Accelerating participatory land rights mapping with SmartLandMaps tools: Lessons learned in Benin

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SUMMARY

Sketching on maps has proven to be a useful tool during participatory land rights mapping. However, the co-creation of information and analog way of mapping necessitates substantial effort to transfer the sketched maps into a georeferenced digital format and combine them with any attribute data. SmartLandMaps addresses this challenge through its approach and tools facilitating the automatic digitization of hand-drawn sketches on existing maps. This paper reports on a pilot study carried out in Benin, in February 2022. In collaboration with the PMAF project (Projet de Modernisation de l'Administration Foncière) and YILAA (Youth Initiative for Land in Africa), SmartLandMaps collected data on more than 400 parcels in an urban and a rural study site using UAV orthoimages as base maps. After the mapping session, the results were automatically digitized and compared with reference data from PMAF and GNSS measurements. Overall, the SmartLandMaps process proves to be highly efficient. In both study sites, more than 95% of all hand-drawn boundaries were automatically extracted and correctly vectorized. Good facilitation of the mapping process enabled most hand-drawn boundaries to be within an acceptable level of accuracy. Scaling up this approach with the support of many mapping teams is feasible, as enhanced workflows and the SmartLandMaps technology enable fast and reliable digitization of analog maps within a few hours and only minimal professional capacity or know-how.

RÉSUMÉ

La numérisation de données collectées avec les méthodes analogiques de cartographie continuent de nécessiter des efforts manuels et un temps considérables. SmartLandMaps relève ce défi grâce à son approche et à ses outils facilitant la numérisation automatique des croquis dessinés à la main sur des cartes existantes. Cet article rend compte d'une étude pilote menée au Bénin, en février 2022. En collaboration avec le projet PMAF (Projet de Modernisation de l'Administration Foncière) et YILAA (Youth Initiative for Land in Africa), SmartLandMaps a collecté des données sur plus de 400 parcelles en utilisant des orthoimages de drone comme carte de base. Les résultats ont été automatiquement numérisés et comparés aux données de référence provenant de mesures PMAF et GNSS. Dans les deux sites étudiés, plus de 95 % de toutes les limites dessinées à la main ont été automatiquement extraites et correctement vectorisées. Une bonne facilitation du processus de cartographie a permis à la plupart des limites dessinées à la main de se situer dans un niveau de précision acceptable.

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1 INTRODUCTION

Sketching on maps has proven to be useful during participatory mapping activities in various contexts such as urban planning or environmental protection (Zare Zardiny & Hakimpour, 2021). It allows an increased stakeholder engagement, and transparency and represents one of the easiest and cheapest ways to co-create spatial data with citizens. Particularly for land rights recording, this form of participatory mapping found endorsement in the FFPLA (Fit-For-Purpose Land Administration) guiding principles and has been applied in various geographical contexts and scales (Ali & Ahmed, 2013; Asiama et al., 2017; Becerra et al., 2021; Mustofa et al., 2018; Panday et al., 2021). Moreover, using photogrammetry or remotely sensed data to derive information on land tenure has a history of more than 100 years, as recently proven by (Bennett et al., 2021).

However, the co-creation of information and analog way of mapping necessitates substantial effort to transfer the sketched maps into a georeferenced digital format and combine them with any attribute data. SmartLandMaps addresses this challenge through its approach and tools facilitating the automatic digitization of hand-drawn sketches on existing maps. SmartLandMaps is a start-up initiative of the University of Münster funded by the European Union under the OP EFRE NRW 2014-2020 program. During the past year, SmartLandMaps increased the efficiency and flexibility of its toolset (Degbelo et al., 2021) and currently implements various pilots to validate the applicability and performance of the technical approach.

This conference paper reports on the SmartLandMaps pilot project in Benin building on the existing land tenure intervention financed by the Netherlands through the Land Administration Modernisation Project, PMAF. For the field data collection in the PMAF project, only GNSS is applied. The beneficiary of the project, the national cadastre agency of Benin, however, is also interested in image-based mapping approaches to find best practices to reach nationwide cadastral coverage. For the SmartLandMaps pilot project in Benin, two sites are selected: an urban area in Cotonou / Sèmè-Podji and a rural area in the municipality of Zè. This paper aims to present the findings from the pilot. First, the mapping workflow is evaluated, including a discourse on different background maps, boundary concepts, and community engagement. Second, the SmartLandMaps technology performance is assessed by comparing automatically extracted polygons to on-screen digitized polygons. Third, the data accuracy is evaluated through independent GNSS measurements of parcel corners and boundaries.

2 CONTEXT

Since 2010 Benin has been engaged in an in-depth reform of the land sector. This reform, covering the legal and institutional aspects as well as the tools for securing land tenure, is based on the *Code Foncier et Domanial* (Land and Domain Act, CFD), which was implemented in 2013 and modified in 2017. The code addresses the land issue in its entirety and introduced a new institutional framework including the National Agency for Land and Property (ANDF). Despite the strong legal basis, out of the 9 to 11 million plots of land in Benin, only about 60,000 have a land title. A major reason for this low number of land titles is the cost of the procedure for obtaining a land title. Especially the less wealthy rural and urban population cannot afford the costs of a land title procedure. It is in this context that the Netherlands initiated and financed the current Land Administration Modernisation Project, in French 'Projet de Modernisation de l'Administration Foncière' or PMAF (Mekking et al., 2021). The project started in December 2018 and addresses the land question in its entirety, aiming at optimizing the land governance (technical, institutional, and legal) by introducing and applying a transparent and participative Fit-for-Purpose approach. Within PMAF, the stated ambition for data collection is to cover around 1250 km², counting at least 200.000 parcels, over three years; the objective being to produce data of optimal quality for the national cadastre and at the same time develop approaches that will allow wider coverage of the national territory with the help of other partners and projects in the future.

The SmartLandMaps pilot project builds on the PMAF project. Two study areas were proposed by the PMAF project. Study area 1 is situated in Sèmè-Podji and covers an urban area encompassing an area of approx. 18 ha. Looking closer at the characteristics of this area, most cadastral boundaries are represented as visible boundaries made up of walls or fences. Study area 2 is situated in the municipality of Zè and is dominated by agricultural use including a rural settlement called Houegoudo. Here, visible boundaries are less prominent but changes in the land use might indicate different land rights holders. Thus, both study areas are complementary and allow us to test the SmartLandMaps approach in different contexts.

3 METHODOLOGY

The data collection and processing methodology applied during the pilot project in Benin entails three main processes. The mapping procedure includes the preparation of the maps and community engagement. Once all participating community members have delineated their plot on the aerial image, the first part of the digitization procedure takes pictures of the annotated map and processes those in a photogrammetric environment to obtain a digital, orthorectified representation of the sketched map. Afterward, the data is sourced into the extraction and vectorization software to generate georeferenced vector geometries of the drawn sketches - geometries ready to be transferred into any existing Land Administration Software or Geographical Information System. Each of these steps is further explained below.

3.1 The Mapping Procedure

The mapping procedure using satellite, aerial, or drone imagery is not specific to the SmartLandMaps workflow and may take different characteristics depending on geographical and cultural context. For the pilot study in Benin, the mapping procedure was determined by local circumstances and cartographic requirements for the subsequent automated digitization.

The spatial and temporal resolution of background maps for participatory mapping has been broadly discussed in various works (Naufal et al., 2022; Stöcker et al., 2019). There is a consensus, that depending on the context, accuracy requirements, and budget, different kinds of background maps may be suitable in different kinds of situations. For this pilot project, the CNES/Airbus and MAXAR satellite data available in a Google Maps QGIS plugin was not suitable, as the resolution (50cm ground sampling distance (GSD)) did not sufficiently allow distinguishing different houses and boundary objects. The aerial image provided by the PMAF project was captured in 2016 (Zè, 50 cm GSD) and 2017 (Sèmè-Podji, 20 cm GSD). Next to satellite and aerial imagery, imagery captured by Unmanned Aerial Vehicles (UAV) was also used in the mapping procedure. SmartLandMaps requested the local drone company *Benin Flying Labs* to capture drone imagery of the selected study areas. In Sèmè-Podji, a DJI Phantom was utilized to capture aerial images of the study site with an extent of 0,23 km². The resulting orthoimage had a GSD of 1,8cm and positional accuracy of 1 cm at ground control points. In Zè, the mapping extent was considerably larger (1,53 km²) and a fixed-wing UAV was applied (SenseFly AeriaX). The final orthoimages reached a GSD of 2,3 cm and positional accuracy of 11 cm at ground control points.
The differences in spatial as well as temporal resolution of the background data are exemplified in Figure 1. For the mapping procedure in Benin, all background maps were prepared beforehand and printed on A0 glossy paper with a scale of 1:500 as recommended in the FFP guidelines for urban areas (Enemark et al., 2016). Whereas one map was sufficient in Sèmè-Podji, the study area of Zè, which was six times larger than Sèmè-Podji, required four individual maps and one overview map.

Figure 1: Close-up view of available background data showing the same place in Zè (first line) and Sèmè-Podji (second line)

In addition to the printed maps, a digital questionnaire was designed to collect information about landowners and their property rights. The questions were aligned to the LADM-based data model of the PMAF project. The questionnaire was realized using Open Data Kit (ODK) and can be filled on any tablet computer or smartphone.

For the fieldwork, SmartLandMaps partnered with YILAA, the Youth Initiative for Land in Africa, to have additional local support for the participatory mapping activity. Particularly YILAA´s knowledge of local languages and customs was crucial for appropriate facilitation. Before going to the field, local authorities were informed about the aim and the mapping procedure in our pilot project. A community meeting took place before data was collected, informing all interested persons about SmartLandMaps and the purpose of our pilot project. Together with the community, the project team decided on a local "task force" consisting of a man, a woman, a youth, and an elderly person to assist with the mobilization and sensitization of landowners. To leverage the benefits of a large-scale map, meeting locations were agreed upon, allowing gatherings of several people around the map, and stimulating discussions. The mapping team worked with removable sticky dots and sticky notes to permit a dynamic consensus building on the position of boundary corner points. Once the location of a corner point has been agreed upon by all neighbors and trusted intermediaries, the sticky dots demarcating the boundary corners were not moved anymore and boundary lines were drawn using a black marker and a ruler. After engaging in the participatory mapping activity, the landowners were asked to fill the questionnaire on a tablet computer, together with a mapping assistant. The answers to the questionnaire were transferred to a secure online server, from which they can be downloaded in various tabular formats. In both study areas, the entire mapping procedure took four days, including sensitization, sketching on maps, and filling out the questionnaire.

3.2 Digitization I: Georeferencing and Orthorectification

Once the mapping is completed, the first part of the digitization starts. Because a scanner to handle A0 maps might in many places not be available, SmartLandMaps developed a workaround to substitute the need for a large-scale scanner. The process is based on modern short-range and UAV photogrammetry and memes a UAV flight over the sketched map Nadir images of the A0 map were taken from different distances, ensuring sufficient (more than 50%) overlap between the pictures. The pictures were fed into the photogrammetric software Pix4D and passed through the classical processing pipeline consisting of image orientation, image matching, and the generation of the orthophoto. To allow for georeferencing, at least five small red crosses which were previously included in the map-making procedure were identified in the photographs and labeled as ground control points. Information on the geolocation of these red crosses was derived from the attribute data of the point shapefile. After the processing, a digital georeferenced and orthorectified representation of the original analog map was generated.

3.3 Digitization II: Extraction and Vectorization of Sketched Lines

Having produced a digital georeferenced picture of the analog map, the next step is to provide the boundaries of the parcels in a file format suitable to existing GIS software. The tools from

SmartLandMaps achieve this using two different software modules: a module for the extraction respectively labeling of boundaries (raster-to-raster), and a module for the creation of GeoJSON files from the extracted boundaries (raster-to-vector). Both modules rely on open-source libraries: image detection libraries (e.g. OpenCV, skimage), libraries to process geometries (e.g. shapely), and libraries for the processing of georeferenced data (e.g. gdal, pyproj). The implementation is done in Python. As for boundary extraction, the georeferenced map is read, cropped, and then divided into small patches. Currently, an approach based on watershed segmentation is used to label the patches, that is, separate pixels belonging to parcels' boundaries from other pixels. The final image is rebuilt from the labeled patches and is stored in a GeoTIFF format. After several empirical testing iterations, patches of the size 572 pixels x 572 pixels were used during the processing of the data from the pilot as they provided the best compromise between detection of boundaries and processing time. As for vectorization, the generation of GeoJSON files follows several steps: a) generation of geometries for the boundaries using a contour approximation algorithm, b) polygons simplification using the Douglas-Peucker algorithm, c) georeferencing of the polygons, and d) generation of the GeoJSON files based on the georeferenced geometries. Several parameters still need to be adjusted manually through trial-and-error at this point (especially for the boundary extraction module). We are currently exploring the use of neural networks to replace this manual optimization.

3.4 Quality Assessment

The data quality of the spatial representation of land plots drawn on the printed maps was assessed using existing cadastral data from the PMAF project as well as ground truth data measured during the SmartLandMaps pilot project in Benin. The PMAF project already collected data in Sèmè-Podji, which can be used as reference data for the quality assessment. The cadastral survey in the PMAF project foresees a fit-for-purpose approach. Each point of a parcel is measured by the surveyor using RTK GNSS. The Fit-for-purpose geometric accuracy requirement is 1m or better. In reality, the precision is a centimeter or decimeter level. Polygons bordering the study area were not considered during the data quality assessment.

As the rural area in the municipality of Zè is not within the scope of the PMAF project, the SmartLandMaps team needed to collect ground truth data themselves to validate the data drawn on the map. For this purpose, the Trimble Catalyst DA 1 antenna was employed to capture reference data. Together with the local task force and landowners, we visited the plots and measured a sample of boundary corners in the study area. The measurement accuracy was between 0.5 m and 2 m, depending on the quality of the GNSS signal, between 0.5-1 m in open areas and 1-2 m in areas covered with a canopy. The Catalyst DA 1 antenna was connected to the Trimble Corrections Hub with an activated high precision subscription. Overall, 107 points were measured in four different areas. It should be noted, that, in contrast to the urban area in Sèmè-Podji, only a fraction of landowners installed monuments and most boundaries were demarcated with specific trees and bushes. Some corner points were not visible at all. In addition to independent ground truth data, the automatically extracted parcel boundaries were also compared to manually digitized vectors. The manual digitization was realized in QGIS. Figure 2 provides an overview of the external reference data.

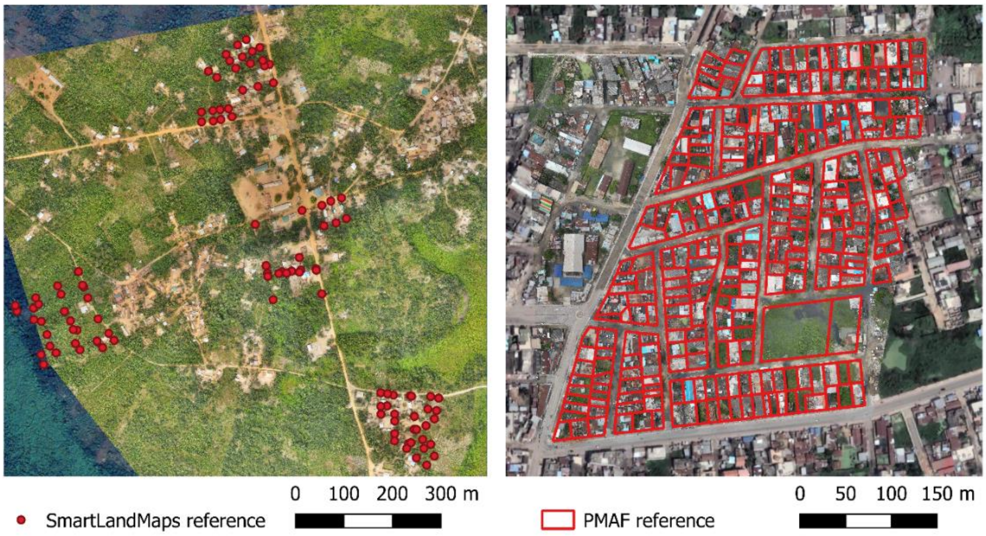

Figure 2: Overview of reference data in Zè (left) and Sèmè-Podji (right)

4 RESULTS

The following subsections present the results of the participatory mapping activities and generated parcel boundaries in both study areas individually. This is followed by a discussion to compare and reflect upon the SmartLandMaps approach and technology.

4.1 Sèmè-Podji – The Urban Study Area

The mapping activity was positively received by the community. Each morning, the activity was announced by a local crier walking the roads of the study area. Then, the task force mobilized the landowners or their representatives in the neighborhood of the mapping location. Interestingly, most people showed up during the morning hours. Overall, 202 parcels were mapped during the field campaign. When people arrived at the mapping location, they were first introduced to the project and to the map. Afterward, they were encouraged to identify important landmarks that they know, e.g., the church, a primary school, a pharmacy, and the office of the district head. Once a general map orientation could be established, the person was motivated to find his/her plot. In most cases, the plot boundary was marked by traceable and visible objects, such as the sidewall of a house, a wall, or a foundation. In some cases, the identification of the boundary was not obvious as it did not relate to a physical object on the ground. Here, the mapping facilitator of YILAA asked several questions to better understand the extent of the parcel such as: “Does this tree still belong to your parcel or not?”, “How many annexes do you have?” or “If you stand in front of your house, how many meters do you have to go to reach the limit of your parcel?”. The answers were translated to the objects visible on the map and supported the discussion about the placement of the sticky dots marking the parcel corners.

During day 2 of our mapping session in Sèmè-Podji, we tried different background maps to infer the impact of the background data on the interpretability of the map. This endeavor was rather challenging, as the purpose to look at different maps with different image qualities but still showing the same extent was not clear to most people. We further observed that some persons were hesitant to place a sticky dot as a boundary marker on a map on which they could not clearly distinguish their houses and corresponding parcels from their neighbors' parcels. Additionally, citizens got distracted from the temporal resolution of the aerial orthophoto of 2016 showing a reality most people could not relate to as a lot of development and construction took place during the past 6 years. Moreover, the aerial image from Benin was an orthophoto that was only rectified with the digital terrain model, but not with the digital surface model. Consequently, buildings higher than one floor, or even some walls showed significant distortions leading to confusion and uncertainty about the correct location of the boundary corner. By comparison, the UAV-based map was much easier to understand for three reasons. First, the orthorectification of the UAV images was accomplished with the digital surface model which eliminated any distortions resulting from higher image objects. Second the spatial resolution: objects of size 0.5 m such as a garbage can, or differences in the pavement of the backyard visible due to the high contrast and color intensity of the UAV image clearly helped local citizens to determine the location of the parcel boundary. Third, the recency of the UAV images substantially supported the map orientation as the people saw the map content showing a present reality and thus making it easier to connect the 'known' real world with the content shown on the map. Guided by these observations and the fact that the mapping team did not want to request more time than necessary from voluntary research participants, the subsequent mapping sessions only used the map showing the UAV orthophoto. The digital questionnaire was filled by 191 persons, of which 49 persons were the owner of the plot, and 142 persons were the representative of the owner.

After the mapping was finished, 150 photographs from different heights were taken to digitalize the analog map. The pictures were transferred to the commercial software Pix4D, where each ground marker (small red crosses) was marked in at least 5 pictures. A total area of 0.31 km² was reconstructed, with a ground sampling distance of 2.40 cm. Thus, the resolution of the digitized map including all sketched boundaries was about the same as the resolution of the original UAV orthoimage. The absolute accuracy of the georeferenced map was in the range of 2-11 pixels, corresponding to a root mean square error of 0.13 m at ground control points. In summary, the analog map co-created during the participatory mapping activity could be brought back to the digital format without introducing large geometrical offsets. The processing took three hours. The derived orthorectified and georeferenced digital representation of the map was further processed using the SmartLandMaps software. As described in the methods section, patches were created and sketched lines extracted and labeled as foreground, whereas all other map objects were labeled as background. All patches were mosaiced again to create a binary GeoTIFF file. As visible in Figure 3, this worked sufficiently well with some minor challenges in areas with dark shadows close to the sketched line (upper right corner) or vegetation (lower right side).

Based on the binary GeoTIFF output, a vector file containing all labeled (white) raster cells was generated. A bunch of GIS tools was applied to the final vector output to ensure topological consistency and that the vectorized parcels represent the middle of the drawn lines. The boundary extraction and vectorization application of the SmartLandMaps technology took 35 min+25 min to produce a vector representation of the sketched lines.

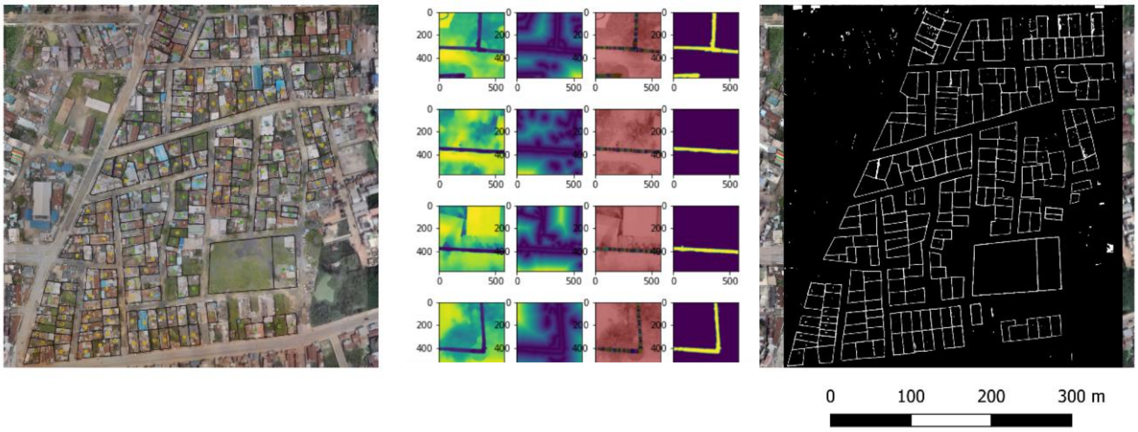

Figure 3: Workflow of SmartLandMaps Technology: a digital representation of the sketched map (right), patches created and classified during the feature extraction procedure (center), and the result of a binary GeoTIFF showing all sketched lines as labeled raster cells (right).

Figure 4 shows a detailed view of the vectorization results. Vectorizing the binary GeoTIFF in the first instance produces a kind of scribble-like polygon as the level of detail is very high. One option for post-processing foresees a parameter to set the degree of simplification and smoothing of lines (post-processed parcels I). Another option for post-processing applies several raster as well as vector operations (post-processed parcels II). Both options still have their challenges, e.g. topological consistency of adjacent parcels (option I) and the maintenance of angular-shaped boundary corners (option II). However, a combination of both workflows seems to be the right way to go in the future.

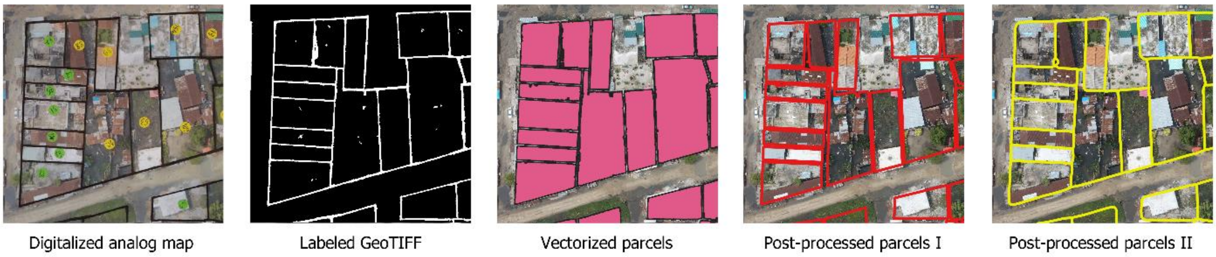

Figure 4: Vectorization procedure of polygons based on labeled GeoTIFF – Sèmè-Podji

4.2 Zè – The Rural Study Area

The participatory mapping activity in Zè followed the same procedure as in Sèmè-Podji. Thus, this part focuses on the differences in the mapping procedure and the data processing. As the study area in Zè was six times larger than in Sèmè-Podji, we spent one day with community sensitization detailing our pilot project. When introducing the maps, trusted intermediaries roughly sketched out family zones that guided the subsequent facilitation of participatory mapping activities. Accordingly, citizens were asked to gather at community meeting locations, typically under a large tree or a communal shelter. The participatory mapping activity was realized in Fon, one of the local Beninese languages. Objects such as the sacred forest, the main road, or the house of the district administration were important landmarks aiding the orientation on the printed map. The cartographic mapping process with the community was similar, although the boundary concepts on the ground largely deviated from those in Sèmè-Podji. In most cases, boundaries were delimited using specific trees or bushes, planted at the corner of a parcel, or even tracing the plot boundaries. Predominantly, the following species were detected: *Newbouldia laevis* (Désrégué), *Spondias mombin* (Akikontin), *Tectona grandis* (Xwletin), *Elaeis guineensis* (Detin), and *Dracaena arborea* (Agnantin). For laymen and laywomen, these *bornes végétales* as they are called in French, are not at all obvious to find in the field, let alone on a high-resolution map. However, it turned out that trusted intermediaries with a high contextual scene understanding and tacit knowledge of local arrangements were able to differentiate these specific trees from neighboring plants on the high-resolution UAV maps. Thus, with guidance from the mapping facilitators and trusted intermediaries, most local citizens were able to detect their parcel boundaries. If a situation could not be settled only by the map, a group of people went out to the parcel and visually inspected the land for possible objects aiding the localization of the parcel boundaries. In Zè, 232 parcels were drawn on the maps and 182 persons completed the SmartLandMaps questionnaire about land tenure arrangements. Overall, 16 plots were held collectively by a family or group of persons, and 159 plots were owned by an individual. The remaining parcels were either owned by the municipality or a church.

Figure 5: Vectorization procedure of polygons based on labeled GeoTIFF – Zè

The data has been digitized following the same procedure as with the data in Sèmè-Podji with the difference that four individual maps had to be processed. The average of the RMSE at ground control points of all four maps was 0.35m. The resulting vector geometries were merged afterward. Out of the total number of 232 parcels, some parcels exceeded the map limits and only closed parcels (212) were considered for further quality assessment.

4.3 Data Quality Assessment

The resulting parcel fabrics were evaluated for completeness and positional accuracy. Whereas completeness quantifies the success rates of the automated digitization, the positional accuracy infers differences between locations marked by the participants on the map and the same locations measured separately with a GNSS, either by the PMAF project or the SmartLandMaps Team. The completeness is assessed with reference to a manually on-screen digitized parcel layer. As shown in Table 1, the total number of parcels and the sum of line strings were compared to the reference data. True positives are defined as the reconstructed parcel polygon or the vectorized line string located on top of the sketched line. False positives are defined as polygons, or lines, which were reconstructed but do not represent a parcel or boundary line. In contrast, false negatives represent the sum of parcels or the length of parcel line strings as not being correctly reconstructed. The ratio of true positives to the sum of parcels mapped provides a metric of the overall completeness.

Table 1: Overview of mapping completeness using the SmartLandMaps technology to vectorize hand-drawn maps (SP = Sèmè-Podji)

	Parcels mapped	True-positive	False-positive	False-negative	Ratio TP/Total
SP (closed parcels)	202 (202)	194	6	8	96 %
SP (line strings) [m]	13823,67	14491,87	675,14	355,86	105 %
Zè (closed parcels)	232 (212)	207	4	5	98 %
Zè (line strings) [m]	33912,76	32225,26	1574,33	459,25	95 %

In Sèmè-Podji, 194 out of 202 mapped parcels were correctly vectorized (96%). Eight parcels were not detected (false negative) and six polygons were falsely created (false positive). Looking at the sum of line strings, the first observation is the ratio of 105% of true positives to the total sum of the length of all line strings. This can be explained by the curviness of some vectorized lines, compared to the straight lines of manual digitization. The total length of 355,86 m of false negatives represents the perimeter of the eight missing parcels that were not automatically extracted. With 675,14 m, the sum of false positives is almost two times higher representing line strings outside of the annotated hand-drawn line. The statistics of Zè reveal a similar picture to Sèmè-Podji, even though the context and background were more challenging for the automated extraction of lines due to more vegetation and shadows. 207 out of 212 closed parcels were automatically created, resulting in a success ratio of 98%. Five parcels were not detected (false negative) and four polygons were falsely created (false positive). Although the number of parcels is almost the same, the sum of all line strings representing parcel boundaries is in the rural area of Zè almost three times higher than in the urban area of Sèmè-Podji. Out of the total length of 33912,76 m, 32225,26 m were correctly extracted, indicating a success ratio of 95%. Less than 5% were incorrectly labeled as boundary lines, not representing a sketch line on the annotated map. As the results show, the automatic extraction of hand-drawn lines works very well with more than 95%. Thus, the considerable effort of scanning analog maps and manual digitization can be massively eased by the SmartLandMaps technology.

4.4 Distance to Reference Data

The second part of the accuracy assessment deals with the positional accuracy of drawn lines and thus, refers to the aspect of identifying objects on the map and not to the SmartLandMaps technology itself. During the pilot study in Benin, two different kinds of reference data were used to assess the positional accuracy of parcel corners based on vertices of automatically vectorized parcels. In Sèmè-Podji, reference lines, provided by the PMAF project, were buffered with 0,5m, 1m, 2m, and 5m, respectively. Afterward, the sum of all lines within the buffer compared to the total sum of all lines was calculated. Figure 5 (left) shows the percentage of lines lying in the buffer. Almost two-thirds (65%) of all lines were identified and drawn on the map, within a buffer of 0.5m of the reference data. This number strongly increases with a buffer of 1m (82%), 2m (92%), and 5m (98%). The two main reasons for the discrepancy were identified in four parcel subdivisions not captured in the reference data, or a mismatch of the outer extent of the boundary towards the road where the building limit mostly exceeds the official parcel boundary.

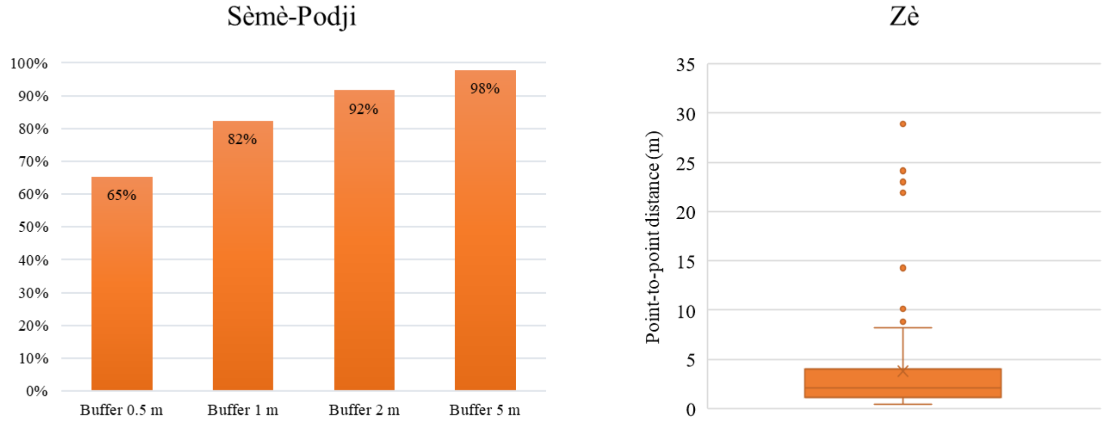

Figure 6: Statistics of the quality assessment for Sèmè-Podji (left) and Zè (right)

In Zè, the sample size of reference data was much smaller, as it was not feasible to measure all parcels with the GNSS device. As indicated in Figure 6, point-to-point distances of reference and vectorized parcels range from 0,44 m to 28,92 m. That said, the Box-Whisker diagram of Zè also shows, that the majority of point distances were below 5 m, as shown by the interquartile range demarcating the upper (75% percentile) and the lower (25% percentile) quartile. The median is calculated at 2,12 m and the mean at 3,78 m impacted by the large distances of the upper outliers. In this case, all outliers above 10 m were observed at the edge of the map, in a densely vegetated area with low visibility of boundary objects. Participants found it very difficult to relate the parcel limits to objects outside the map extent but still decided to draw their boundaries on the map even though the limits were not clear. In this particular case, it would have helped to take the overview map into account and identify where exactly the map ends and show that some parcels might be outside of the map. However, the other reference points clearly highlight the ability of the population to identify boundary corners with an accuracy of a few meters (50% better than 2 m, 80% better than 5m) even though most boundaries were not demarcated by physical objects. During the GNSS measurements, it was observed that pointing out the boundary at a very exact location is a challenge in itself, as most boundaries are more organic (e.g. as a tree or a point in the sand between two trees) and not accurate to a few cm. Thus, even a repetition of accurate GNSS measurements might lead to point differences up to some meters.

5 DISCUSSION

Overall, the SmartLandMaps pilot project in Benin reveals insights into three main aspects. First is the large potential of participatory mapping and community involvement in the co-creation of cadastral data. The approach is time-efficient and resource-efficient. Roughly 50 parcels could be mapped in a day with one field team that required only an hour of initial training on how to facilitate the mapping process. Furthermore, the sensitization and mobilization of local authorities and communities turned out to be key in the process, and, moreover, incentivizing the co-creation of cadastral data by empowering youth, women, and disabled persons, to take part in the process. Discussions about the location of a parcel boundary were mediated by mapping facilitators, trusted intermediaries, and the indisputable reality shown by the up-to-date high-resolution orthoimage. However, if a boundary itself is contested, the map will not succeed to settle this dispute and a local dispute resolution committee should be consulted.

Secondly, it was found that the high-resolution UAV data representing an up-to-date situation strongly contributes to the quality of the mapping results, as participants could retrieve familiar objects representing local boundary concepts. The questionnaire further revealed that almost 90% of all participants found it very easy (65%), or somewhat easy (22%) to indicate the boundary of their plot on the map. However, it should also be noted that this result is still very much dependent on land cover and land use and mapping facilitation might need to be adapted in case of homogeneous land cover (Naufal et al., 2022). Furthermore, high-resolution UAV images might be a cost-factor accounting for 500-1000$ US per km^2, depending on the location, the UAV equipment at hand, and the scale of the mapping project. Thus, the choice of a suitable base map is not only a decision considering the map context and the required level of accuracy, but also a decision guided by the available budget.

Thirdly, the SmartLandMaps process proves to be highly efficient. In both case study areas, more than 95% of all hand-drawn boundaries were automatically extracted and correctly vectorized. To reach these results, a clear and opaque pen is essential as well as the mandatory cleanliness of the drawing in the sense that only final lines are drawn with the black pencil. In this regard, the drawing of lines and the use of sticky dots can be adjusted to local (accuracy) requirements.

Several considerations for further scaling emerge from these findings and the results of the pilot project in Benin. Good facilitation of the mapping process enables the majority of plots to be mapped in a participatory manner with an acceptable level of accuracy. Once the concept of general boundaries is accepted, scaling up this approach with the help of many mapping teams is feasible, as it does not require expensive equipment, much know-how, or time to digitize. In this regard, YILAA as a pan-African organization and network promoting and defending youth and women’s land rights might play a crucial role in mobilizing citizens and implementing such a bottom-up land rights mapping approach. Furthermore, it is conceivable to combine this approach with other fit-for-purpose approaches as currently employed in Benin, especially in places with a demand for higher positional accuracy.

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