UAV Technology: Opportunities to Support the Updating Process of the Rwandan Cadastre

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Summary: Amongst others, Unmanned Aerial Vehicles (UAVs) are emerging as a tool for alternative land tenure recording. The advent of low cost, reliable and lightweight UAVs has created new opportunities for collecting timely, tailored and high-quality geospatial information. Even though UAVs appear a promising technology, it is not clear to what extent it can contribute to existing land tenure recording workflows of communities and governments. The case study method was applied to obtain valuable insights into the opportunities of UAV technology to support the updating process of the Rwandan cadastre. Field data were collected in Rwanda in February 2019, which encompassed several UAV flights and GNSS measurements. Additionally, a participatory mapping pilot study was initiated to allow the comparison of the existing cadastral base data with parcel boundaries delineated on top of the plotted UAV orthophoto. Results revealed an apparent discrepancy in the spatial location and extent of both parcel datasets and pinned the need to update the cadastre. Independent quality control with GNSS measurements showed a mean accuracy of 1.3 m - 1.5 m in the determination of parcel boundaries. It was found that especially in areas with significant developments and a poor quality of the first level registration, UAV-based orthophotos provide profound and reliable base data for participatory boundary delineation to update the spatial representation of the cadastre.

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1. INTRODUCTION

Since the early 2000s, UAVs became a substantial gain for scientific as well as commercial applications worldwide. The advent of low cost, reliable, user-friendly lightweight UAVs, recent developments in digital photogrammetry and structure from motion (SfM) image processing software solutions, creates new opportunities for collecting timely, tailored, detailed and high-quality geospatial information. Due to their flexible operational setups, UAVs can bridge the gap between time-consuming but high accuracy field surveys and the quick yet relatively expensive classical aerial surveys. Resulting data products include true orthoimages, digital elevation models, and 3D point clouds, which can all serve as a basis for cadastral mapping applications. Various authors have tested the applicability of UAVs in western European cadastral systems (Rijsdijk *et al.*, 2013; Barnes and Volkmann, 2015; Kurczynski *et al.*, 2016) as well as in African and Asian countries (Mumbone *et al.*, 2015; Hardiono *et al.*, 2016; Ramadhani, Bennett and Nex, 2018; Stöcker *et al.*, 2019). Based on pilot studies, authors argue that UAVs might have the ability to transform current data collection strategies for land administration by reducing surveying costs, allowing flexibility in workflows, independence from satellites, and enabling timely and local data acquisition. However, challenges are also outlined and include sufficient image overlap, the limited resolving power of low-cost camera systems, and regulations. The data obtained by UAVs have proven to be highly beneficial for (semi) automated feature extraction workflows (Crommelinck *et al.*, 2018; Fetai *et al.*, 2019) or as base data for community-driven mapping.

However, the potential of UAV-based mapping and surveying has not been exploited yet. Most countries in the Global South do not maintain complete cadastres and informal land transactions, as well as insufficient updating mechanisms, are evident. In this conference paper, we aim to assess a UAV-driven participatory mapping approach as an alternative concept to contemporary ground-based boundary surveying workflows in a case study in Rwanda. Data were collected in two main steps: 1) UAV data collection; 2) participatory mapping activity with the local citizen. The evaluation of UAV technology is based on an independent quality assessment and observations during the case study. Even though this case study does not reach a technology readiness that fully integrates technology in the existing operational environment, it is hoped that it can contribute to a better understanding of the feasibility of UAV technology to support land data acquisition in general and the updating process of the Rwandan cadastre in particular.

The conference paper begins with a brief overview of the study area. It will then go on with a description of the various data collection strategies and methods to analyze the data. The fourth and fifth section present and discuss the findings of this research. Remarks and recommendations complete the conference paper.

1.1 Country background

Rwanda is a small land-locked country in Eastern Africa, which shows one of the highest population densities within the African continent. A substantial and steady population growth unavoidably results in increased pressure on land and tenure insecurity. As a response to that, Rwanda has initiated major land tenure reform programs during the past 20 years to bring land tenure security. This was reinforced by several institutional and legal reforms and culminated in a nationwide land registration program called “Land Tenure Regularization” (LTR), which is characterized as a one-off, low-cost, community-based process. Over eleven million parcels were surveyed, registered, demarcated, and adjudicated within a period of a few years (2006-2013). The formalization of land in Rwanda was based on aerial images for the community-driven demarcation process, digitization of all land data collected and further centralization in a national land register and cadastre (Ngoga et al. 2017).

Even though the LTR tells a story of success, the challenge is ensuring that land transactions are being registered to keep the land data updated. (Ngoga et al. 2017) conclude that only one-third of all land transactions in rural areas are officially registered. Furthermore, areas with rapid developments are likely to show significant discrepancies between the reality and the spatial representation of the cadastre as well. Another problem was identified in the correctness of the boundaries. One of the land administration professionals at the national level said that “ almost all people in Rwanda have their land titles with errors on boundaries”. Concerning titles that were issued during the first registration, reasons for errors are seen in the poor training of the para-surveyors, the time delay between capturing aerial images and demarcation on printed orthophotos and cases in which parcel boundaries were not visible (Stöcker 2019).

1.2 Study area

The study area for the UAV data collection covers 3km² of the northern part of Ruhengeri Cell, District of Musanze, Northern Province of Rwanda. The area of interest was chosen due to significant urban developments that occurred during the past years (cf. Figure 1). These changes are not visible in the aerial images from 2009 and mainly also not updated in the Land Administration Information System (LAIS). Consequently, disputes arise as the current cadastre does not reflect the real situation on the ground, causing problems with updating mechanisms, correct compensations, and transactions. One of the villages in our study area was selected by Rwanda Land Management and Use Authority to conduct a systematic updating of the cadastre during the financial year 2019-2020. To show the potential of UAV technology, we chose this village to trial the community-based participatory mapping activity.

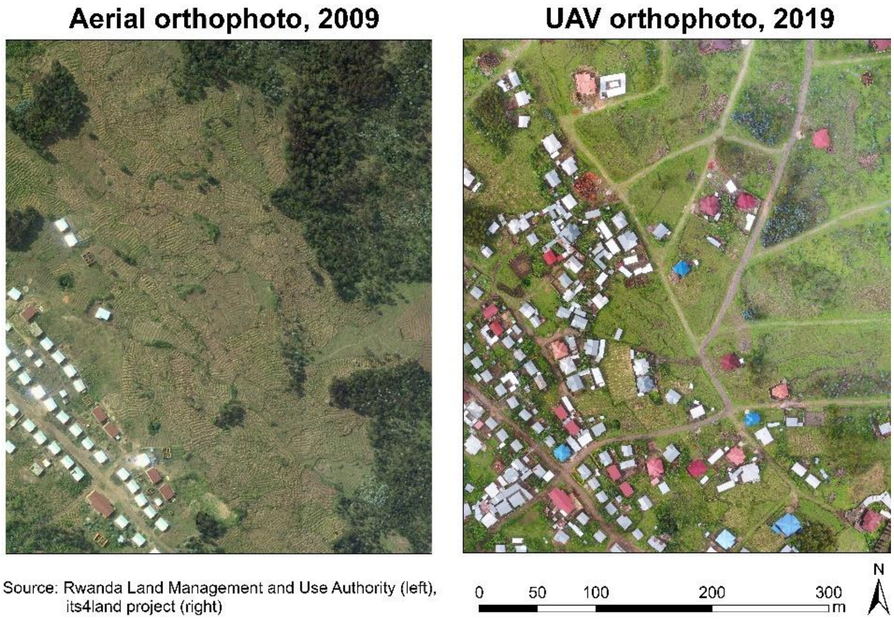

Figure 1: Case study area for community-based participatory mapping

2. MATERIAL AND METHODS

A case study approach was used to conduct this exploratory study. The research data is drawn from three main sources: 1) UAV data collection and measurement of ground control points conducted in February 2019, and 2) a participatory mapping activity with local residents immediately after the UAV data collection, and 3) GNSS measurements of parcel boundaries. The evaluation of UAV technology for the updating process of the Rwandan cadastre is based on the geometric quality assessment and observations during the case study.

In collaboration with RLMUA, INES Ruhengeri and Esri Rwanda, we captured the area of interest with more than 8000 high-resolution images. The flights were carried out by the only licensed UAV company in Rwanda: Charis UAS Ltd., which holds all required licenses and permissions of the Rwanda Civil Aviation Authority to perform UAV flights. We employed a DJI Inspire Pro UAV (see Figure 2 left) with an RGB sensor to take pictures during the flight. The mission was planned and executed with Pix4D capture. Parameters were programmed according to the maximum allowed flight height of 120 m, which implicates an ideal ground resolution of 2 cm (equation 1).

$$GSD = \frac{flying\ height}{focal\ length} * pixelsize$$

Equation 1

Image overlap was set to 80% (forward) and 75% (side lap) to cater for unexpected wind turbulences and to ensure the creation of a reliable orthomosaic that is based on a strong image network. Additionally to the UAV data, we also collected ground truth data with a survey-grade GNSS (Trimble R8). For means of georeferencing, in total 14 visible ground control points were marked throughout the study area. The points were deployed with spray paint and had a round shape with an identifiable centroid (Figure 2 B). All locations were measured during two consecutive measurement campaigns with an accuracy below 2 cm as the GNSS devices were connected to the RTK network of the continuously operating reference system. The data was processed using the photogrammetric software Pix4D (Figure 2 C). Here, 8 points were used as ground control points within the photogrammetric processing. Remaining 6 points were used as independent checkpoints for quality control.

Figure 2: UAV data collection. A: checking the UAV DJI Inspire Pro before the flight; B: measurement of ground control points for georeferencing; C: data processing in Pix4D

The second part of the data collection was focused on a participatory mapping activity to see how local inhabitants demarcate their land on the orthophoto. Furthermore, this mapping activity provided exciting insights into the ability of locals to identify their houses and boundaries. For this, we selected an area in Susa village, which is known to have land conflicts as well as unrecorded land transactions. Relevant local government stakeholders were notified and informed about the data collection. The UAV data of the respective area was processed during the weekend and printed with a scale of 1:300 on an A0 sheet (Figure 3 A). The map was protected with a thin lamination layer and waterproof markers were used for the drawing. Accompanied by a village elder, we approached residents in their houses during the daytime on two consecutive days and asked if they could delineate their parcel boundary on the printed map (Figure 3 B and C). If the parcel was drawn successfully, we additionally collect information on the identification number of the parcel and the situation of ownership.

Figure 3: Participatory mapping activity. A: printing the orthophoto; B: identifying houses on the orthophoto; C: drawing the parcel boundary on the orthophoto

To allow for independent quality control of the hand-drawn parcel outlines, additional GNSS measurements of nine selected parcels were carried out with a Trimble R8 GNSS device. Parcel corners were surveyed in RTK mode, with a baseline of approximately 2 km. Measurements revealed a horizontal accuracy of less than 2 cm. The following steps were accomplished to prepare the data for the quality assessment: 1) Scanning the A0 paper with hand-drawn parcel outlines, 2) georeferencing the scanned map based on clearly identifiable landmarks, 3) digitizing parcel outlines by tracing hand-drawn lines, 4) measurement of Euclidian distances of corner points. The statistical comparison of point coordinates is graphically depicted in boxplots.

3. RESULTS

This section provides a brief quality assessment of the UAV dataset and findings of the comparison of the hand-drawn parcel outlines with the LAIS as well as with GNSS measurements.

3.1 UAV dataset

During the photogrammetric processing, three main data products can be derived from the UAV images. Firstly, a 3D point cloud is reconstructed, which presents a 3D visualization of the entire scene. As shown in Figure 4, the surface, as well as rooftops, are represented consistently. Since the UAV only captured nadir images, the representation of vertical features such as walls of houses show lower point densities and are less consistent. Next, to the 3D point cloud, a digital surface model (DSM), as well as the orthophoto, can be derived. Even though all three datasets could be used to derive parcel information during a participatory mapping, the emphasis in this study was put on the orthophoto as this represents the dataset, which is the easiest to interpret for local residents. The overall geometric accuracy of the orthophoto is 10.3 cm, with a ground sampling distance of 2.1 cm.

A **B**

Figure 4: Data products derived from UAV images. A: 3D point cloud; B: digital surface model; C: orthophoto

3.2 Participatory mapping results in comparison to the LAIS database

During the participatory mapping activity, 32 parcel boundaries were delineated by local residents. It was found that 72% of all people could identify their houses without or with little guidance. Landmarks such as construction works, a road, or special buildings that are known to everyone guided the orientation of local people. Furthermore, the high level of detail helped to accurately draw the boundary as fences, walls, special plants that usually demarcate the boundary, and even slight changes in the paving of streets were easy to detect. Few people refused to participate in the mapping activity as they reported land-related conflicts.

The next step after successful delineation of the parcel boundary was to pose the question about the title document. In this context, only 37% of all residents were able to present their titles. Reasons to not show the title varied widely, including those persons who were only tenants, women who did not have access to the title of the husband, or that the title is currently at the land office due to a planned land transaction process.

During data analysis, the parcel boundary drawn by the resident was linked to the existing parcel outline in the LAIS. The link was made parcel IDs, or via the location of the parcel if the parcel ID was not known. One-third of all parcels could not directly be linked to an existing parcel as none of the conditions mentioned above was fulfilled. An overview of both datasets – parcel outlines derived from the participatory mapping as well as parcel outlines from the cadastral data LAIS – is presented in Figure 5. It is clearly visible that some parcels have the same extent in both datasets, especially for parcels with a regular rectangular pattern (lower left area in the map). In other cases, two to three parcels from the participatory mapping activity form one parcel derived from the LAIS, which indicates that the land has not been officially subdivided yet. Lastly, in some instances, the drawn parcel boundary by local residents does not reflect the parcel outline from LAIS, neither in shape nor in size. This problem can be attributed to several issues: errors during first level registration in 2013, informal land transactions, or a faulty survey of the parcel during land transactions. In this specific case, especially the first level registration could be a potential source of errors as many developments took place during the period from 2009-2013, and the first level registration was carried out during 2012-2013, whereas the base maps were bound to the aerial image from 2009.

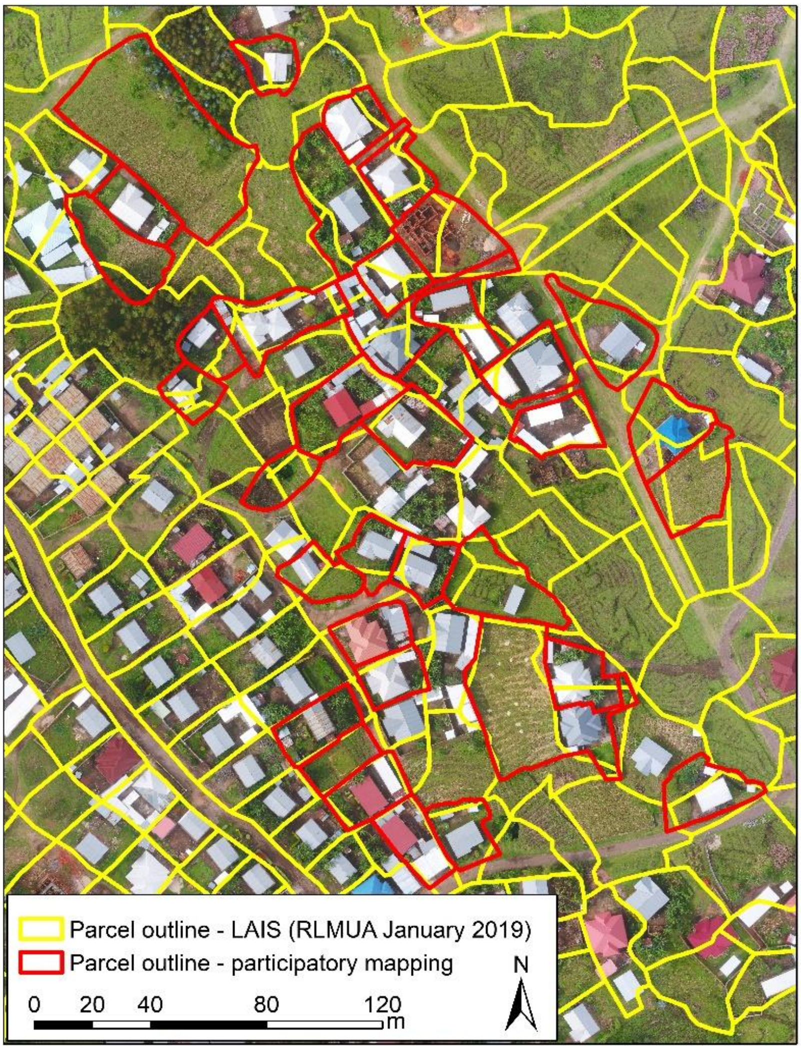

Figure 5: Overview of parcel boundaries derived from participatory mapping (red) and cadastral database LAIS (yellow)

A closer analysis of the parcel shapes reveals that on average 70% of the dawn parcels overlay with the official parcel data in LAIS. From the diagram in Figure 6, it can be seen that the range is very large and spreads from a minimum of 15% overlay to a maximum of 98% overlay. In this context, it should be noted that this average only refers to parcels that could be linked (25 out of 32), whereas the overall average might decrease when considering the „odd" parcels as well.

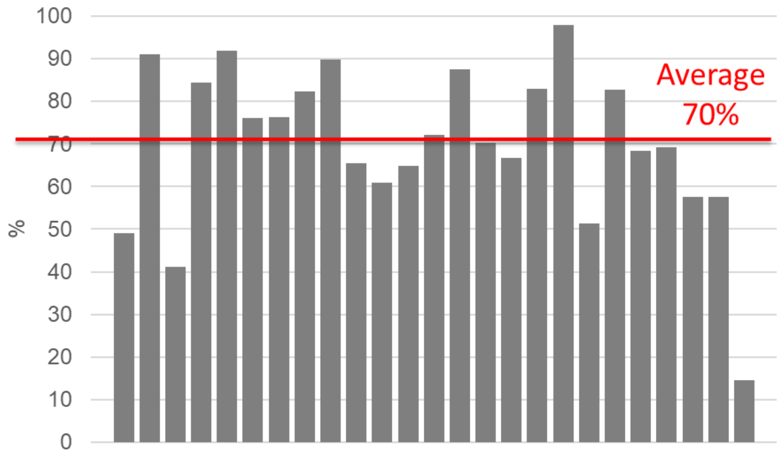

Figure 6: Percentage of overlay from parcel area derived from participatory mapping with parcel area from LAIS

As the percentage of overlay alone does not provide the full picture of discrepancies in the spatial extent, we further compared the size of parcels. Here, negative values indicate that the drawn parcel is smaller than the parcel in LAIS, whereas positive values indicate that the drawn parcel is larger. The diagram in Figure 7 shows two extremely negative values with more than 1000m² of land. Both parcels refer to a case in which the parcel size in LAIS is significantly larger as the land has been informally subdivided. The maximum value on the positive balance reflects a case, where the owner has already bought the property of his neighbour but did not report this transaction to the District. Besides those extreme deviations, all remaining differences are in a range of +/- 300 m². Most of those deviations can probably not be explained by land transactions that are not yet processed but by an apparent discrepancy of the situation on the ground and the information in the cadastral database.

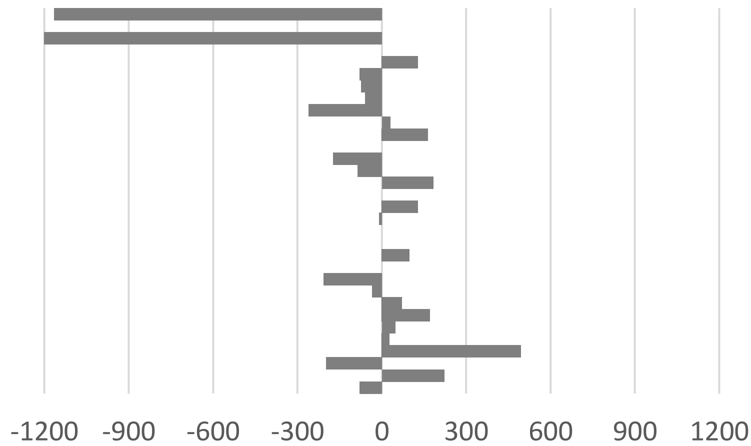

Figure 7: Difference in parcel size (m²).

3.3 Participatory mapping results in comparison to GNSS measurements

Whereas the previous subsection focused on the areal extent of the parcel, this subsection assesses the geometric accuracy of hand-drawn parcel outlines compared to GNSS point measurements as a reference. Since bot data was collected at the same time and under the same condition, data from both survey methods can be directly compared. For means of a more transparent analysis, parcels have been distinguished according to their shape. Regularly shaped parcels refer to a parcel with a standard geometric shape such as a rectangular or a circle, whereas irregularly shaped parcels include all other forms. Two main observations are visible in the statistical analysis (Figure 8).

Firstly, significant geometric differences have been found for parcels with hardly any visible boundary. In both cases – regularly and irregularly shaped parcels – the maximum point distance of (more than) 5m can be ascribed to parcel corners without clear landmarks such as walls or specific plants. Two irregularly shaped parcels are shown in the lower right of Figure 8. Whereas the agricultural area with maize crops shows only minor discrepancies between differently surveyed parcel corners, the residential parcel has almost no visual features to determine the parcel boundary towards the North. Consequently, the GNSS point measurements and the hand-drawn parcel boundary do not represent the same spatial extent.

Secondly, irregularly shaped parcels show a significantly larger variance of point distances as represented by the interquartile range, thus tend to have a higher uncertainty in the representation of the hand-drawn outline. In contrast, both types of parcels show almost the same mean distance with 1.30 m for regularly shaped parcels and 1.47 m for irregularly shaped parcels, respectively.

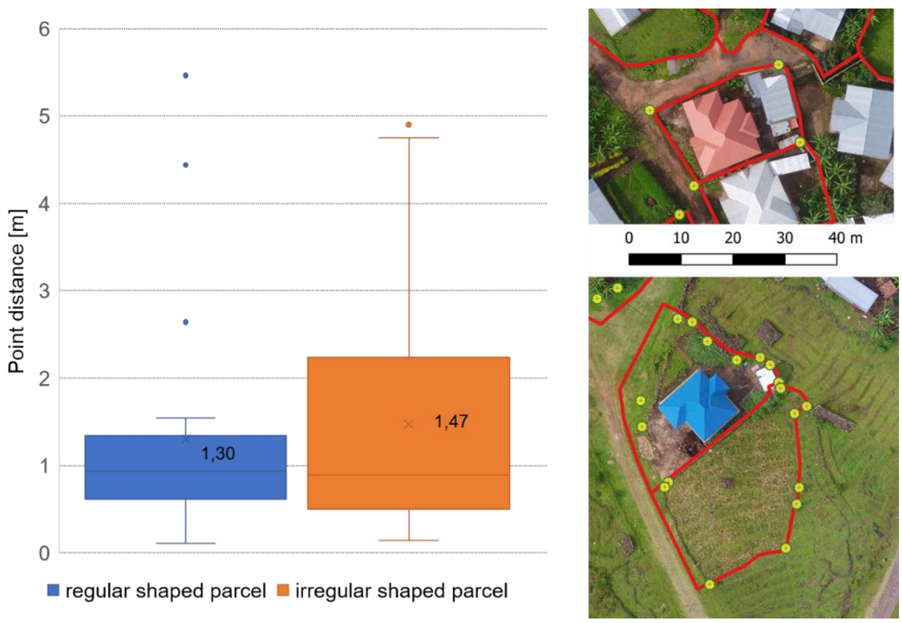

Figure 8: Statistical analysis of distances of parcel corner points derived from GNSS measurements and participatory mapping (left), graphical examples for a regularly shaped parcel (upper right) and irregularly shaped parcel (lower right).

4. DISCUSSION

The discussion firstly reflects on the potential consequences of the discrepancies of parcel data for local residents as well as for the government system. Afterwards, the accuracy assessment opportunities for UAV technology to address those potential negative implications are discussed.

The Rwandan tax system is currently based on the areal extent of the parcel as well as the land use zone. As an example, landowners pay 40 RWF per m² annually in a residential area. Deviations in the parcel extents derived from this study ultimately imply that landowners pay too little or too many taxes. This might lead to conflicts, especially when residents come in touch with the conventional system. Re-surveying and fixing of existing parcel boundaries cause several problems. Firstly, almost all neighboring parcels are affected by the survey and would require a re-survey as well. During the process of fixing boundaries, surveyors are still using the old aerial images or google earth to validate and adjust the polygon of the geodetic survey in the field not to raise concerns by the official land authorities. If the proposed cadastral parcel plan would deviate too much from the original parcel, the re-survey might be rejected. Missing survey standards and a lack of well-trained professionals add to this problem and cumulate in a cadastral updating process, which is neither efficient nor reliable. Musanze is one of the fastest developing secondary cities in Rwanda, and land prices are increasing tremendously. In this regard, it will be a matter of time until conflicts during land transactions arise, especially when people pay the wrong amount of taxes or do not get compensated correctly due to the discrepancy of the LAIS and the reality on the ground.

Looking into the measurement accuracy of UAV-based participatory mapping of parcel boundaries, the accuracy assessment with GNSS measurements as reference data revealed a mean offset of 1.3m for regularly shaped parcels and 1.47m for irregularly shaped parcels. The geometric difference in point locations has various error sources. Both surveying methods contain different levels of accuracy. Whereas the accuracy of the GNSS measurement is determined by the mode of ambiguity resolution, the UAV-based participatory mapping approach shows various sources of errors. Firstly, the error of the photogrammetric reconstruction, and secondly, the error of the drawing, which can be subject to map scale, the thickness of the pencil, as well as the ability of the local citizen to correctly determine and draw the parcel boundary. Aside from extreme outliers in the range from 4-5m point distance, the results in this study suggest a measurement accuracy of 1m to 2m for UAV-based participatory mapping of parcel boundaries when following the approach described in this conference paper.

Despite the geometric measurement accuracy, we could validate that people can understand the map and identify their houses, primarily due to the high resolution and clear visualization of small features such as walls, surface characteristics of roads, and even particular forms of vegetation. The immediateness of the data delivery of only a few days from the UAV data collection and the printout of the map certainly helped in this procedure as we observed that people are more likely to identify small features such as little piles of sand or stones that they are used to see in their every-day life. The high level of detail further reduced disputes about the location of boundaries to a minimum. Although we went from house to house and did not include all neighbors during the process of boundary delineation, not even one party disputed the line which was drawn by its neighbor.

Even though the discrepancies of the LAIS and the hand-drawn parcel outlines cannot be solely ascribed to one or another reason, it could be shown that UAV orthophotos can help to detect informal land transactions. Secondly, significant boundary offsets from the first registration can be spotted, especially when parcel boundaries are crossing houses and are not aligned to any visible boundaries on the ground. At a lower level of implementation, UAV data could further be used by the District government to validate geodetic surveys of professionals. Referring back to the situation that some regions in Rwanda were nominated for a systematic re-survey, UAVs would be a suitable technology to provide an up-to-date base map for those regions which extent is limited to a few km².

5. CONCLUSION

This conference paper set out to examine the opportunities of UAV technology for a real-world case study in Rwanda, namely to support the updating process of the Rwandan cadastre. The results of this exploratory research have shown that in the study area the current LAIS data shows significant discrepancies from the real situation on the ground. The case study showed that UAV-based up-to-date base data could significantly improve current surveying practices either for means of validation or even as a primary data source for participatory mapping activities to determine general boundaries with an overall accuracy of 1 - 2 m. The suggested workflow shows strong benefits compared to contemporary ground-based surveying, particularly in terms of transparency of the data collection, the participation of local residents and time efficiency. Especially the task of systematic re-surveying of small-to-medium scale areas should be considered to employ UAV technology as a fit-for-purpose (Enemark, McLaren and Lemmen, 2016) mapping and surveying practice.

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BIOGRAPHICAL NOTES

Since 2012, Claudia Stöcker is working with unmanned aerial vehicles (UAVs) and UAV data. As a physical geographer by training, she first focused on high-resolution surface reconstruction to study soil erosion. Fascinated by the almost unlimited capabilities of UAVs for data capture, she is pursuing a Ph.D. which is associated with the EU H2020 project its4land (www.its4land.com) at ITC, University of Twente. Her Ph.D. research aims to design, test and verify UAV-based data acquisition workflows as a tool for responsible land administration. A comprehensive analysis of stakeholder requirements and extensive test flights will provide profound pre-requisites for the design of UAV workflows to assure the target focuses on the needs of the society in East Africa rather than solely on potentials of high-end technologies. So far, she has written three ISI journal papers that are frequently cited. Her work has been presented on numerous occasions such as former FIG conferences, ISPRS conferences, and the World Bank Conference in Washington DC.

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