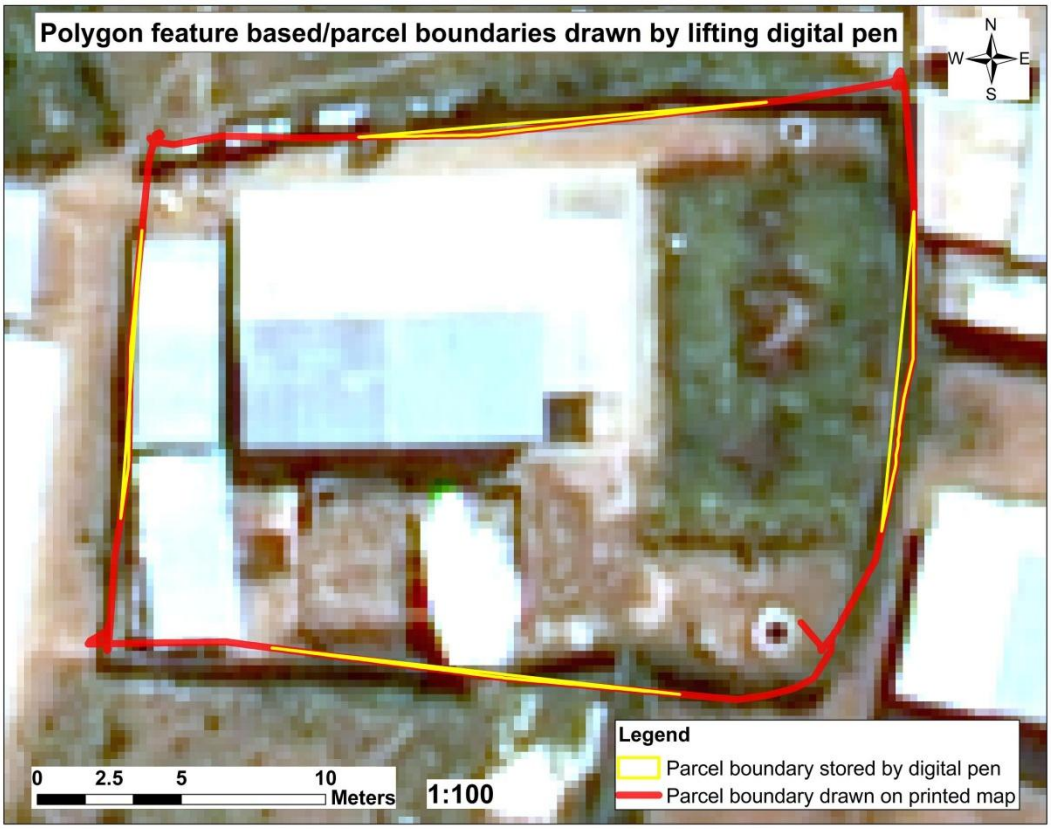

Figure 6. Polygon feature based/parcel boundaries drawn by lifting digital pen

If a polygon drawn on digital paper (map) is not closed (the ending point not at least close to the starting point), then the closing of the polygon by the application software is done in an unpredictable way. See line in red as drawn on printed map and calculated polygon in yellow, to the left side of the figure 7. For

this reason, when drawing parcel boundaries, the operator has to close the polygon (the ending point at least close to the starting point), see to the right side of the same figure (figure 7).

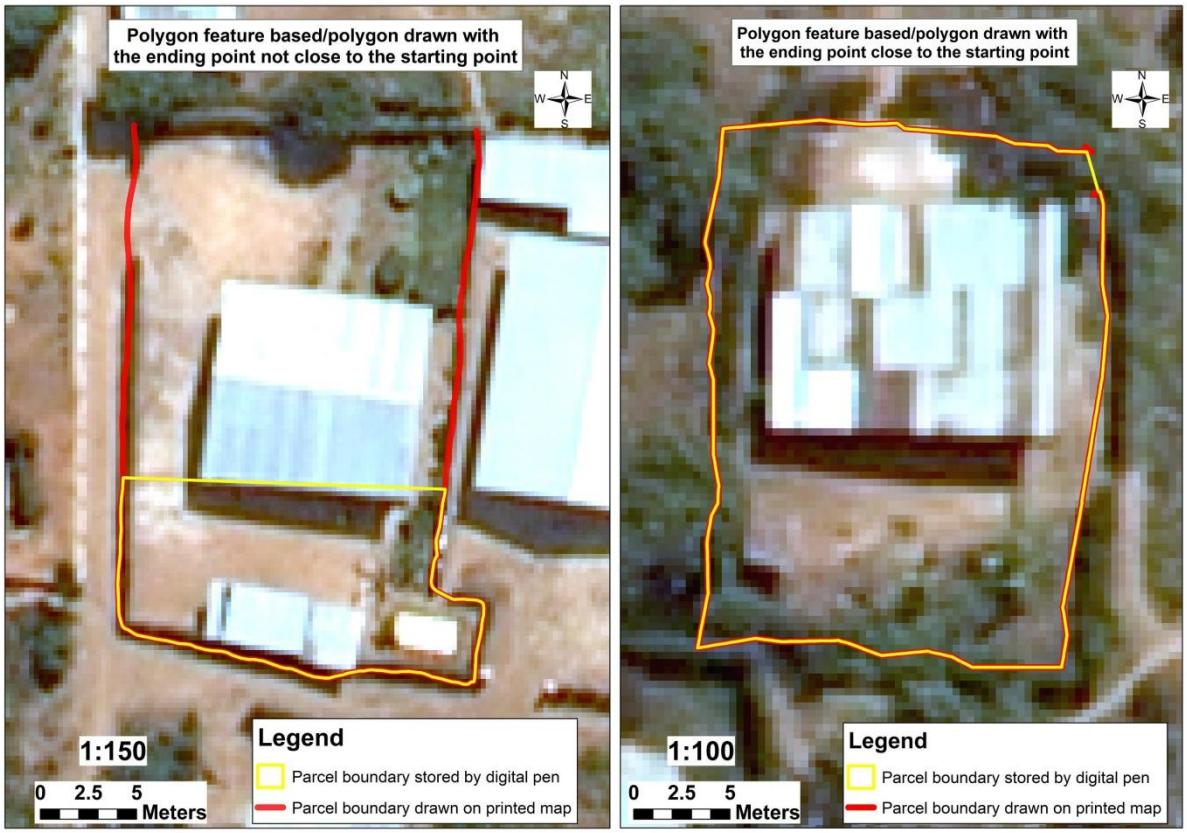

Figure 7. Polygon feature based/the ending point not close (left) and close (right) to the starting point

Another case is when drawing boundaries between neighbours. The figure 8 presents 2 cases. For case 1, to the left side of the figure, two polygons are drawn as complete closed polygons. This results in gaps and/or overlaps. For case 2, to the right side of the figure, the polygon presented to the right has been inserted in connection to the polygon to the left. The result is in this case that the polygon which is drawn incomplete (but in connection to the existing polygon) is closed in an incorrect way. This is because the application software (Capturx for ArcGIS) for digital pen doesn't have auto-complete polygon option.

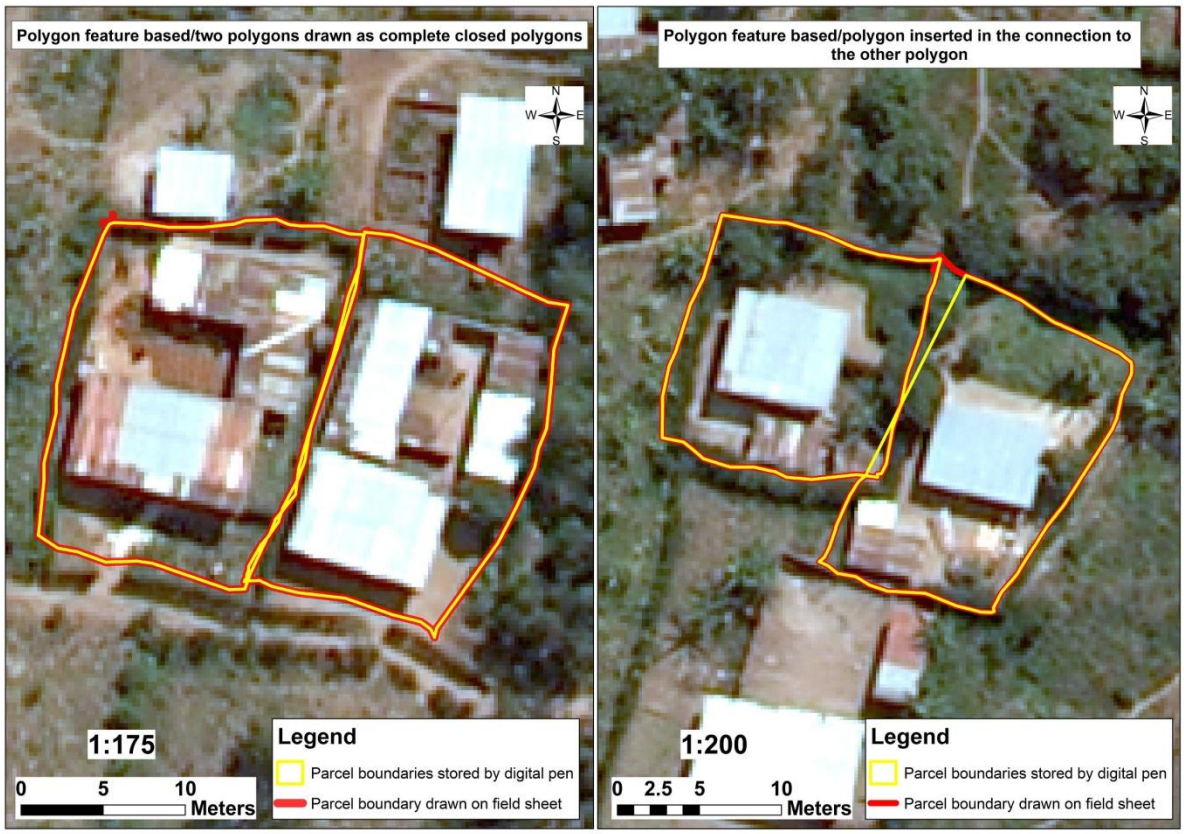

Figure 8. Polygon feature based/representations of boundaries between neighbouring parcels

But even if the application software for the digital pen would have the option of auto-complete polygon, the operator in the field would have the problem on drawing parcel boundaries in different segments, thus demarcating parcel boundaries from 1 boundary to another as he/she is going around the parcel perimeter until closing the complete perimeter. The issue here would be the one mentioned in figure 6. The approach of using polygon feature based requires to collect objects in complete polygons. This would not allow the operator in the field to collect objects as boundaries. With this regard, spatial unit based on line was the one adopted in this research for data collection.

5.1.2. Spatial unit based on line feature

The parcels boundaries demarcation in the field requires drawing boundaries, one by one, observe the boundary in the field, draw it on map as a representation of how it appears on the ground, the same to other boundaries until closing the entire parcel perimeter, then the para-surveyor issues a unique consecutive number of a parcel. To do this with digital pen, it requires choosing the line feature as map legend, and so after drawing one boundary, it is possible to move the pen from the map, check the following boundary on the ground, draw it, and continue drawing parcel boundaries on map until the completion of parcel perimeter. The approach of line feature based is to collect boundaries.

5.1.3. Functionality of digital pen in parcels boundaries demarcation

The main steps to plot a map as digital paper, to collect data and to correct the mapping mistakes after uploading data from digital pen to the computer, in ArcGIS, are described in appendix 1.
The use of the digital pen for drawing parcel boundaries, the operator selects the feature type in the map legend by crosschecking it with digital pen, and then draw parcel boundaries on the map as a representation of how the boundaries appear on the ground. If the digital pen is moved from the map when drawing parcel boundaries, the operator has to crosscheck again the feature in the legend before continuing drawing the following parcel boundaries.

Regarding the use of markup layer for annotations on the map, the operator can write as much as needed when he/she is still using the same annotation type before changing to another legend type. The annotation on map is used in the field to mark the parcels IDs, mistakes and remarks, and this is visualised on map after uploading data from digital pen to the computer. According to the application software (Capturx for ArcGIS), these annotations are stored in the pen not as digital attributes to display for example in excel spread sheet, they are digital parcels IDs only to display on map, in ArcGIS, they are figures. This means that to record parcels IDs in attribute table it's done by typing manually in ArcGIS by referring to the ones displayed as annotations inside every parcel.
Continuation of crosschecking digital pen into the legend on map (either for line feature or/and Capturx markup layer (annotation)) doesn't matter. To crosscheck many times in the previous location is possible, but the operator has to pay attention for not tearing the paper.
The digital pen uses ink and as a matter of fact everything drawn and written on the map stays on it; it cannot be erased on field sheet as it can be done when using pencil in the existing method where any mistake done on map is erased by using the eraser/rubber, the available option for the digital pen method is the one of marking mistakes(with a class "mistake" in the legend).

5.1.4. Test in the office

After plotting 1 field sheet, it's better to make a test before printing other maps. This means drawing few imaginary parcels boundaries and write imaginary parcels IDs on the digital paper and upload data in ArcGIS to check if the pen stores correctly features drawn and related records written on the printed map. It can happen that the teams go to the field and pass all the day working, and when back in the office data are not displayed in ArcGIS because the pen didn't store everything or anything for the reason that the preparation and printing of maps was not done properly for the use of the digital pen. The ArcGIS operator should pay attention to this before deploying the teams to the field.

5.2. Tests of the digital pen method in participatory mapping

The tests for the digital pen method in P-mapping were done in 2 different periods. In the first period, September 2010, the researcher was in the field to perform direct observation, to train local people on the use of the digital pen method, to assess the time it takes for para-surveyors to get familiar with the digital pen method and to assess the skills required for the use of the digital pen method, to assess the acceptability of the operators/para-surveyors on use of the digital pen method in P-mapping, but also the attitude of local people (land holders) towards digital pen. In the second period, December 2010, for further test, the para-surveyors were working without the presence of the researcher, and they used the knowledge that they have got in the previous test. This was tested in P-mapping in combination with desk work.

5.2.1. Field test of the digital pen method in participatory mapping/first period

As mentioned in chapter 3.5.4., when doing LTR in a certain administrative cell, there are 4 teams working in the land adjudication process in the field. The field test of the digital pen method was done for the para-surveyors of the 4 teams which were working in Musezero Cell during research field work of September 2010.
On the first day of field testing the digital pen method in P-mapping, 2 teams of para-surveyors were working in parallel for each parcel, one team using the existing method, and another team using the digital pen method. The first para-surveyor using the digital pen method got the training by the researcher, and after 1 hour, this para-surveyor was familiar with the method, and he continued using it for more 2 hours and 30 minutes. Later the 2 teams exchanged the maps, and so the para-surveyor who was using the existing method did also practice on how to operate in the digital pen method. This second para-surveyor got the first training from his colleague para-surveyor who was using the digital pen method, and for the rest the researcher was supervising and facilitating the second para-surveyor. This second para-surveyor

got also familiar with the digital pen method after 1 hour and he continued using it for more 2 hours and 30 minutes.
On the second day, the other 2 teams did also practice on how to use digital pen. This was done as the previous day, 2 teams working in parallel on the same parcels, one para-surveyor using the existing method and another para-surveyor using the digital pen method, and later the 2 teams exchanged the maps. The third para-surveyor got the first training from his colleague para-surveyor of the second team, and for the rest the researcher was supervising and facilitating the third para-surveyor. After 3 hours and 30 minutes, the third para-surveyor exchanged the maps with the fourth para-surveyor who was using the existing method. The third para-surveyor gave the first training to the fourth para-surveyor on how to use digital pen, and for the rest the researcher was supervising and facilitating the fourth para-surveyor. For these other 2 teams, third team and fourth team, each para-surveyor got also familiar with the digital pen method in 1 hour, and for the rest of time it was for more practice. To get familiar with the digital pen method for those 4 para-surveyors, it took 1 hour for each para-surveyor and the rest of time was for them to continue practicing.
The point of view of those para-surveyors is that what is important is how to interpret the image as it is in the existing method, and the rest is to use digital pen as they do in existing method using pencil, and to remember first to crosscheck digital pen in the legend before using it for drawing parcels boundaries and to mark annotations. The para-surveyors understand the role of the legend for the digital pen method; they understand that the legend is there for allowing the operator to give command to the pen according to what the operator wants to record on map (parcel boundaries, mistake, parcel number and remark).

5.2.2. Time needed in the digital pen method compared to the existing method

During the test of the digital pen method for parcels boundaries demarcation in P-mapping, in the 2 days of working in the field with 4 different teams, for each day, the number of parcels demarcated in the field was the same for both methods, and the spatial units were the same. The use of the digital pen was not a constraint for para-surveyors; they used it at the same speed as they do in the existing method using pencil.. The total number of parcels demarcated during field work, in Musezero Cell, was 123 parcels, from parcel number 1200 to parcel number 1322.

5.2.3. Acceptability of the digital pen method

During the exercise of the digital pen method in parcels boundaries demarcation, local people got explanations of the purpose of testing the digital pen method. The operators (local people para-surveyors) of digital pen understand the purpose of this method, and they also understand the purpose of doing first a test of this method to assess whether it would be applicable. Their point of view is that the digital pen method is easy for data collection in the field, they find it almost similar to the existing method, they can use it without difficulties.
Regarding the attitude of local people (land holders) towards digital pen, they didn't mention that there is a new tool application on site, this is because of similarities between the existing method and the digital pen method.

5.2.4. Skills required for the use of the digital pen method

Most of the para-surveyors working in surveying of general boundaries in Rwanda are with secondary school level. This is not because it is a criterion for recruitment, anyone who has at least skills to read and write (thus with at least primary school education level) and who is motivated is allowed to pass the exam. The test to be recruited as a para-surveyor is to be able to identify a certain location on image/orthophoto where the interviewee is standing, and be able to read and write. For the digital pen method it is also to remember to crosscheck the digital pen in the legend before drawing parcels boundaries and record parcels IDs, and/or mark additional information on map. Someone with primary school level would also gets familiar with the digital pen method without difficulties if he/she is be able to get familiar with the existing method.

5.2.5. Visibility of the digital paper compared to the normal print

Even if it's possible to identify features on a digital paper, but compared to the existing method with normal print, the patterns on digital paper reduce the visibility of the image, this changes the true colour of the image. (see figure 9).

Figure 9. Comparison of visibility of map prints: normal print (left) and digital paper (right)

The figure 9 shows the contrast between the map printed for the existing method, to the left side, and the map printed with patterns (digital paper) through Capturx for ArcGIS for the digital pen method, to the right side. Even though the visibility of the digital paper (with patterns for the use of digital pen) is less compared to the map printed in the ordinary way (without patterns in the existing method), this was not a constraint for para-surveyors to see the objects on map during parcels boundaries demarcation. But in reality objects are more visible on map printed without patterns than objects on map printed with patterns.

5.2.6. Tests for para-surveyors in the use of the digital pen method/second period

In order to assess whether the para-surveyors who were trained on the use of digital pen during research field work of September 2010 could still remember how to use it after a certain time without using it, further tests were done. In this regard, the equipments for the digital pen method were sent to Rwanda, in December 2010, and the para-surveyors used again the digital pen method. This was assessed in two ways, parcels boundaries reconstruction for the area done during research field work of September 2010, and another P-mapping in another area. During these further tests, the para-surveyors did the work by themselves using the digital pen method without anyone to show them again how to use it.
For parcels boundaries reconstruction with their related parcels IDs, these para-surveyors did it by referring to the parcels boundaries drawn and parcels IDs written on maps used in the existing method. They have reconstructed the 123 parcels done during research field work in Musezero Cell. For another P-mapping in another area, Kibenga Cell, the para-surveyors did it by rotating for the use of digital pen as they did it in the previous P-mapping. Thus 2 teams were working in parallel for each parcel, one para-

surveyor using the existing method, and another para-surveyor using the digital pen method. For the outputs of further tests, see appendix 3.

Figure 10. Parcels boundaries demarcation in the field/further test

Source: Courtesy by NLC GIS staff/Biraro Mireille, 2010

In the figure 10, to the left side, is parcels boundaries demarcation in the existing method, and to the right side, is parcels boundaries demarcation in the digital pen method, and this was during further test for para-surveyors in P-mapping in Kibenga Cell. During this further test, 73 parcels were demarcated within 2 days, from parcel number 2706 to parcel number 2749, and from parcel number 2971 to parcel number 2999. During these 2 days it was raining, and in this working condition the number of parcels demarcated was limited. Regarding the rain conditions, it's the same for the existing method.
The results of both further tests, parcels boundaries reconstruction and field work in P-mapping, showed that the para-surveyors could remember how to operate in the digital pen method, they could remember the use of the map legend (crosschecking digital pen before drawing parcels boundaries and mark parcels ID, and/or other information on map).

5.3. Further usability testing

In this research, there was to assess the usability of digital pen in data capturing in terms of data storage, and how long the battery of the pen can last in the field being used before getting recharged, the security of data stored in the pen when the battery is discharged. Other tests were done to assess the reliability of the digital pen method for climate conditions, but also there was to assess any other technical matter which can occur.

5.3.1. Reliability in the use of the digital pen method

Digital pen has a lithium-ion rechargeable battery which can last for long time. During field work, at the beginning of a day, when the battery was full, it was used 7 hours for parcels boundaries demarcation during a day, and the battery was still charged of 87 % at the end of the day. The para-surveyors were trained to keep digital pen closed by its cover when they were not using it, and to open it only when using it on the map, and so to save the battery.
After recharging the battery; data are still stored in the memory of the pen and are uploaded to the computer, in ArcGIS. This test was done by drawing a certain number of parcels boundaries (imaginary parcels boundaries) and writing imaginary parcels IDs on map, and then leave the pen open, thus not to put its cover, and so to make the battery be empty, and it was totally discharged after 19 hours 21 minutes. The purpose of this test was to check if data stored in the pen before the battery getting discharged were

still stored in the pen. The result of this test was that all data were still stored in digital pen and they were uploaded from digital pen to the computer, in ArcGIS and visualised.
Regarding climate conditions, the digital pen method is reliable. Digital pen can capture the information recorded on digital paper under dust conditions. And if the rain falls on digital paper, and before drawing parcels boundaries and writing parcels IDs, the paper has to be first dried, then the digital pen can also capture the information recorded on the paper. The tests related are explained in appendix 2.

5.3.2. Technical matters

There are technical matters related to digital paper related to the printer used. Technical issues which happened during field work, and the details of the tests which were done are explained and demonstrated in the appendix 2. The equipments used for pre-field work test, during field work and after field work were the same. All the tests done during this research were done by using the same equipment, and so it was possible to do the comparisons under different circumstances.

5.4. Approaches for line feature based for spatial data capturing

During research field work and further tests for para-surveyors, the approach for line feature based was to draw parcels boundaries by connecting lines and try to avoid as much as possible the gaps and overlaps between lines. With this approach, there were many errors (gaps, but also some overlaps creating extra polygons), and these errors are visible after uploading data from digital pen to the computer, in ArcGIS. In the automatic correction of these errors, the ones which are not covered by the topology tolerance defined (preferably small tolerance), the manual editing workload for correcting the remaining errors is time consuming. After the results of this approach 1, the line feature based (approach 2) was tested, and this was to draw parcels boundaries by overlapping intentionally the lines in their connections in order to avoid the gaps but paying attention of not overlapping the lines in way that they create extra polygons when converted to polygons.

5.4.1. Line feature based/approach 1

When demarcating parcels boundaries by using digital pen, the pen stores everything recorded on the map even if there is no ink, and the operator is able to check only what is really drawn. After uploading data from the pen to the computer, in ArcGIS, it can be checked what has been recorded in the memory of the pen. There are errors to be corrected according to how lines are drawn on digital paper. These errors are especially gaps between the connections of lines, but also overlaps. During the research field work, and later in further tests for para-surveyors, the approach for line feature based was to draw parcels boundaries by connecting lines in ordinary way, thus without putting gaps or overlaps intentionally. In this approach, the gaps and overlaps which happened were not done by the intention of the operator, it was related to the manual drawing. With this approach, there are many errors happening, and this has a big impact when converting line feature to polygon feature. For gaps, 2 parcels or more are merged in 1 parcel according to how many gaps are between lines connecting parcels. For overlaps, according to how lines are overlapping, there are overlaps which create new polygons which don't represent any parcel existing on the ground. The figure 11 shows those kind of errors.

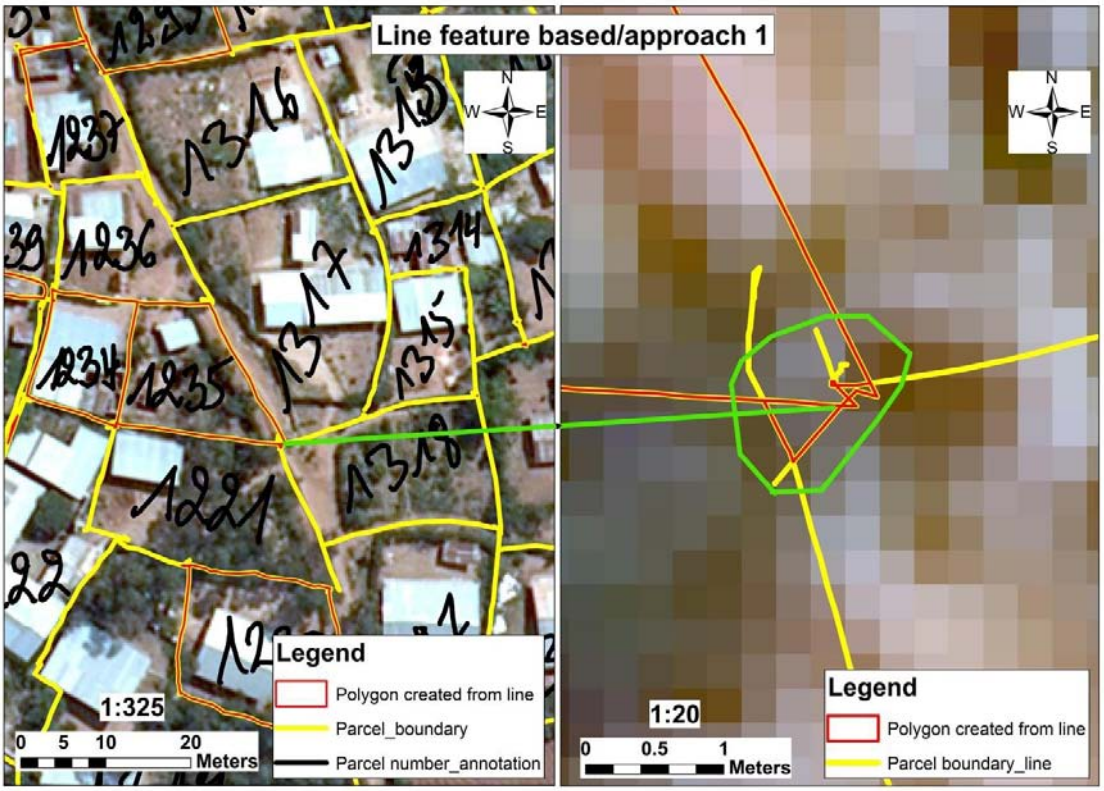

Figure 11. Line feature based/approach 1 (mistakes based on gaps and overlaps between lines)

The errors shown in the figure 11 are visible after uploading data from digital pen to the computer, into ArcGIS. These errors are more visible by visualising at higher scale to the one used for data collection. The parcels boundaries shown in this figure were drawn by para-surveyors during parcels boundaries reconstruction at the map scale of 1:000 which was the same scale as the one used in data collection in the field. This figure 11 shows the connection of 4 parcels existing on the ground (parcels numbers 1221, 1235, 1317 and 1318). By converting line feature to polygon feature, line features were converted to polygon features only for 1 parcel (parcel number 1235), and for the other 3 parcels it was not possible because of gaps between the connections of their lines. But also there are other 4 new created polygons in the connection of those 4 parcels. The new created polygons are not the real parcels existing on the ground, there are converted to polygons because of the way the line features are overlapping. This requires too much editing workload for correcting these errors before converting line feature to polygon feature, especially for gaps.

According to the application software (Capturx for ArcGIS), the digitisation for the line feature based approach is done in streaming mode when drawing parcels boundaries on digital paper, and this implicates redundancy of vertices (coordinates) for parcels boundaries (vertex representing field distances of around 0.1 meter and 0.2m, even a field distance of 0.01m between some vertices). Because of the errors happening in the connections of lines, there are involuntary/unintentionally extra lines created as the pen moves across the map, this implicates many errors to occur, and the automatic correction of these errors can create wrong boundaries because parcels boundaries are mixed (wrong boundaries and the true boundaries). The manual correction is also time consuming and difficult.

Before the correction of errors, in order to reduce the redundancy of vertices, and so to facilitate the manual correction of errors, the simplification of line feature class was tested at 1 m maximum allowable offset for simplification tolerance. Although a small tolerance was tested, the simplification removes vertices in some curves (corners) of parcels boundaries. After geo-processing of simplifying line feature, the correction of errors was first tested automatic by using the topology tolerance of 0.25m. The reason of simplifying the feature class of parcels boundaries at the stage of editing line features, is that if it is done

later (after converting line features to polygon features), it causes gaps and overlaps between polygons. This is because the vertices which were connected for line feature class are not still the same, they are changed by the automatic simplification of polygon feature. To correct these errors for polygon features would require to do other corrections by using topology creation with automatic correction, and manual correction for errors not covered by automatic correction. The issue here is that doing automatic correction twice would increase the loss of originality of the collected data.
The correction of errors for line feature class was also to do the manual correction for errors not covered by automatic correction, and after manual correction of errors, the line feature was converted to polygon feature. After these corrections, the attributes (parcels IDs) were entered in attribute table. During the entry of attributes, the errors of parcels boundaries which were still found they were corrected manually by connecting concerned vertices.
According to the errors happening in this approach 1, and the time it takes to correct these errors, another approach was tested to assess the way digital pen can capture cadastral data in a line feature based approach.

5.4.2. Line feature based/approach 2

After the results of field work and further tests for para-surveyors in regard of errors found for line feature based/approach 1 and time used for editing, another approach was tested to identify how data collected by using the digital pen method with line feature based would not cause too much editing workload after uploading data from the digital pen. This test was done by the researcher by redrawing the 123 parcels done during research field work, with their parcels IDs.
When demarcating parcels boundaries by using line feature based, an overlap for lines is helpful in order to connect the lines without gaps. It's not necessary to have snapping option with this approach if the intended final outputs are the polygons in order to get the areas (surfaces) of parcels. The following figure shows the way overlapping lines are converted to polygons without missing parcels because there are no gaps between lines.

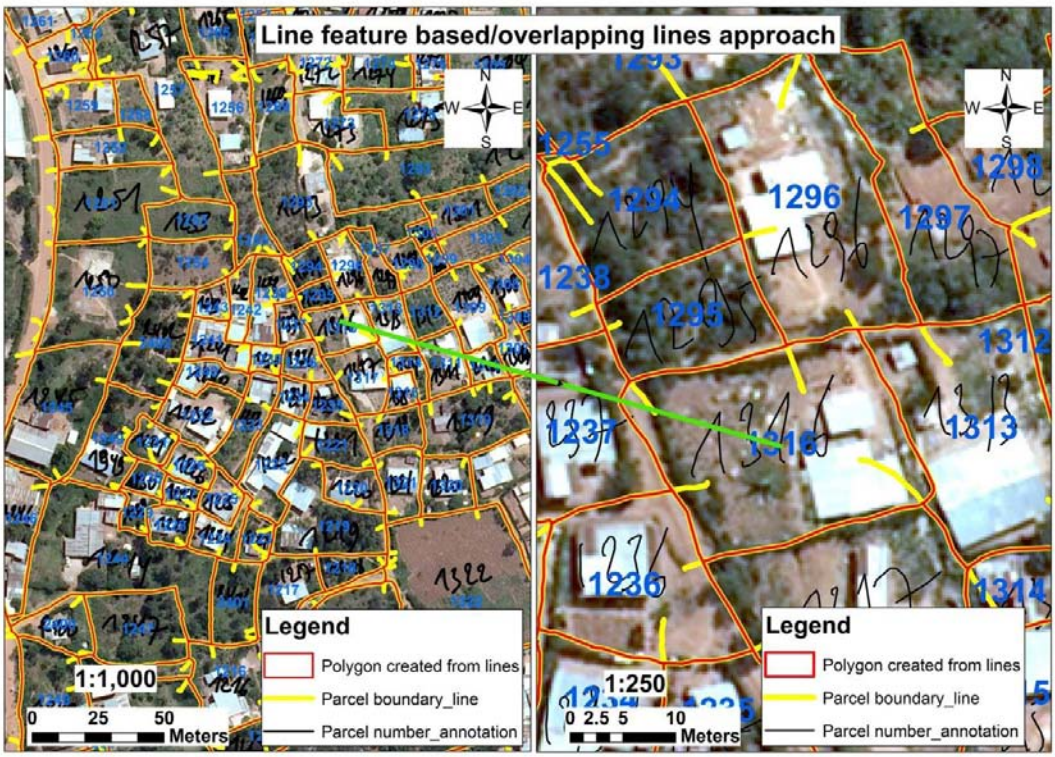

Figure 12. Line feature based/approach 2 (polygons converted from overlapping lines)

The attention has to be paid not to overlap the lines in way that when they are converted to polygons; those overlaps create extra polygons which don't represent real parcels on the ground. The following figure shows those kind of extra polygons.

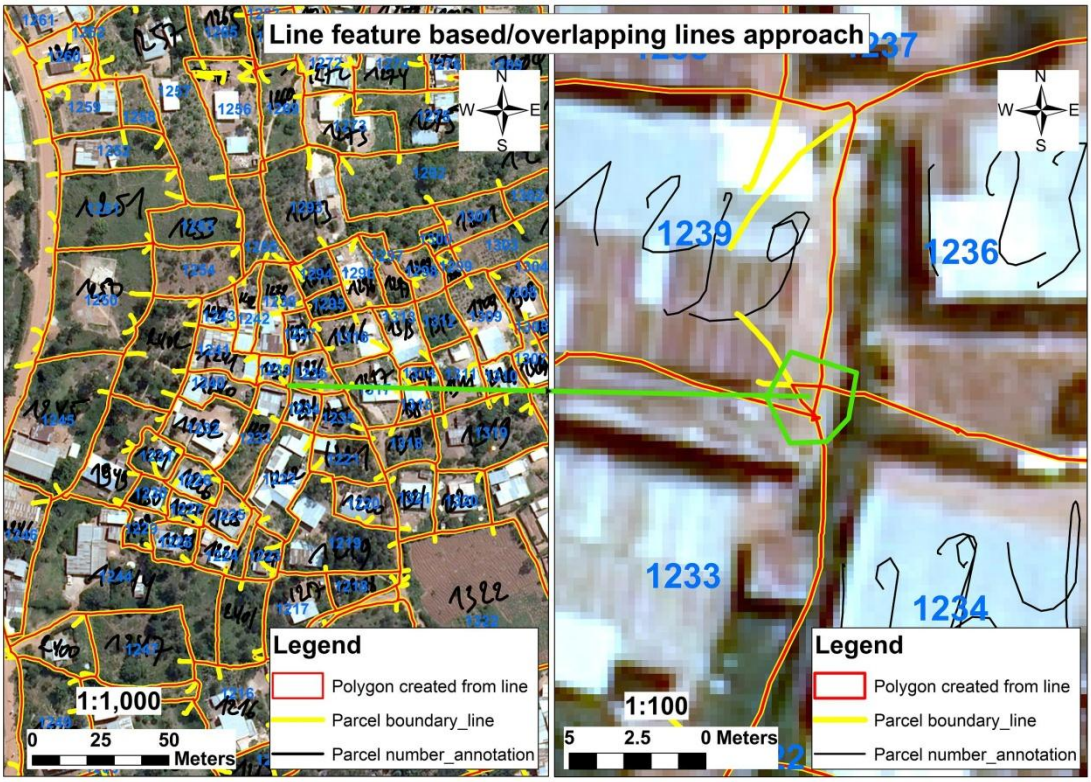

Figure 13. Line feature based/approach 2 (Extra polygons/mistakes in overlapping lines)

After converting line feature to polygon feature, the checking and correction of extra polygons was done after the entry of parcels IDs. The polygons with "Null" for parcels IDs were the ones to be corrected, thus the extra polygons, and the post-processing was to merge each extra polygon with one of its intersecting polygons, the most showing to be the extent of the extra polygon. These extra polygons are very small, they are visible when parcels boundaries are visualised at higher scale to the one used in data collection. These kind of extra polygons happen by mistake when digital pen touches on digital paper unintentionally by the operator on unwanted location. When drawing in streaming mode (streaming mode digitisation) without the option of point mode digitisation, the precision becomes less for the operator drawing parcels boundaries on digital paper, thus the control on coordinates becomes less.

5.4.3. Comparison of line feature based approaches (approach 1 and 2)

After testing the 2 approaches of line feature based, the comparison was done. To do the comparison of both approaches, another reconstruction of parcels boundaries was done by the researcher using the approach 1, and so to be able to compare the editing workload based on the same parcels reconstructed by the same operator. Regarding the time used for parcels boundaries reconstruction was the same for both methods. The following table shows the time for editing workload.

	Digital pen method/line feature based/approach 1	Digital pen method/ line feature based/approach 2
Human resources	1 person	1 person
Work done (parcels boundaries reconstruction)	123 parcels	123 parcels
Time used for post-processing workload	114 minutes	79 minutes

Table 4. Comparison of line feature based/approach 1 and 2

The table 4 shows that the time used for post-processing workload for line feature based/approach 2 is less compared to the time used for post-processing workload for line feature based/approach 1. But this depends on the situation in the field and the number of errors.
But in terms of quality, compared to line feature based/approach 1, the outputs of line feature based/approach 2 *reflect more the original collected data* because there is no automatic correction of errors, in this approach errors are corrected manually and easily. The two approaches what they have similar is the streaming mode digitisation in data collection, and this is related to the application software (Capturx for ArcGIS) which doesn't have point mode digitisation for line feature. In this regard, another approach was tested for point mode digitisation, and this was done by using point feature based.

5.5. Point feature based approach for spatial data capturing

With point mode digitisation, parcels boundaries demarcation can be done with control on how the digital pen moves over the map, thus with better control of resulting coordinates (vertices). For a parcel which has boundaries on more than 1 map sheet, the coordinates were also controlled in the overlap of the 2 maps. Another reconstruction of parcels boundaries was done by the researcher using the point feature based approach. This test was done on the basis of the 123 parcels done during research field work in Musezero Cell. During this test, the point feature was marked where there is a curved parcel boundaries. For each parcel boundaries, the lines were drawn on the map to connect the points thus composing the complete perimeter, in order to know which point belongs to which parcel boundary. Those lines were drawn by using one of the annotations in the legend. This means that in the map legend, one of the annotations was used for connecting point features. After uploading data from digital pen to the computer, in ArcGIS, the digitisation of parcels boundaries was done by using polygon feature class, and snapping to the collected points uploaded from digital pen. In this vectorisation of boundaries, also other editing options were used for polygon feature such as auto-complete polygon, and where necessary cut polygon. The complete perimeter for each parcel boundaries was done by referring to the annotation lines also uploaded from digital pen. The outputs of this approach are shown in the following figure.

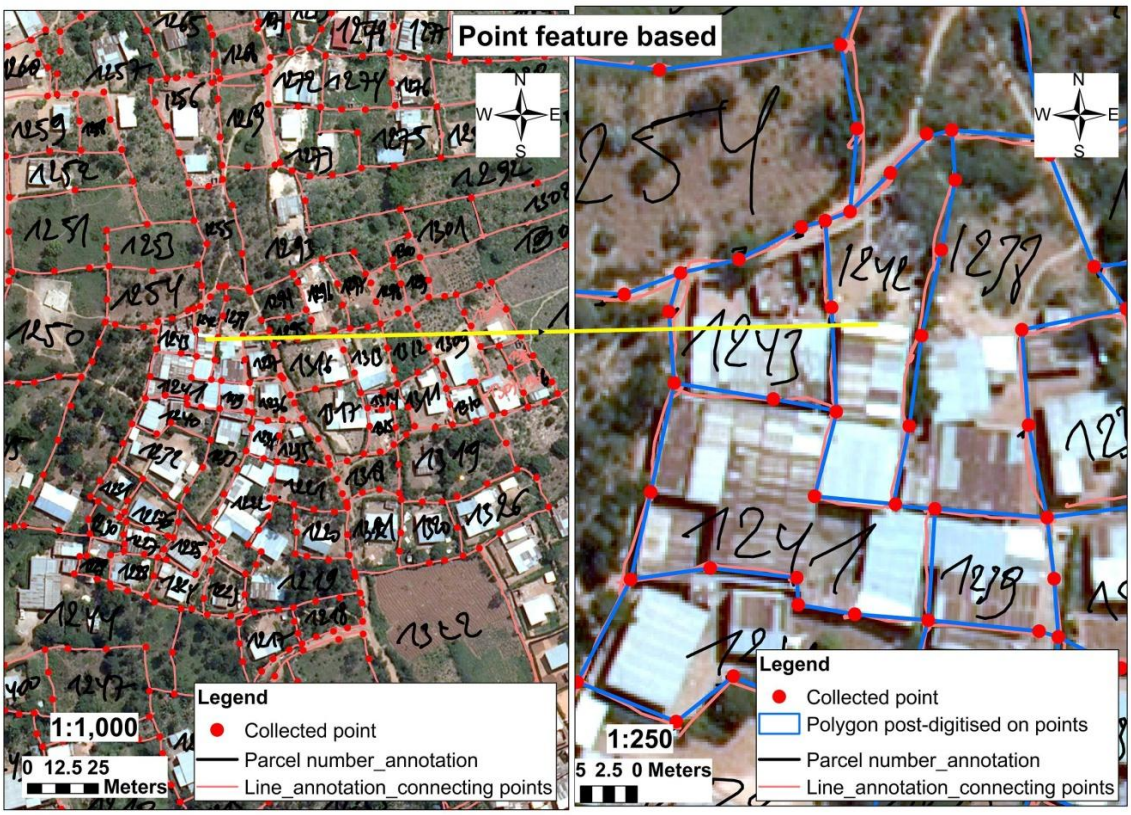

Figure 14. Point feature based approach (polygons digitised by snapping to the collected points)

The figure 14 shows the post-processing digitisation of parcels boundaries by snapping on the collected points uploaded from digital pen. The approach of point feature based is to collect objects in different composing points. This approach was compared to the line feature based/approach 2 for both parcels boundaries demarcation and editing workload, in terms of time and quality of outputs.

5.6. Comparison of the digital pen method/line feature based and point feature based

The comparison of approaches for the digital pen method were assessed between the line feature based/approach 2 and point feature based. The reason of the choice of line feature based/approach 2 is that the results of this approach showed that it the more practical for editing compared to the line feature based/approach 1.

	Digital pen method/line feature based/approach 2	Digital pen method/point feature based
Human resources	1 person	1 person
Work done (parcels boundaries reconstruction)	123 parcels	123 parcels
Time used for parcels boundaries reconstruction	161 minutes	173 minutes
Time used for post-processing workload	79 minutes	58 minutes
Total time	240 minutes	231 minutes

Table 5. Comparison of line feature based approach and point feature based approach

The table 5 shows that the time used for line feature based is almost the same as the time used for point feature based. Regarding the time for editing outputs of line feature based, this would depend on how many mistakes created in data collection when overlapping the lines which create extra polygons when

converting lines to polygons. The time used for editing workload could be more less or more high according to how the operator would overlap the lines in data collection.
In terms of the quality of outputs, in the point feature based the data are collected in point mode digitisation, it is more controlled compared to the line feature based when drawing parcels boundaries points on digital paper. On the other hand after uploading data from digital pen to the computer, into ArcGIS, the point feature based approach requires manual post-processing digitisation of parcels boundaries to close the complete perimeters, and if not snapping well to the collected points, this would cause errors in changing the original collected information.
Regarding line feature based, data are collected in streaming mode, and the control on coordinates is less compared to point feature based. To reduce the redundancy of vertices as a result from streaming mode in line feature based, the simplification of line feature class can be done after uploading data from digital pen to the computer, in ArcGIS, but the simplification removes vertices in some curves (corners) of parcels boundaries, it would be better not using the simplification option of feature class for parcels boundaries. On the other hand, line feature based approach doesn't require manual post-processing digitisation for parcels boundaries, the boundaries are directly collected in lines, and so line features can be directly converted to polygon features for calculating areas of the collected parcels. But the errors found have first to be corrected, such as extra polygons mentioned in 5.4.2.

5.7. Comparison of the existing method and the digital pen method

The comparison of the existing method and the digital pen method resulted in a preference for line feature based/approach 2 on the side of the digital pen method. The choice of line feature based/approach 2 is that compared to other tested approaches for the digital pen method, this approach is practical , and it would be even more practical if the application software is improved.
Regarding the time for drawing parcels boundaries and writing parcels IDs and/or any other information on digital paper, as mentioned in 5.2.2., the para-surveyors can work at the same speed when using the digital pen method as they do in the existing method. The time shown in the following table is the one for post-processing the collected data. The time for post-processing vectorisation of boundaries in the existing method is the one used by the researcher because he was also the one for post-processing data uploaded from digital pen in the digital pen method.

	Post-processing in the existing method					Post-processing in the digital pen method
Tasks and human resources	Redrawing and rewriting over the pencil marks by using the normal pen	Scanning field sheets	Georeferencing field sheets	Post-processing vectorisation of the collected data	Total	Editing the collected data
	1 operator	1operator	1 operator	1 operator		1 operator
Number of parcels post-processed	123			123		123
Time used for post-processing workload	59 minutes	9 minutes	45 minutes	78 minutes	191	79 minutes

Table 6. Comparison of the existing method and the digital pen method

The table 6 shows that the time used for post-processing editing of the collected data in the digital pen method is less than the time used for post-processing in the existing method.
For the post-processing vectorisation in the existing method, the parcels were vectorised by the researcher by using the same scanned georeferenced field sheets as used at NLC. The vectorisation was for the 123 parcels done during research field work (from parcel number 1200 to parcel number 1322 of Musezero Cell). The parcels boundaries of Musezero Cell were also vectorised by NLC GIS staff as normal daily work, and the time used for vectorising the 123 parcels was calculated, it was done in 90 minutes. The time used by the researcher was not the same with the one used by NLC GIS staff, but it's almost the same. In the existing method, in addition to the time used for post-processing vectorisation of the 123 parcels, there is time used first for scanning and georeferencing the field sheets. In daily work of scanning and georeferencing the field sheets, the time for scanning 1 field sheet is between 4 and 5 minutes (average of 4 minutes and 30 seconds), and the time for georeferencing 1 field sheet is between 20 and 25 minutes (average of 22 minutes and 30 seconds). Regarding the 123 parcels, they were on 2 field sheets, and so the time shown in the table 6 is for scanning and georeferencing the 2 field sheets.
In addition to this, for post-processing workload in the existing method, as mentioned in chapter 3.5.6. there is preliminary work of redrawing and rewriting over the pencil marks on field sheets by using the normal pen to make the pencil marks more visible before scanning field sheets. The time shown in the table 6 is the one used by the researcher in redrawing over the boundaries of the 123 parcels and rewriting over their parcels IDs by using normal pen by referring to the 2 scanned georeferenced field sheets covering these parcels. These scanned georeferenced sheets were printed at 1:1000 scale which was the scale used for land adjudication process in Musezero Cell.
In terms of quality, the digital pen method is more precise in preventing to decrease original accuracy and the originality in general (evidence from the field). The figure 15 shows the post-processed digitised parcels boundaries in the existing method and the same parcels boundaries reconstructed in the digital pen method.

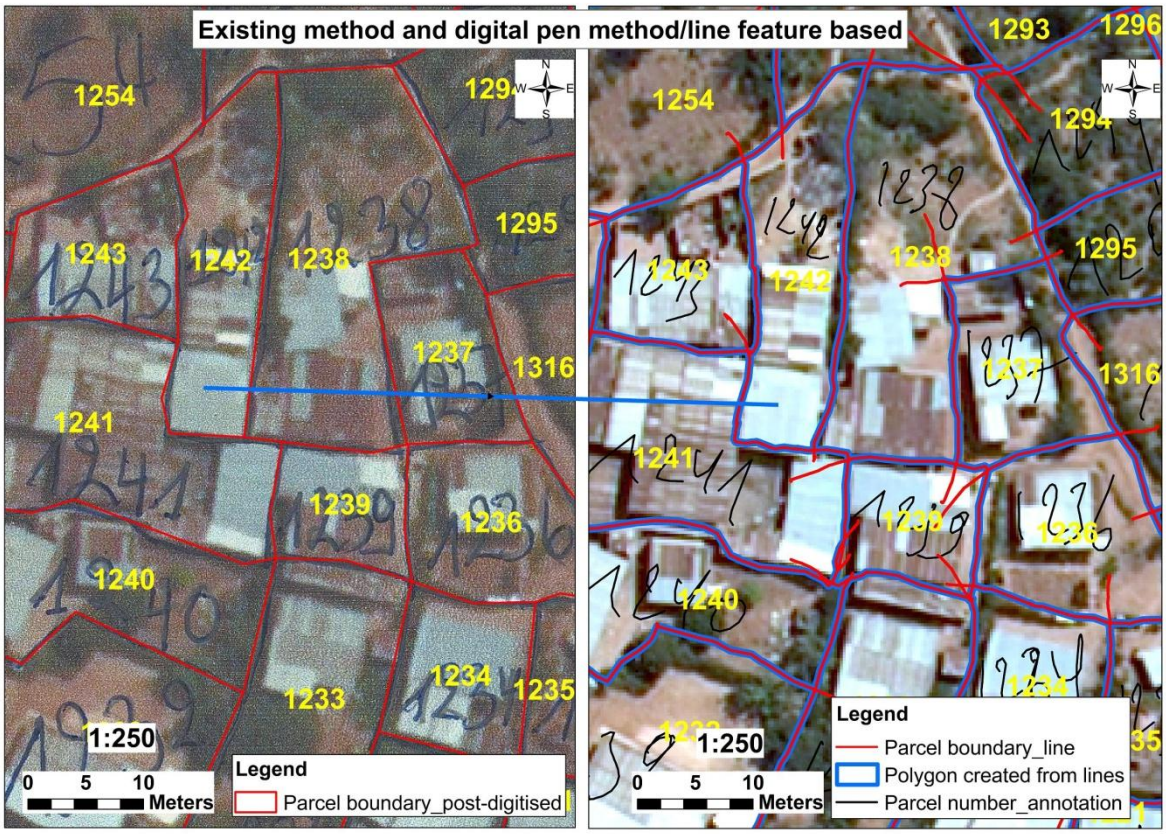

Figure 15. Comparison of the existing method (left) and the digital pen method (right)

Refer to the figure 15, in the existing method, to the left side, the vectorised boundaries are overlaid to the scanned georeferenced field sheet used in the post-processing vectorisation. In the digital pen method, to the right side, data are collected digitally and georeferenced, they are directly vectorised on site. There are no intermediate steps of redrawing and rewriting over the collected data, no scanning of the sheets used in data collection, no georeferencing of those sheets, and no post-processing vectorisation to get vectorised parcels boundaries for the collected data, they are directly visualised and overlaid to the original orthophoto for editing where necessary.

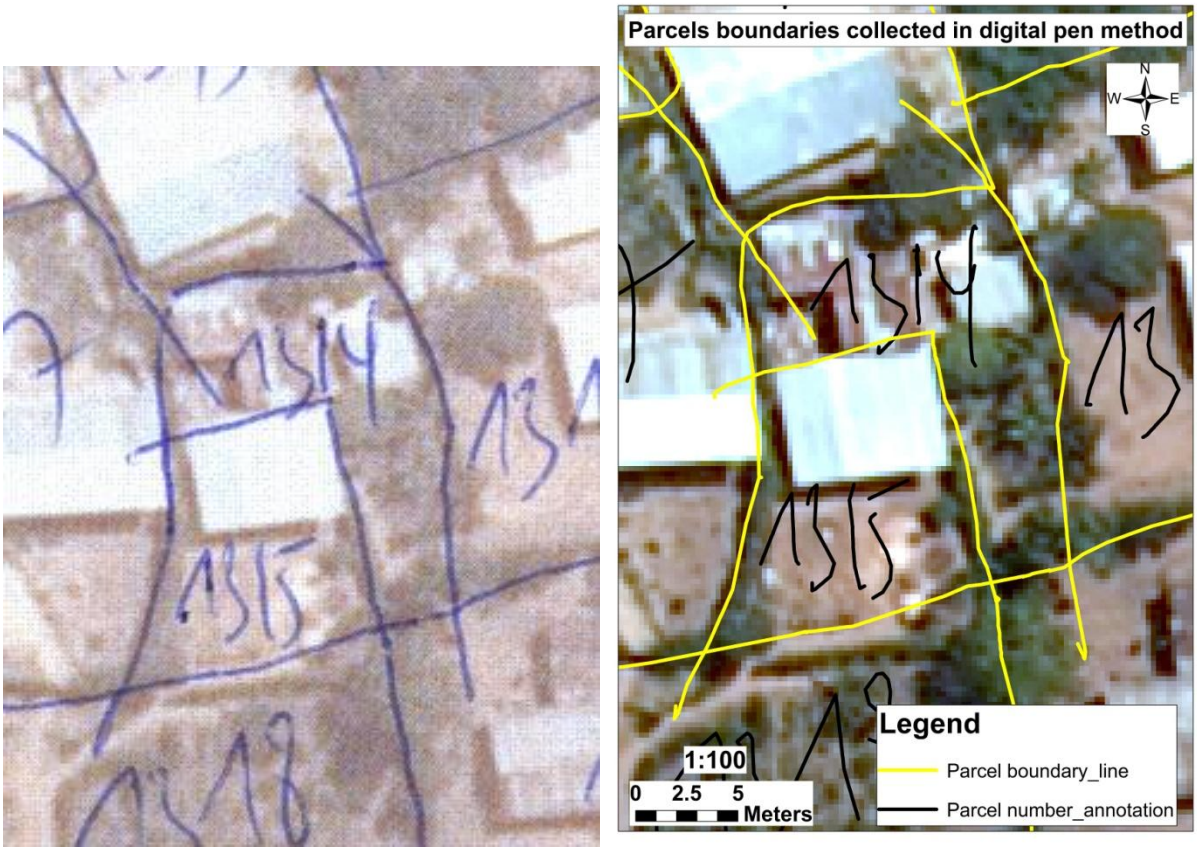

Figure 16. Collected data (left) and uploaded data from digital pen (right)/the digital pen method

The figure 16 shows, to the left side, the digital paper with parcels boundaries drawn and parcels IDs written by using digital pen on digital paper. The original scale of printed map was at 1:1000 in data collection. To the right side, there are the same parcels boundaries and parcels IDs stored after recording by the digital pen, and uploading to the computer, in ArcGIS, directly visualised, and overlaid to the original orthophoto. This prevents the errors which can happen in each of the intermediate process used in the existing method. The parcels boundaries visualised in ArcGIS are true to the original parcels boundaries drawn on digital paper.

Regarding the outputs when vectorising parcels boundaries on scanned georeferenced field sheets, it is relative to different factors, and among them, the operator vectorising, it can change from 1 operator to another. The following figure shows the same vectorised parcels boundaries post-processed vectorised by 2 operators.

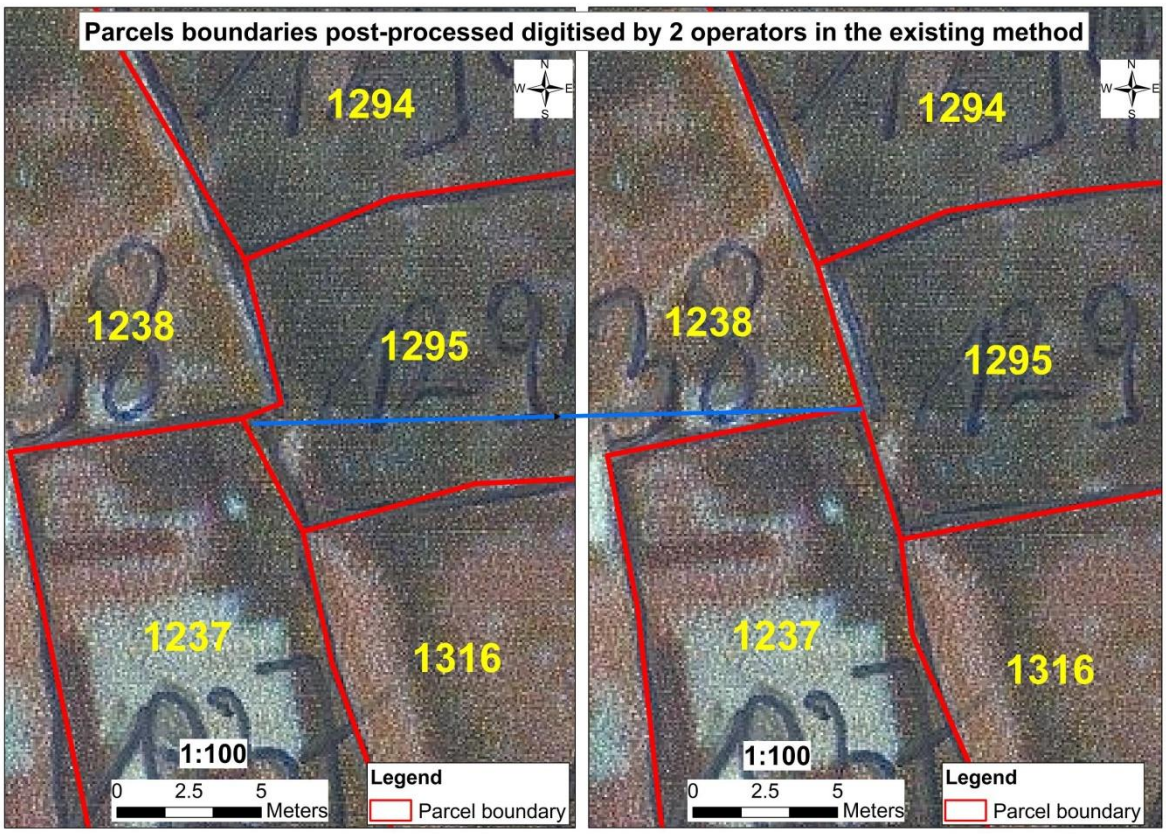

Figure 17. Comparison of the outputs in the existing method

The figure 17 shows the personal relativity of the outputs of parcels vectorised on scanned georeferenced field sheet according to the operator vectorising. To the left side are parcels boundaries vectorised by the researcher, and to the right side are the same parcels boundaries vectorised by NLC GIS staff. The input was the same (scanned georeferenced field sheet post-processed at NLC), and scale for post-processing vectorisation was also the same (1:500 scale). In this figure, the vectorised outputs are visualised at 1:100 scale.

5.8. Concluding remarks

The digital pen method is almost similar to the existing method in P-mapping, local people can get familiar of this method as they do in the existing method, the essential is the ability of image interpretation for parcels boundaries demarcation. The digital pen method is also practical in P-mapping in terms of reliability for field operations.

Compared to the existing method, in the digital pen method data are collected digitally and georeferenced, they are directly vectorised on site. After data collection, these data are uploaded from digital pen to the computer, in ArcGIS, and directly visualised. The uploaded data from digital pen are true to the collected data. The editing process is done where necessary. The time used in the digital pen method to get the final digital outputs is also less compared to the existing method.

In the current status of the digital pen method/line feature based, data collection is in streaming mode digitisation because of the limitation of the application software. The parcels IDs are also collected as figures to display on map, they are not real digital IDs for attribute table.

6. DISCUSSION ON THE DIGITAL PEN METHOD FOR CADASTRAL SURVEY

This chapter discusses the results presented in chapter 5. The discussion is based on the four criteria used in this research (P-mapping, quality, time, and process). The research questions are focus of attention in this discussion.

6.1. Parcels boundaries demarcation in participatory mapping

The results of this research showed that the digital pen method can be used in P-mapping, this method is not difficult for local people to use it in spatial data capturing. The digital pen method is also reliable for field operations. During this research, there were also observations on how P-mapping is processed.

6.1.1. Practicability in participatory mapping

The digital pen method is practical in terms of reliability for field operations. The battery of digital pen can last for long time in the field before getting recharged, but also the collected data are still stored in the pen when the battery is discharged. The digital pen method is also reliable for climate conditions. If the digital paper is covered by dust, it doesn't stop digital pen to capture the information recorded on the digital paper. And if the rain falls on digital paper, and before drawing parcels boundaries and writing parcels IDs, the paper to be first dried, digital pen can still capture the information recorded on the paper provided that the patterns are still on the paper.
Local people can get familiar with the digital pen method without difficulties, this method is almost similar to the existing method.

Figure 18. Pencil based (left) and digital pen based (right) for orthophoto based land adjudication

The figure 18 shows, to the left side, the existing method using pencil for drawing parcels boundaries and marking parcels IDs, and eraser to correct the mistakes done on map. To the right side, the figure shows the digital pen method using digital pen for also drawing parcels boundaries and marking parcels IDs. The mistakes done on digital paper are marked by using the pen based on the map legend. Digital pen is also a pen and which has an advantage of collecting data directly into georeferenced digital format when used on digital paper.

To measure how GIS is a tool for better governance (McCall, 2003) formulates the following questions: "*Can the goals of good governance be met in applications of geo-information (GI) with the governance criteria of accountability, legitimacy, respect for rights, equity, and competence?"* To answer this, he adds the sub-question: "*What degrees of participation' are found in participatory mapping (P-mapping)?*" The digital pen method can keep the participation in P-mapping as in the existing method, and in addition to this it can promote more the participation. The legend used in the digital pen method can be practical to highlight on map the disagreement on parcel boundary between neighbouring parcels when doing parcels boundaries demarcation in adjudication process. The data can be projected to the board and presented to the local people directly in the field at the end of each working day for their feedback. This means that in the map legend, there can be a layer for disagreement on parcel boundary. After uploading data from digital pen to the computer, in ArcGIS, what was recorded on site can be directly visualised. The following figure shows the example.

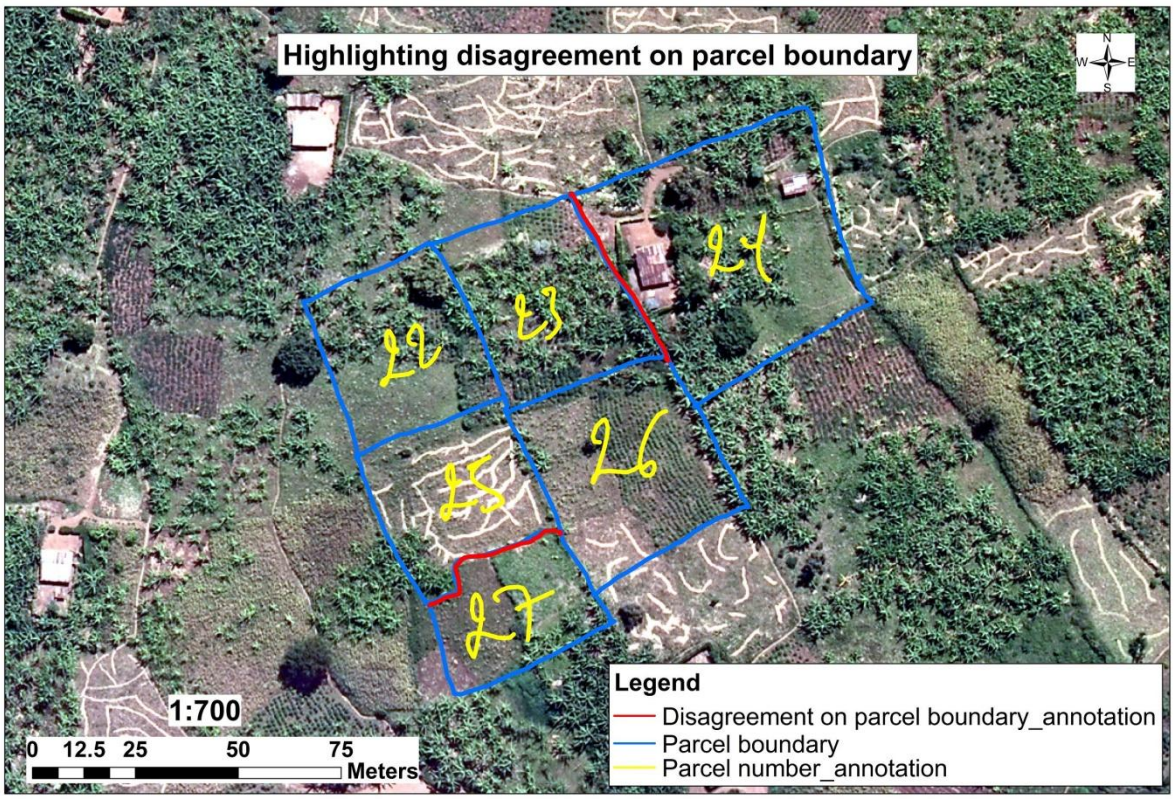

Figure 19. Highlighting on map disagreement on parcel boundary between neighbouring parcels

The outputs of the figure 19 are imaginary drawn and written by the researcher on digital paper to show the way the information needed can be recorded and be visualised directly after uploading data from digital pen to the computer, in ArcGIS. The digital pen method can be useful in highlighting other information according to the purpose. The collected data (vectorised boundaries) for each daily work can be presented (vectorised boundaries overlaid to the original orthophoto) to the local people directly on site. This would lead to win the time for the checking and the correction of errors compared to the

existing method where there is time of field work for data collection in analogue format and again the time to go back to the field for the checking and the correction of errors after post-processing digitisation.
The attention to be paid in the digital pen method is that when using digital pen, it happens that the ink of the pen doesn't appear on the map on some places, as it can also happen to another kind of pen. In case this happens to digital pen, even if the ink is not visible on the map, the records are already stored in the memory of the pen when it is moving on digital paper. In that case, if for example the operator of digital pen redraws a certain parcel boundary to make it appearing on the field sheet and/or when trying to refine the boundaries on the digital paper, in the memory of digital pen, it is recorded again, and so the boundaries become superimposed according to how many times the same boundary is redrawn on the map. After drawing a certain parcel boundary on map, and the ink of digital pen not appearing on map, that parcel boundary can be redrawn by using ordinary pen, because the first boundary drawn by using digital pen is already stored in the memory of digital pen even if the ink doesn't appear on map, and this is the same for writing parcels IDs or other remarks on digital paper.
The attention has also to be paid on how to operate in the digital pen method for parcels which have boundaries on more than 1 map/field sheet. In the overlap of 2 consecutive field sheets, the continuous parcel boundaries have to be drawn once in order to avoid duplicated boundaries to be stored in the memory of digital pen, this means that the boundary has to be drawn only on 1 field sheet. This can be difficult to organise, but the problem is the same in the existing approach.

6.1.2. Observation for participatory mapping

The attention to pay in P-mapping is on the way the teams work in the field, and so to prevent the overlaps and/or gaps between parcels boundaries done by different teams. Even if the teams are deployed in a way that every team has a limit of the area to demarcate within a cell administrative boundaries area, but some errors happen between the delimitations of those teams in case every team demarcates parcels boundaries located in the line of division of their delimitations. This can happen where the line of division between the 2 teams is not natural or physical feature, for example when there is neither river nor road, such as in some forests, some farms, and in some marshlands. For every line of division between 2 teams, parcels boundaries located in that line of division should be drawn once by 1 team, and the teams have always to exchange the field sheets on which there are the lines of divisions. This situation is not different in principle from the existing pencil based approach.
Attention to this has to be paid not only within a cell area, but also between 2 neighbouring cells, and this is also where the line of division between those cells is neither natural nor physical features. By paying attention to this, it would help to overcome the issues mentioned in chapter 3.5.6., thus the issues found by NLC GIS staff on field sheets when doing post-processing digitisation such as overlaps between parcels boundaries demarcated, parcels not demarcated, and any other issue related.

6.2. Quality of spatial data (parcels boundaries)

The digital pen method can overcome the sources of errors happening in the existing method.

6.2.1. Sources of errors in the existing method

In the former approach which was used in the existing method for post-processing digitisation directly on original orthophoto, by looking at redrawn parcels boundaries and rewritten parcels IDs which are on field sheets, and then look at computer screen to redraw those boundaries and rewrite those parcels IDs digitally, there were much more risks of errors compared to the approach used currently by vectorising the redrawn parcels boundaries and recording parcels IDs which are on scanned georeferenced field sheets (see chapter 3.5.6.). Despite these changes, the method of pencil based for parcels boundaries demarcation in the field (analogue data), post-processing by redrawing and rewriting over the pencil marks using normal pen to make the parcels boundaries and parcels IDs more visible on field sheets (duplication of analogue data), scanning the field sheets, georeferencing them, and post-processing vectorisation of the

collected parcels boundaries is very complex. It implicates many steps to be performed to get the final digital outputs. The complex process is where errors happen for each step by changing the originality of the collected data from the field. The intermediate step of redrawing and rewriting pencil marks is helpful to make boundaries and parcels IDs more visible on field sheets, but in terms of the quality of data, this implicates the change of the original collected data because of double manual drawing, and at this level data are still analogue. A part from this, the quality of the scanned field sheet compared to the original orthophoto depends on different factors, and amongst them: the paper used for printing the map, the printer resolution used for printing map/field sheet, the scanner resolution used for scanning field sheet, etc . When georeferencing the scanned field sheets using map grids, the field sheets don't match exactly with the original orthophoto. This depends on resolution of scanned field sheets, on the way the original orthophoto used to plot field sheet was taken (visibility according to the time during a day the image was taken, covered by clouds or not, and other factors), on the optical quality of human eye of the operator georeferencing, etc. The printed map by itself doesn't have the original resolution of the image which is used to produce the orthophoto field sheet, it has a little less resolution compared to the original orthophoto. Then after scanning the printed map/field sheet, the resolution becomes a bit less again. The following figure shows the difference of resolution between scanned field sheet and original orthophoto. It shows also the point marked on the scanned georeferenced field sheet and the same point visualised to the original orthophoto.

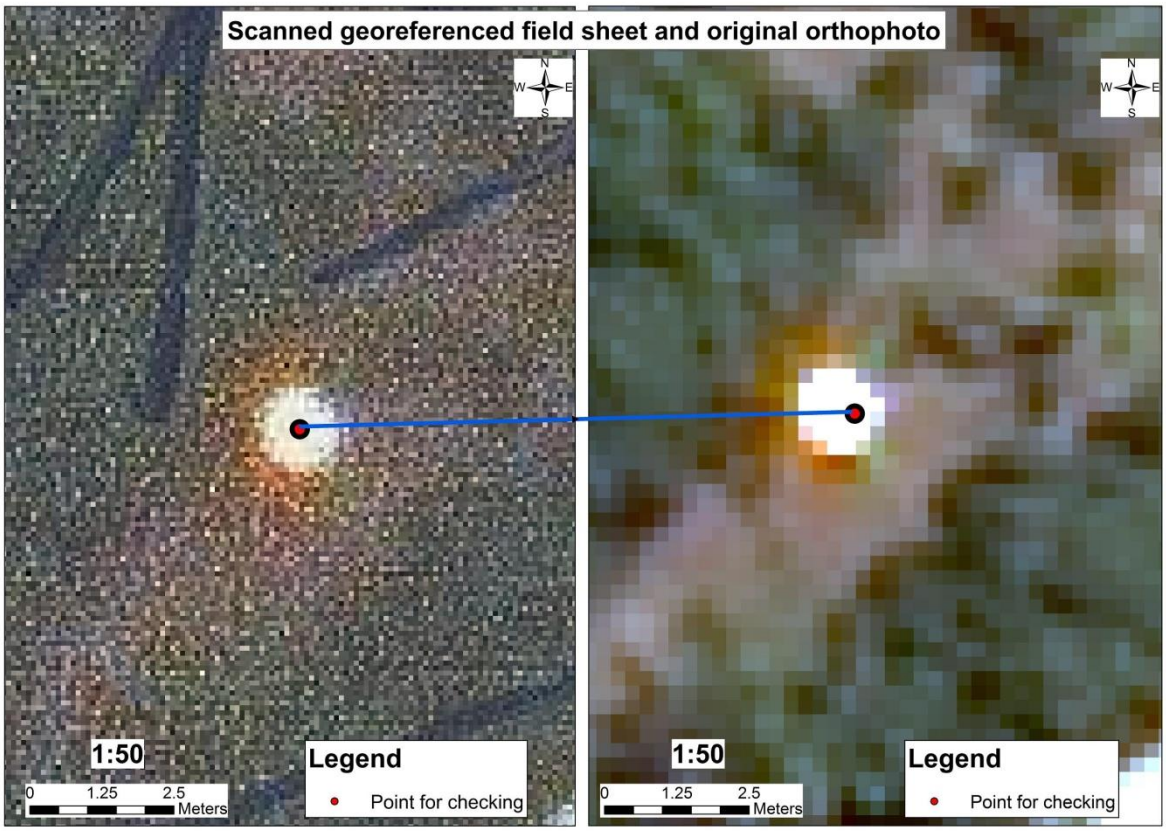

Figure 20. Scanned georeferenced field sheet (left) and the same area of the original orthophoto (right)

Referring to the figure 20, to the left side is the scanned georeferenced field sheet, and to the right side is the original orthophoto. The 2 images don't have the same resolution. The position of the point marked on the object on the scanned georeferenced field sheet doesn't match the same position on the original orthophoto.

Regarding the digitisation (vectorisation) of parcels boundaries by referring to/following the ones on the scanned georeferenced field sheets, it should be remembered that snapping is not possible, the scanned boundaries are not digital features to snap to. A part from being relative to the operator vectorising, even

if 1 operator would vectorise parcels boundaries, and again revectorise the same parcels boundaries, the outputs would not come again the same as previously because of vectorising on scanned parcels boundaries, it is not snapping on those parcels boundaries.

6.2.2. Data acquisition in the digital pen method

The intended purpose of using digital pen is for general boundaries survey in P-mapping. "*From a more legal perspective, the general boundaries rule allows for leaving the exact position of the boundary within the feature undetermined. The idea is that in this way the main body of the property is reasonably defined, and that it can be identified beyond doubt*" (Bogaerts & Zevenbergen, 2001). The digital pen method can improve the existing data acquisition for general boundaries, data are collected digitally and georeferenced, they are directly vectorised on site. After data collection, these data are uploaded from digital pen to the computer, in ArcGIS, and directly visualised without intermediate steps done in the existing method to get the vectorised data. This means that in the digital pen method, there are no intermediate steps of redrawing and rewriting over the collected data, no scanning of the sheets used in data collection, no georeferencing of those sheets, and no post-processing vectorisation. The uploaded data from digital pen are true to the collected data.

The digital pen method/line feature based, data collection is in streaming mode digitisation because of the application software (Capturx for ArcGIS). Data collection in streaming mode digitisation implies many vertices, the operator has less control on coordinates. In the current status of the digital pen method, point feature based approach gives more control on coordinates compared to line feature based and polygon feature based approaches.

But when demarcating parcels boundaries, line feature based would be the practical approach to apply and so to collect objects as boundaries by going around each parcel boundaries, from 1 boundary to another until the completion of the entire perimeter without duplications in boundaries. The overlap for connecting lines is helpful in order to connect the lines without gaps, and after uploading the collected data from digital pen to the computer, in ArcGIS, the lines can be directly converted to polygons, and the corrections can be done where necessary.

In case of snapping option only without the approach of overlapping lines, the operator would not be able to control if the lines are well snapped or not, what the operator can see in data collection are the records on the printed map. The snapping option would require to be able to visualise digitally the records during the action on site, and this is not possible for the digital pen method when collecting data. Only data can be visualised after the upload from digital pen to the computer, in ArcGIS. But even when digitising (vectorising) the lines in ArcGIS, by using the snapping option, it happens that the operator doesn't snap well some lines in their connections, and this causes the gaps between those lines. But if the intended purpose is to convert lines to polygons, the approach of overlapping lines is practical to prevent the gaps to happen between the connections of lines, but also by paying attention in overlapping lines in the connection of more than 2 lines in order that it would not create extra polygons when converting lines to polygons.

Compared to the line feature based/approach 1 (the approach of not overlapping lines in data collection), the line feature based/approach 2 (the approach of overlapping lines in data collection) is only for easy post-processing, but it would not have a legal meaning of representing the boundaries as existing on the ground before line features are converted to polygon features.

Regarding the record of attributes in data collection, in the current status of the digital pen method, parcels IDs are collected as figures to display on the map, they are not real digital IDs for attribute table. This is because of the limitation of the application software (Capturx for ArcGIS).

6.3. Time used for spatial data capturing

Digital pen is practical for parcels boundaries demarcation in the field in P-mapping, the local people can use it at the same speed as they do in the existing method, it's used as normal for drawing boundaries. For post-processing, the digital pen method can also help in saving of time compared to the existing method.

But in the current status of the digital pen method, the correction of errors takes more time compared to the one expected to be according to the way data are directly collected digitally and georeferenced. Most of these errors are the ones related to the limitations of the application software (Capturx for ArcGIS), and this limits the operator for some operations in data collection, such as to be limited on streaming mode digitisation because there is no option of point mode digitisation, and this implies less control on coordinates.

6.4. Process used to get vectorised data

In the existing method, because of a number of steps used to achieve the final digital (vectorised) outputs, a number of additional archives is maintained for cadastral information which are in addition to the original data (orthophotos). These additional archives are field sheets used for parcels boundaries demarcation, and the scans of those field sheets. With the option of spatial data acquisition directly into georeferenced digital format, the number of steps can be reduced. This would implicate in reduction of the number of archives. After uploading data from digital pen into ArcGIS, the evidence from the field would be directly the vectorised parcels boundaries overlaid on the original orthophoto, this would not require the big space for archiving compared to the existing method.

6.5. Concluding remarks

Digital pen captures spatial data directly into georeferenced digital format (directly vectorised) and the collected data are directly visualised in ArcGIS and overlaid to the original orthophoto without intermediate steps used in the existing method to get vectorised data. In addition to this, the uploaded data from digital pen are true to the collected data. This can have an impact in preventing sources of errors which are in intermediate steps used in the existing method to get vectorised data, but also this can have an impact in saving the space for archiving. This method can also implicate saving of time. The digital pen method is also practical in P-mapping, local people can use it without difficulties, and at the same speed as the existing method. The digital pen method is also practical in terms of reliability for field operations, and it can promote more P-mapping.

The digital pen method/line feature based would be the practical approach to apply for parcels boundaries demarcation. But there are some limitations for the operator in data collection. Because of the application software, data collection is done in streaming mode digitisation, no available option for point mode digitisation, and the operator has less control on coordinates. The parcels IDs are also collected as figures to display on map, they are not real digital IDs for attribute table.

7. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions of this research. It also presents the recommendations related to this work and suggestion for further research.

7.1. Conclusions

Spatial data acquisition from orthophoto through P-mapping has advantages of making progress in the land adjudication process for land administration purposes in Rwanda. In the existing method for LTR a normal pencil is used in data collection to draw boundaries of parcels on plotted orthophotos. In this existing method, post-processing has to be performed to get vectorised boundaries. This implies different sources of errors, it is time consuming, and it uses a lot space for archiving.

Orthophoto based land adjudication could be improved in efficiency by collecting data directly into georeferenced digital format in the field in order to prevent the sources of errors happening in the existing method. This research did a comparative study between the existing method and the alternative method of using digital pen. The criteria of assessment were quality of data, time used, P-mapping, and process used in terms of archiving.

The main objective was to assess whether the use of digital pen can improve the efficiency for spatial data acquisition for general boundaries survey. The specific objectives were to assess the sources of errors in the existing method that can be addressed by the digital pen method, to identify the time that the existing method takes compared to the time that the digital pen method would take for spatial data capturing, to assess the process used for the existing method and the digital pen method in terms of the space for archiving, and to identify practical field operations in P-mapping when using the digital pen method for spatial data capturing compared to the existing method.

The digital pen method is efficient for spatial data acquisition for general boundaries survey in Rwanda. In terms of quality of data, the digital pen method can address the sources of errors happening in the existing method. The digital pen method can overcome sources of errors of data collection in analogue format and the intermediate steps for post-processing to get the vectorised outputs. In the digital pen method there is no post-processing of redrawing and rewriting over the collected data to make them visible on field sheets for the purpose of post-processing digitisation. In the digital pen method, there is no scanning of field sheets needed (printed maps used in data collection), no georeferencing of field sheets, no post-processing vectorisation of parcels boundaries. In the digital pen method data are collected directly into a georeferenced digital format, and they are directly uploaded from digital pen to the computer, and overlaid to the original orthophoto, and these uploaded data are true to the original collected data in the field. This would also lead to win the time for post-processing.

By collecting data directly into georeferenced digital format, the digital pen method would improve the process in terms of saving the space for archiving, there are no intermediate steps used in the existing method to get the final digital outputs from the analogue collected data.

If the intended purpose is to convert lines to polygons, the approach of overlapping lines in data collection to prevent the gaps to happen between the connections of lines is practical for easy post-processing. After uploading the collected data from digital pen to the computer, in ArcGIS, the lines can be directly converted to polygons, and the corrections can be done where necessary.

In the current status of the digital pen method/line feature based, data collection is in streaming mode digitisation because of the application software (Capturx for ArcGIS). Data collection in streaming mode digitisation implies many vertices, the operator has less control on coordinates. There is no available option of point mode digitisation for line feature based.

The digital pen method is practical for field operations in P-mapping. The local people can get familiar with this method without difficulties, and they can continue working at the same speed as with the existing method. The digital pen method is reliable for field operations. The battery of digital pen is rechargeable after long time used, but the digital pen also secures the collected data, there is no loss of data when the battery is discharged. The digital pen method is also reliable for climate conditions in terms of dust and rain conditions for the readability of the pattern on the digital paper by the digital pen.
In addition to this, the digital pen method can be useful in highlighting the disagreement on parcel boundary between 2 neighbouring parcels, but it can also be useful in highlighting other information. *The digital pen method would promote P-mapping by presenting the daily work to the local people at the end of each day for their feedback. The collected data (vectorised boundaries) for each daily work can be presented (vectorised boundaries overlaid to the original orthophoto) to the local people directly on site. This would lead to win the time for the checking and the correction of errors compared to the existing method where there is time of field work for data correction in analogue format and again the time to go back to the field for the checking and the correction of errors after post-processing digitisation.*

7.2. Recommendations

Some improvements are proposed to be developed for functionalities related to the digital pen method to make it more practical. The application software is proposed to be improved by an option for point mode digitisation for lines.
The application software is proposed to be improved with option for data collection of parcels IDs as digital attributes.
Further it is recommended to test the promotion of P-mapping by presenting the daily work to the local people at the end of each day for their feedback using projector.
Further research on the use of digital pen in cadastral data capturing for both spatial data and administrative data and the link between them is proposed.

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APPENDIX 1. PLOTTING DIGITAL MAP, DATA COLLECTION AND CORRECTION OF MAPPING MISTAKES

The following are the main steps to plot a map as digital paper, to collect data and to correct the mapping mistakes after uploading data from digital pen to the computer:

- Creating a new line feature class in geodatabase for parcel boundary
- Producing a map containing orthophoto to use for collecting data
- Adding the legend to the map (line feature for parcel boundary and Capturx markup layer for annotation)
- Printing of a map using Capturx for ArcGIS to get a map as digital paper
- Using the legend icon and digital pen to draw feature (parcel boundary) and to write annotation (parcel ID, or/and mistake done, or other remark) on the map during data collection
- After data collection, connecting the pen via USB port to a computer to upload data in ArcGIS, in the map document (mxd file[15])which was used to print the map.

With the digital pen method, there are errors happening in data collection according to the way of using the map legend during parcels boundaries demarcation. The following are cases of those kind of errors:

Case 1: The use of digital pen in data capturing is done by crosschecking the pen into the legend for both feature class, and markup layer for annotations, see chapter 5.1.3. It can happen that the operator of digital pen forgets to check the appropriate feature class item in the legend before drawing some parcels boundaries. For this case, if the legend has a markup layer, those parcels boundaries are stored in digital pen as annotations, and they are displayed as such in ArcGIS after uploading data from digital pen to the computer. In this case the parcels boundaries are not recorded as features. The ArcGIS operator can then post-digitise the missing parcels boundaries according to the annotations lines. For this case, in the ArcGIS layers view list, the parcel boundary layer has to be on top of Capturx markup layer. The operator is then be able to identify easily what are the missing parcels boundaries, and digitise them by following the annotations lines.

Case 2: As in case 1, the ArcGIS operator can digitise the missing parcels boundaries according to the annotations lines. In this case, during data collection, recording parcels IDs on map which doesn't have Capturx markup layer in legend, it can be done by writing parcels IDs without any checking of the pen in the legend, digital pen stores automatically the records as annotations. But it would be a constraint when marking other records such as mistakes and remarks. And when uploading data from digital pen into ArcGIS, Capturx for ArcGIS desktop will ask to add first Capturx redline/markup layer. After adding Capturx markup layer, all annotations records are displayed in ArcGIS in the same colour (red colour by default), so it's a constraint to make difference between those records.

Case 3: If a map is printed without any legend but as digital paper, and during data collection use digital pen directly on digital paper (map), thus doing parcels boundaries demarcation without working under any legend, digital pen stores everything drawn (parcels boundaries) and written (parcels IDs, and other records such as marking mistakes and/or remarks) as annotations. And when uploading data from digital pen into ArcGIS, Capturx for ArcGIS desktop will ask to add first Capturx redline/markup layer. After adding Capturx markup layer, all records are displayed in ArcGIS as annotations, and all in the same colour (red colour by default). This case combines 2 constraints. The first one is the same as the one mentioned in the case 2. The second constraint is that to get parcels boundaries as features, this would require to do post-processing digitisation (vectorisation) for all parcels boundaries demarcated in data collection. This can be done by following the lines recorded by digital pen as annotations. This would be time consuming but also it would reduce the accuracy because each parcel boundary redrawn on computer is not original as it was drawn in the field. Particularly, snapping cannot work with those annotations, as they are not spatial features that can be snapped to in ArcGIS. When printing digital paper without any legend, Capturx for ArcGIS Desktop remarks that there seems to be no legend in the layout view, and it

[15] mxd file is map file format used by ESRI mapping software, such as ArcMap that is the central application used in ArcGIS.

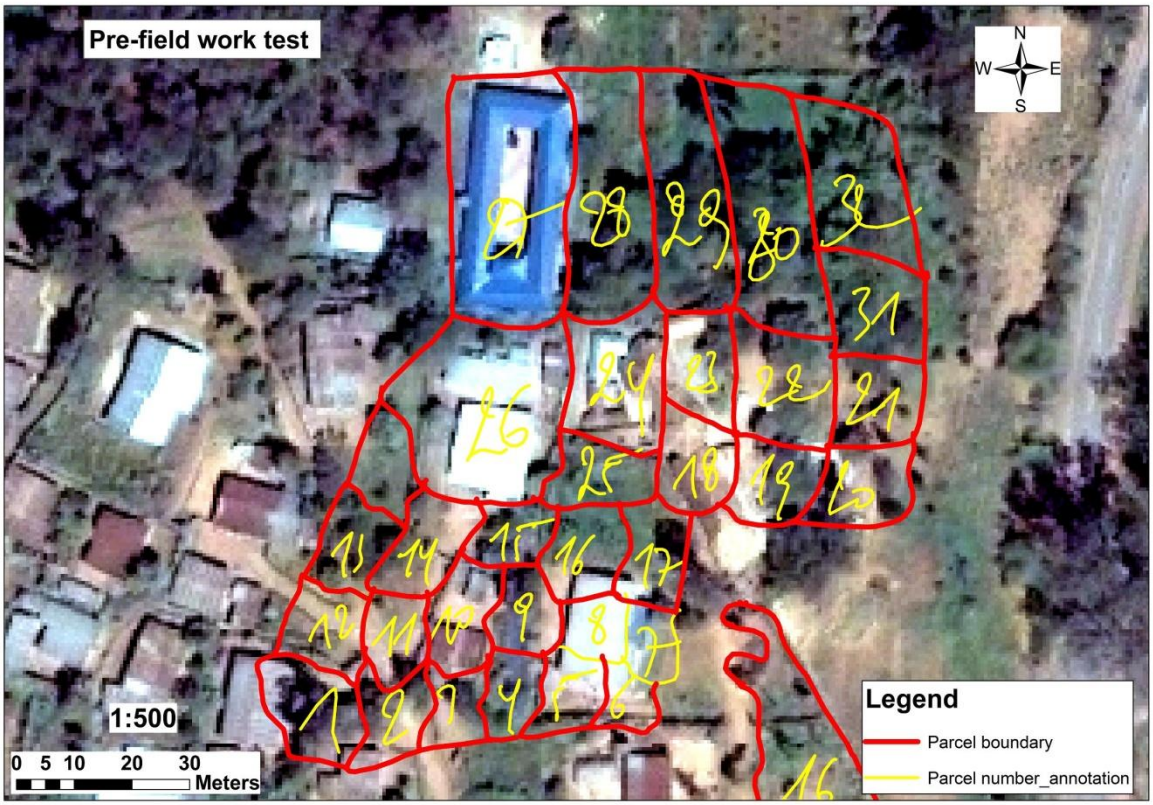
asks the operator to insert a legend from the main menu. But it also asks whether to continue printing anyhow. When the operator decides to continue printing without any map legend the consequences are as explained.

The approach to overcome these issues is to produce a map which has both a line feature layer and annotation layer in the legend, and so even if the operator of digital pen forgets first to crosscheck the pen into parcel boundary layer in the legend before demarcation of some parcels boundaries, the pen stores automatically those parcels boundaries as annotations. After uploading data from digital pen to the computer, the ArcGIS operator can digitise the missing parcels boundaries by following the annotations lines. This would only happen in case the operator forgets to give a command to digital pen according to what he/she wants to record, either parcel boundary, or parcel ID, mistake, or remark. This would happen as human error, but not for all parcels.

APPENDIX 2. TESTS FOR DIGITAL PEN FUNCTIONALITIES

Pre-field work test

Before going to field work, different tests were done to test the functionalities of digital pen, to identify the approach to use in the field for data acquisition, and to check whether the equipments for field work were in good conditions. The maps were produced and printed as digital paper for use with the digital pen. These maps were printed on Xerox-WC7435 printer which has print resolution of 1200 * 2400 dpi print resolution, and which is a post-script capable.
The input data during these tests was Quick bird image (0.60m resolution) of Nyamugali Cell, in Gatsata Sector/Kigali City, which is one of the LTR trial areas. In these tests, boundaries of imaginary parcels were drawn on a digital paper and were attributed imaginary parcels IDs. After this, the recorded data were uploaded from the digital pen to the computer, and displayed in ArcGIS.
After getting familiar with functionalities of the digital pen, and defining which approach to use in the field, the other boundaries of 32 imaginary parcels were drawn and attributed imaginary parcels IDs. The digital pen was working properly to record the spatial data and mark the annotations/parcels IDs. These data were all displayed into ArcGIS and visualised, showing that no record was missing.

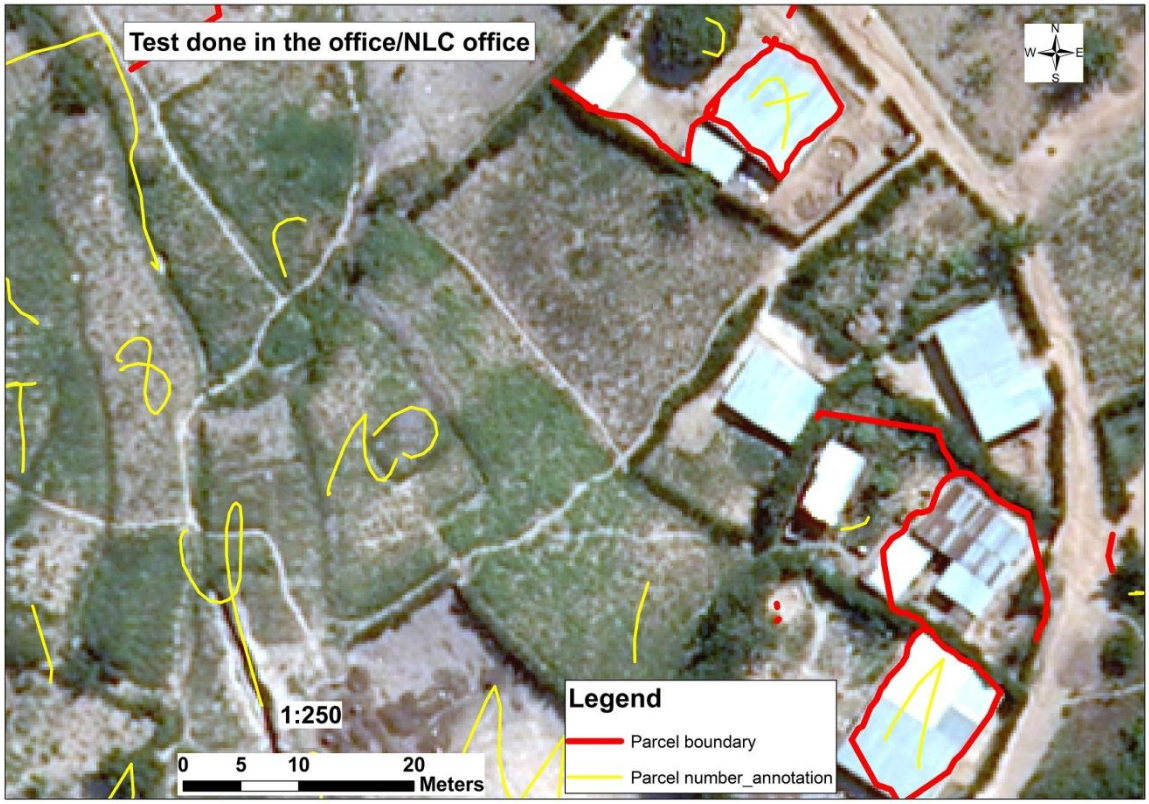


Appendix figure 1. Lines drawn and attributed IDs for pre-field work test

Office test during field work

During field work, it was not possible to print orthophoto maps as digital paper on the different printers available at the field work location/NLC office. The available printers (HP Design Jet 110 plus, HP Office jet 6300 All-in-one, HP Office jet K 7100) did not comply with Capturx requirements. Even though these printers have the required print and colour resolution they don't print the pattern required for digital paper. Most likely the post-scripts capability is the limiting factor of these printing.

The print of map as digital paper was only possible for Xerox Phaser 7500N PS printer which has print resolution up to 1200 * 1200 dpi print resolution, and which is a post-script capable. During the test done in the office before taking the maps to the field, other technical issues were raised. The digital pen did not recognise the pattern on the digital paper. As a consequence the pen was giving signals (vibrations) which indicate that something is wrong when drawing on the paper. For each vibration signal, it means features and/or annotations are not stored in the memory of the pen, and therefore cannot be displayed in ArcGIS after uploading data from the digital pen to the computer.
During this office test, boundaries of imaginary 15 parcels were drawn on digital paper and attributed imaginary parcels IDs, but after uploading data from the digital pen to the computer, in ArcGIS, almost all parcels were without boundaries but also without parcels IDs.

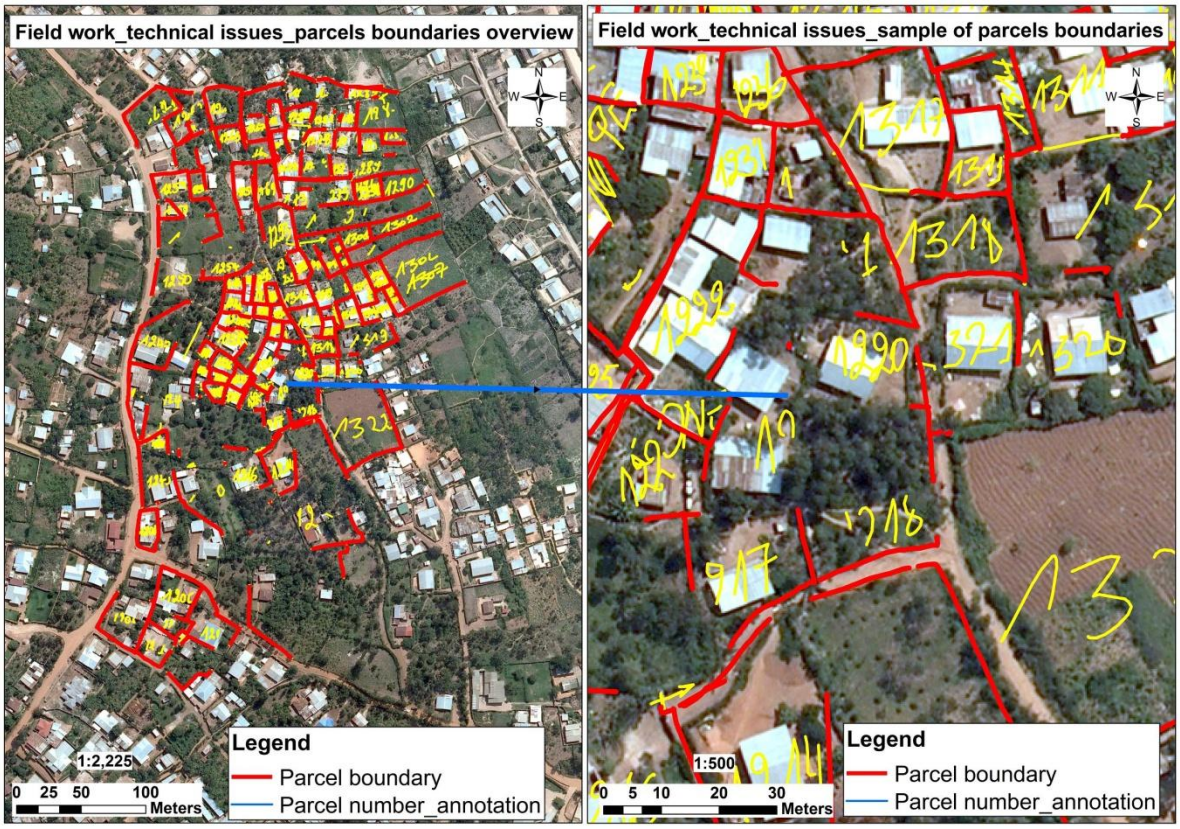


Appendix figure 2. Incomplete records related to technical issue of printing digital paper/office test

Despite these technical issues which were occurring, the assessment of practicability of the digital pen method in P-mapping could be done and it was assessed whether local people can be able to use this geo-application tool (digital pen) for demarcating parcels boundaries. It was assessed how local people can get familiar with the process for data acquisition.

Test of the digital pen method in participatory mapping

During field work, in Musezero Cell, 123 parcels were demarcated in the field by para-suveryors, from parcel number 1200 to parcel number 1322. For the first day, parcels demarcated were from parcel number 1200 to parcel number 1260, thus 61 parcels, and for the second day, from parcel number 1261 to parcel number 1322, thus 62 parcels. Among these 123 parcels demarcated in the field by para-suveryors, digital pen was still giving signals (vibrations) that something was going wrong. Many of the demarcated parcels boundaries were incomplete, missing segments, and some were missing parcels IDs. The reason was that the digital pen didn't store these records even if they were drawn and written on the digital paper. This was the same issue as during the office test at NLC.

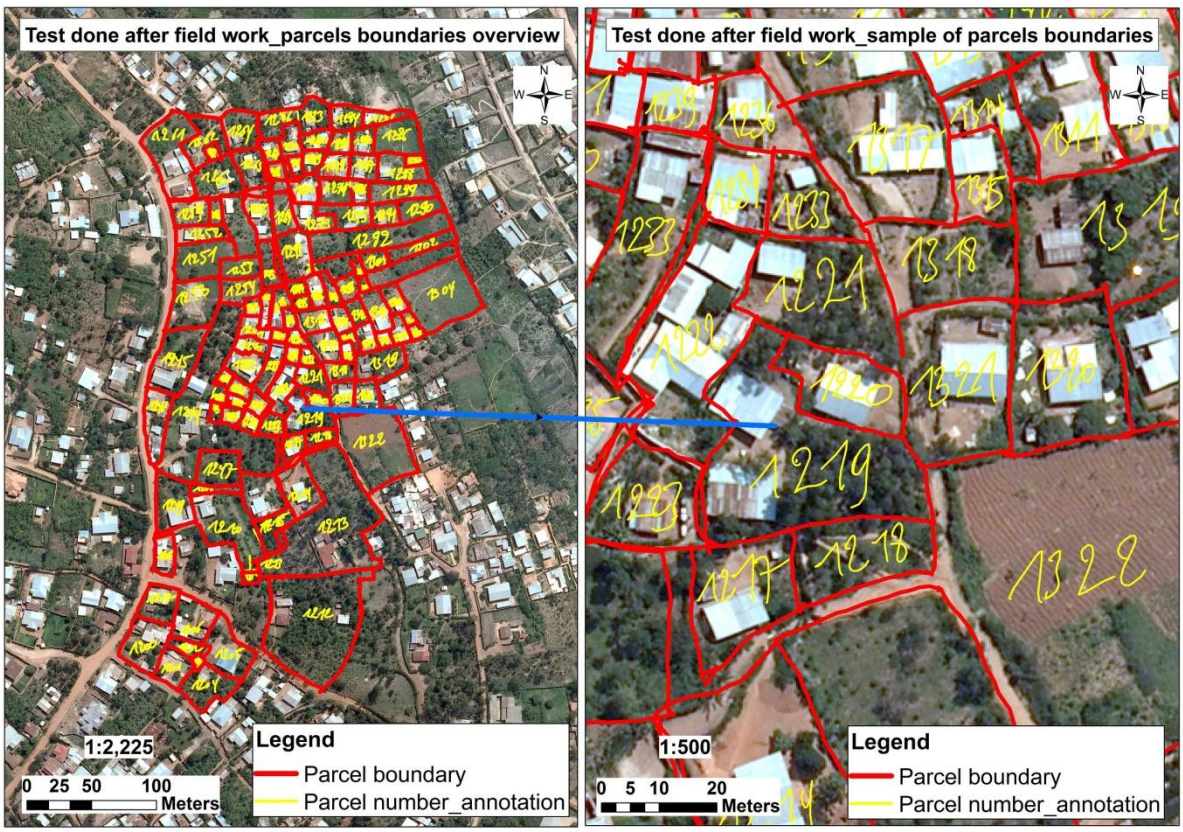


Appendix figure 3. Incomplete records related to technical issue of printing digital paper/field work test

It was important to know whether these problems were caused by printing, or for instance by dust, as in Rwanda different places are not paved, creating dusty roads and in the period of field work it was dry season. The dust is especially outside, but also it gets in the office through opened windows and doors, and office materials (printers and papers) are covered by some dust. The assumption here was that the dust which was in field work area was covering the patterns on printed maps and would reduce the readability of the pattern on the digital paper by the digital pen.
Another assumption was that the digital pen would have technical problems inside of it, as can happen to any electronic device, and this would cause vibrations when using digital pen on the digital paper. A test of all these assumptions was done after field work back in the Netherlands.

Test after field work

After getting back to the Netherlands, new maps were printed by using Capturx compliant printers (Xerox-WC7435). During this test, the 123 parcels demarcated by para-surveyors in the field were redrawn and their attributes/parcel IDs were also marked on the maps. This was done by the researcher by referring to the printed maps used in research field work. The result of this test showed that with maps printed by using the printer Xerox-WC7435, digital pen was again working well without giving signals (vibrations). The issues which occurred during field work were therefore not caused by digital pen itself. In this test, all records (parcels boundaries and parcels numbers) were stored in the memory of the pen, and were uploaded from digital pen to the computer and be visualised in ArcGIS, no record was missing.



Appendix figure 4. Parcels drawn after field work

Another test was to check whether technical issues which occurred during the field work in Rwanda were caused by dust. So, this test was done by putting dust on maps printed by using the Xerox-WC7435 printer. The dust spread on maps was from three soil types: yellow soil from Spain, löss soil from Limburg/ the Netherlands, and red soil from Rwanda.

With each dust test the result was the same. The digital pen was working properly without giving signals (vibrations) that something might be wrong, even if the pen was struggling to go through much dust which was put on the map (digital paper). The entire map was covered by ample dust, even the legend. During these tests, boundaries of 33 imaginary parcels were drawn on digital paper for each test, and were attributed imaginary parcels IDs. All these records were stored in the memory of digital pen, and were uploaded from digital pen and visualised in ArcGIS, no record was missing, for both parcels boundaries and their parcels IDs. After all these tests, the results showed that technical problems which happened during field work were caused by printing issues.

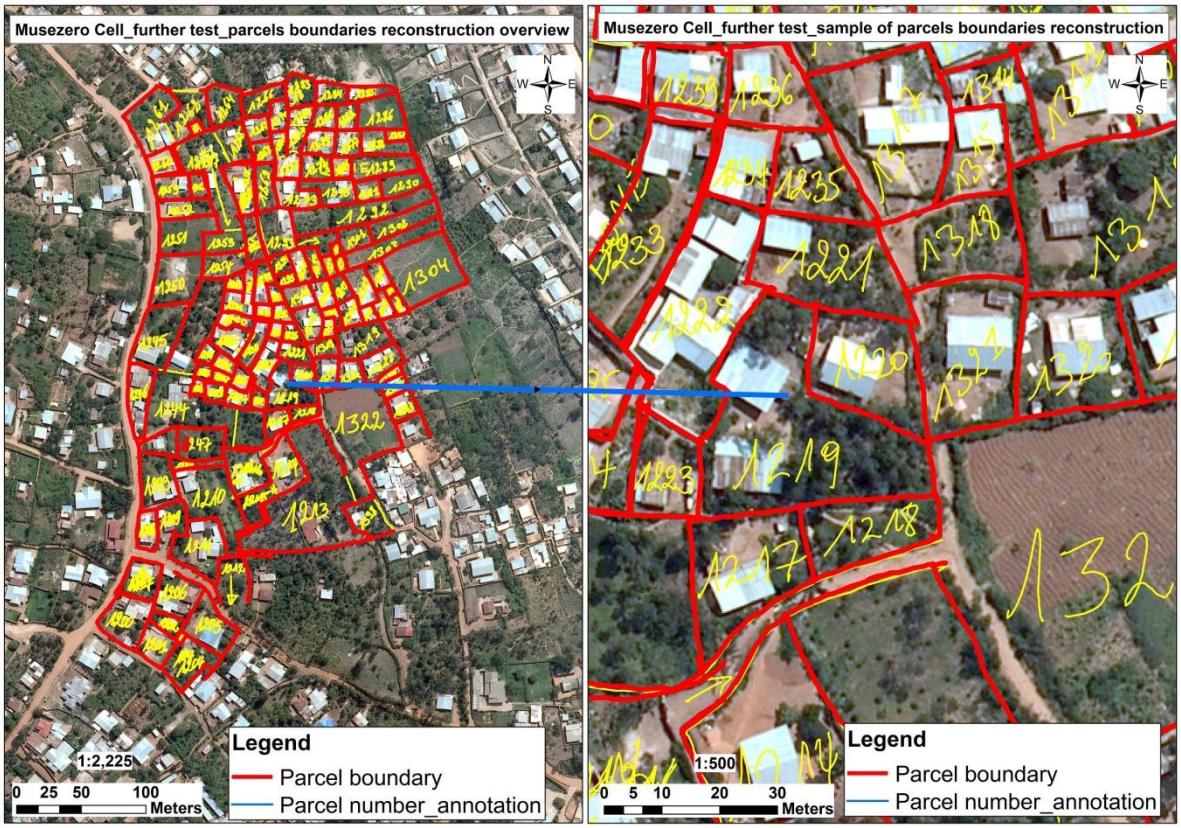
A part from technical issues which happened during field work, a further test was done to check the usability of digital pen in rainy circumstances. The purpose of this test was to check whether digital pen can still work on digital paper after being exposed to the rain. This was checked by putting the map (digital paper) outside in the rain for 10 days. During this time it was raining on the map, and the paper would dry again when there was sun shine.

Before drawing parcels boundaries and writing parcels IDs, the paper map was first dried under a heater. On the dry map, boundaries of imaginary 47 parcels were drawn and were attributed imaginary parcels IDs, and the result was that digital pen was still working well and was storing what was drawn and written on map. For some few places on the map however, the digital pen was giving signals (vibrations) that something was wrong. This was related to the places on map where the pattern was damaged by the exposure to the rain. After uploading data from digital pen to the computer and displaying them in ArcGIS, almost all parcels boundaries were visualised with their attributes/parcels IDs. Only 4 parcels had

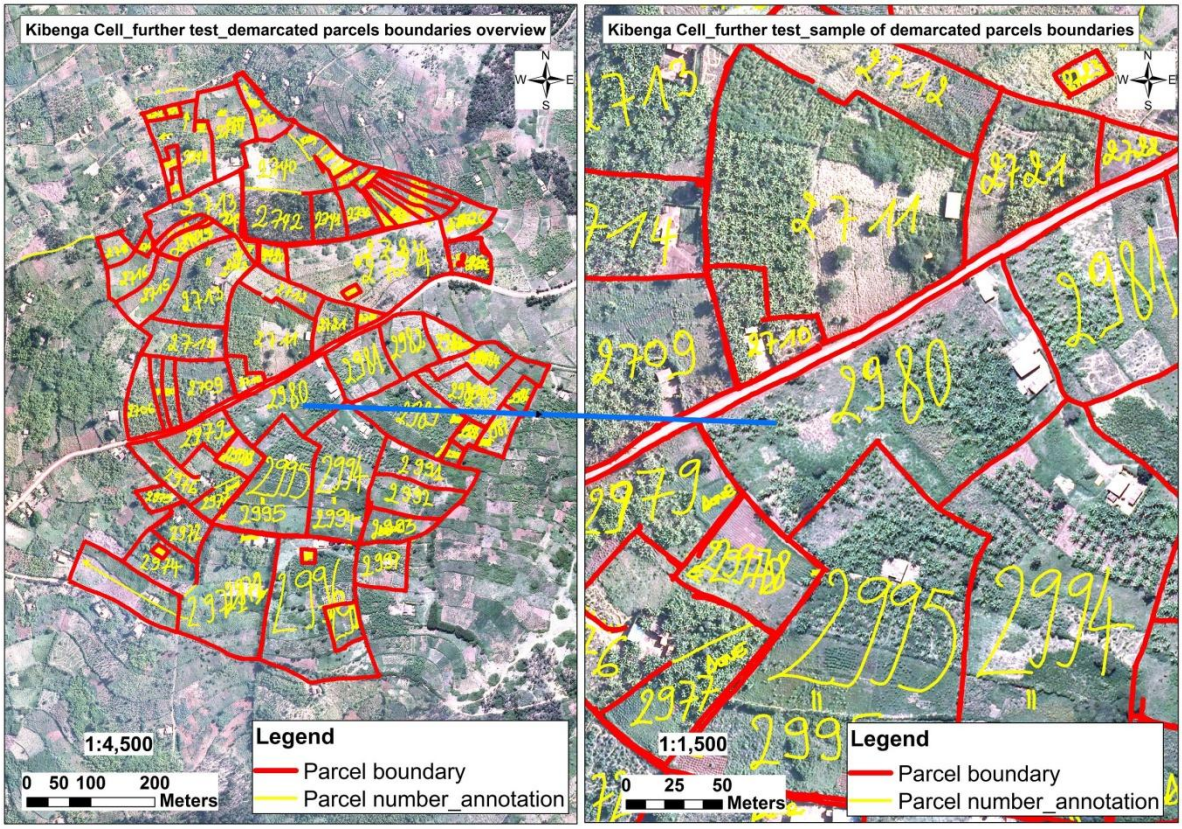
a small gap in their line segments, and 5 other parcels IDs were not complete. The missing records occurred in the places where the digital pen was giving signals (vibrations).

APPENDIX 3. OUTPUTS OF FURTHER TESTS FOR PARA-SURVEYORS

As mentioned in chapter 5.2.5. in December 2010 further tests were done for para-surveyors to assess whether the para-surveyors who were trained on the use of the digital pen method during research field work of September 2010 could still remember how to use it after a certain time without using it, and without anyone to show them again how to operate it.
These further tests were parcels boundaries reconstruction of the 123 parcels done during research field work in Musezero Cell, and another P-mapping in another area, in Kibenga Cell. The following figures show the outputs of the further tests, respectively the outputs of parcels boundaries reconstruction and the outputs of parcels boundaries demarcation in P-mapping.



Appendix figure 5. Further test/outputs of parcels boundaries reconstruction



Appendix figure 6. Further test/outputs of parcels boundaries demarcation in P-mapping