Validation of a cadastral map created using satellite imagery and automated feature extraction techniques: A case of Nepal

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Key words: Cadastral map, land administration, visual boundaries, satellite image, validation, automated feature extraction.

SUMMARY

Estimates suggest that only 30 percent of the world's population has access to formal land administration systems to register and protect their land rights. Surveying and mapping cadastral boundaries using traditional, field-based methods is accurate, but can prove to be extremely time, cost and labour intensive. This makes it difficult to create or update existing cadastral maps in developing or less developed countries. Alternate methods that could provide cheap, fast and effective solutions to speed up cadastral boundary mapping are being actively investigated. With the advent of very high resolution (VHR) imagery, satellite remote sensing offers an advantage as it has potential to provide automatic feature extraction tools/methods for boundary extraction, which could be used for fit-for-purpose land administration approaches. In this paper, we assess and validate the utilization of automatic feature extraction method in Dholakha district, Nepal in support of cadastral map creation. The validation of the automatic feature extraction is done by comparing the results with boundaries collected through three different methods. First, we compare the topographical boundaries generated by the automatic feature extraction with an existing cadastral map. Second, the results are compared with the farm tenure boundaries collected by participatory mapping methods. Third, we compare the results with farm boundaries acquired using a mobile application for spatial data collection. In the latter two cases, farmers provide the boundary information. Visual interpretation shows deviations among the results of different methods. Considering this study is one of the first attempts in validating methods for cadastral map creation in a mountainous terrain, the results will give an insight on the potential of automatic feature extraction for this purpose in Nepal. Promising results could lead to fit-for-purpose applications for large-scale cadastral mapping using this method.

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1. INTRODUCTION

Cadastral maps are a core ingredient of any land administration system and comprise information about the extent, value and ownership of land, which are essential for recording and updating land records (Williamson, Enemark, Wallace, & Rajabifard, 2010). Estimates suggest that seventy percent of the world's population has no access to formal land administration systems to register and protect their land rights. Surveying and mapping cadastral boundaries using field-based methods have been carried out traditionally for creating cadastres (Dale & McLaughlin, 2000). These methods produce accurate maps but require resources that can prove to be extremely time, cost and labour intensive (Enemark, McLaren, & Lemmen, 2016). This makes it difficult to create or update existing cadastral maps, especially in developing or less developed countries. The problem is accentuated by the fact that many such countries either completely lack any data or are still rely on upto century old legacy (cadastral) maps. Alternate methods that could provide cheap, fast and effective solutions to speed up cadastral boundary mapping are thus being sought (Luo, Bennett, Koeva, & Lemmen, 2017; Luo, Bennett, Koeva, Lemmen, & Quadros, 2017; Wassie, Koeva, Bennett, & Lemmen, 2017). These methods specifically aim to support fit-for-purpose land administration solutions that seek to provide rapid and low-cost cadastral mapping, and thus cater to immediate societal needs in contexts where no reliable data exists (Enemark et al., 2016).

With the increasing availablity of very high resolution (VHR) imagery with world-wide and cloud-free coverage, satellite remote sensing offers tremendous opportunities. Various advanced methods are being explored for a number of application fields such as urban and regional research, agriculture, forestry etc. to exploit and utilize the information derived through images (Li, Ma, Blaschke, Cheng, & Tiede, 2016; Schneider, Seto, & Webster, 2005). These are particularly helpful in getting up-to-date information in the form of maps. In the field of land administration, remote sensing based feature extraction tools/methods can be used for topographical boundaries extraction that are visible on an image (Wassie et al., 2017). These boundaries enclose a plot (complete or partial) with visible extent that separates it from the adjoining plots. It should be noted here that not all visible boundaries are cadastral boundaries. A set of plots may comprise a farm that specifically represents tenure status. Thus, not all cadastral boundaries are visible plot boundaries or farm boundaries. A cadastral boundary may be invisible – example is a boundary in case of inheritance and the subsequent subdivison on the cadastral map. Hence, the detected plot or farm boundaries have to be identified by the rightholders or a representative of the rightholder.

There is high potential in terms of visible boundaries detection and mapping which could further cater to fit-for-purpose solutions (Enemark et al., 2016). There have been several studies in this domain, which demonstrate the use of participatory mapping and on-screen visual interpretation approaches to map cadastral boundaries (Ali, Tuladhar, & Zevenbergen, 2012; Lemmen, Zevenbergen, Lengoiboni, Deininger, & Burns, 2009; Rugema, Verplanke, & Lemmen, 2015; Sengupta, Lemmen, Devos, Bandyopadhyay, & van der Veen, 2016). These studies created cadastral data by involving different stakeholders which seems to be a straight forward and fit-for-purpose approach to map boundaries from imagery. However, the methods used can also be time-intensive, difficult to repeat and highly variable in terms of accuracy. Use of (Semi)-automatic methods are thus being increasingly explored for fast detection of boundaries (Crommelinck, Bennett, Gerke, Yang, & Vosselman, 2017; Luo, Bennett, Koeva, & Quadros, 2016; Wassie et al., 2017). Once detected, these boundaries can be then validated in the field after further editing as well as correction.

A recent study showed that the percentages of visible cadastral boundaries may vary considerably amongst different contexts, ranging from 0 to 71 % in sample case studies (Kohli, Bennett, et al., 2017). Some contexts or landscapes, in terms of urban, rural etc. are potentially more relevant for automated detection of boundaries than others, e.g. smallholder agricultural parcels appear to show the most promising results with more than 70 % identification. These are cases where high percentage of visible plot boundaries coincide with cadastral boundaries. Whereas areas with mountainous terrain could be challenging, at least in the studied case. Another study using lidar data showed that around 50% of the cadastral boundaries could be semi-automatically extracted using an object-based workflow in an urban areas (Luo, Bennett, Koeva, Lemmen, et al., 2017). The visible boundaries are often manifested physically by visible artefacts such as hedges, stone walls, fences, ditches, or land use changes (Wassie et al., 2017). In this study, we focus on such visible plot boundaries in a case study in Nepal and use object-based image analysis (OBIA) methods that appear promising as these mimic the human interpretation process of identifying features.

In Nepal, the official process of cadastral mapping began in 1964 and was completed in 1998 by using traditional field based methods such as plane table surveys (Adhikary, 2002). Many studies have refelected on the need of efficient and effective methods for updating the old legacy maps using advanced technologies (Dangol & Kwak, 2013; Tamrakar, 2013). This paper is based on observations and analysis of the potential of automated feature extraction methods for visible boundaries identification as a basis for improvement of the cadastral map in the Dholakha district, Nepal. This work envisages a contribution to the general objective of providing support to fit-for-purpose land administration process.

In the first ever attempt of applying remote sensing based methods in the mountainous landscape of Nepal, the researchers compare the results of an automatic feature extraction method for cadastral map creation with farm and cadastral boundaries collected by two different methods. First, we compare the output of the automatic feature extraction with an existing cadastral map. Second, the results are compared with the farm boundaries collected by participatory methods. Additionally, we explore the use of a mobile application in the field for mapping farm boundaries. In the latter two cases, local inhabitants (i.e. farmers) provided the boundary information.

2. METHOD

2.1 Study area

This research is a part of a pilot project titled, 'Implementation of Fit-For-Purpose Land Administration and interventions towards the improvement of earthquake recovery and resilience for affected communities for sustainable and improved livelihoods'. The project is being run by UN-Habitat with the support of Global Land Tool Network (GLTN)[1] and Netherlands' Kadaster[2], Land Registry and Mapping Agency (Kadaster). Specifically, it seeks to provide technical support after the earthquakes in Boshimpa, Dihi and Phashmi, the three affected pilot villages of Dolakha district in Nepal.

The general objective of the project is to pilot fit-for-purpose land administration process to facilitate relocation of vulnerable housing/ settlements and to design or develop integrated settlements to facilitate sustainable human settlements post-disaster; and to support in developing tools for security of informal tenure holders for access to housing grants and facilitate housing construction (GLTN & Kadaster, 2017). Part of Dolakha district in Nepal is thus selected for the exploration of automated feature extraction. As per the requirement of the project, promising results could lead to fit-for-purpose applications of the method for assisting large-scale cadastral mapping.

2.2 Data

Official cadastral maps covering the study area, available in vector format from the Survey Department of Nepal, were used as reference in this study. WorldView-3 images with red,

[1] GLTN is a network of more than 75 intergovernmental, governmental, non-governmental and academic organizations worldwide hosted by UN-Habitat focusing on the development and implementation of land tools to support good land governance (www.gltn.net)
[2] Kadaster, also a GLTN partner, is the national institution in the Netherlands responsible for mapping, land use issues, cadaster and mapping activities. It helps foreign governmental organizations to design systems for land registration and geographic data (https://www.kadaster.nl/internationaal).

green and blue bands and 0.4 m spatial resolution were used for automatic boundaries identification. The images cover the three areas covering the pilot project sites.

2.3 Correction of official cadastral map

Nepal lies in the UTM zone of 44^0N and 45^0N. Although at present, WGS 84 is regarded as the global coordinate system, it came into common use only during the late 20th Century. The Everest 1830 coordinate system has been in use for more than 150 years. As a result most of the available data and records in Nepal are available in this coordinate system. The images and other collected data were in WGS 84 coordinate system. The cadastral map seemed highly shifted when displayed in original form and thus, had to be transformed (Figure 1).

Transformation between one geographic coordinate system to another geographic coordinate system requires transforming the coordinates between different Datums (spheroid or ellipsoid). There are many ways to transform the coordinate systems. Popular ones are the Equation-based methods (Three-parameters method, Seven-parameters method, Molodensky method, Abridged Molodensky method) and Grid-Based Method (NADCON and HARN methods). For the transformation, we used Molodensky transformation which converts directly from one geographic coordinate system to another without calculating the intermediate X, Y, Z coordinates. This is done by using the transformation shift (Delta X, Delta Y and Delta Z) between the two coordinate systems and the differences between the semimajor axes (Delta A) and the flattenings (Delta f) of the two spheroids. According to the User's HandBook Datum Transformations by the International Hydrographic Bureau, Monaco, the Everest 1830 can be converted to WGS 84 using transformation parameters of 282 ± 10 (Delta X), 726 ± 8 (Delta Y) and 254 ± 12 (Delta Z). We used the transformation tool available within the ArcGIS software for transformation of datum to WGS 84.

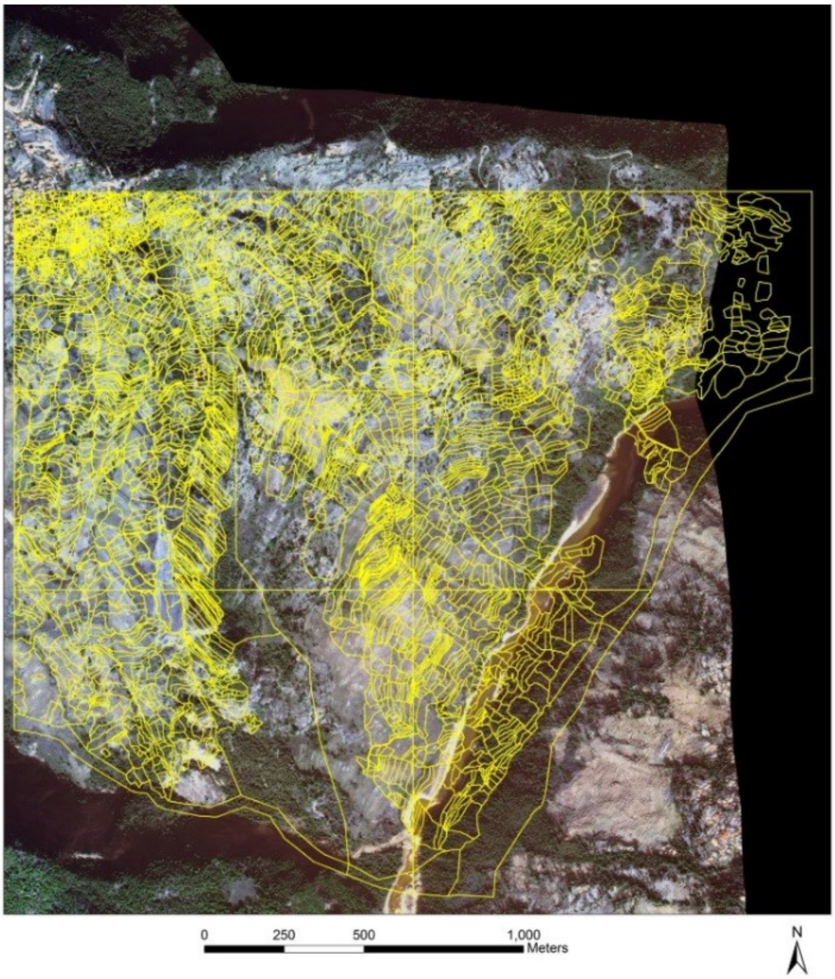

Figure 1 The cadastral map (in yellow color) of Phullapa area overlaid on the Worldview-3 satellite image without transformation, showing a major shift.

2.4 Algorithm for automatic boundaries extraction

The first step in object-based image analysis (OBIA) is segmentation. Segmentation is the process of dividing an image into regions or objects of homogeneous pixel values within segmented objects (Blaschke, 2010). Subsequently, classification is performed on image objects using supervised or unsupervised methods. Image segmentation in an object-based environment can potentially be used to generate segments coinciding the visible plot boundaries (Kohli, Crommelinck, Bennett, Koeva, & Lemmen, 2017). In this research, eCognition image processing software was used for segmentation (Trimble, 2016). The size and constituents of segments are controlled by assigning appropriate values to the key parameters: scale, shape and compactness to segment objects – the larger the Scale Parameter (SP), the larger the size of resulting segments. The choice of values can be determined manually using ‘trial and error’ approach or by using tools like the Estimation of Scale Parameter’ (ESP) tool proposed by Dragut et al. (2014). The ESP tool identifies optimal scale parameters based on the local variance in an image. Through visual interpretation, it was observed that the ESP tool identifies SP that helps in extracting visible boundaries. The fact that the tool optimizes the SP for each image automatically, based on local variance, it is not required to choose the value manually for each image – thus saving a lot of time that could be spent on trial and error approach for selecting appropriate SP. The ESP tool can be integrated with the eCognition software and be used to segment an image at three spatial levels (scales), i.e. level 1, 2 and 3. Level 1 represents lowest identified SP resulting in smaller segments. Whereas, for higher levels (2 and 3), more heterogeneity is allowed and hence resulting in larger segments (with higher SPs). The choice of level for further analysis is dependent on the size and characteristic of feature of interest. For example, for tree crown classification, level 1 segments will probably be the most suitable. After running the tool on the sample subsets, the results were generated and compared. At level 2, the extracted plots were bigger in size as more heterogeneity was allowed within a segment whereas at level 1, the segments were relatively smaller in size. The third level aggregated large areas including farm boundaries and hence was ignored. We chose level 1 results as they showed better correspondence to the farm boundaries.

2.5 Mapping boundaries using participatory mapping

Under the project, farm tenure boundaries were collected using a participatory approach (PA). At the site, there were enumerators working with the farmer who used printed copies of satellite images to identify and draw farm boundaries on the image. This exercise was done in the presence of the farmers associated with farms as well as the other community members. The process included a meticulous practice of the enumerators checking with the farmers, very carefully and guiding them by identifying different landmarks in order to identify the farm boundaries. These hardcopy maps with the collected data on the images were further converted to a digital geo-referenced version. Complete details on the process of cadastral boundaries mapping using participatory approach in three selected areas of Dolakha are provided in Unger et. al (2018).

2.6 Mobile application for farm boundaries mapping

The farm boundaries were recorded using GPS points from a mobile phone application called Mapit GIS (MapitGIS, 2017). MapIt is an application that can be downloaded on a mobile phone and can be used to map spatial features like point, polygons and lines. It is also possible to choose base maps/satellite images from a range of sources, e.g. google, bing maps. The purpose was to map polygons representing farm boundaries. This approach was carried out with the help of a local member of the community (in our case the farmer who owned or used the land) and farm parcel boundaries were derived. The Farmer walked the boundary of their farm and a person with the phone followed, recording the boundary position by tracking points in the app. The tracking was turned off once the starting point was reached again, and a closed polygon was derived. Originally the idea was to provide the farmer with the phone/mobile application but they refused and felt more comfortable showing instead of recording themselves.

3. RESULTS AND DISCUSSION

3.1 Correction of the cadastral map

The cadastral map obtained from the official sources did not fit well when overlaid with the high-resolution image. The map was in the local Everest 1937 datum, created originally by plane table surveys, scanned, digitized and geo-referenced. There seemed to be error propagation at each step, hence the map was shifted (Figure 1).

According to the User's HandBook Datum Transformations by the International Hydrographic Bureau, Monaco , the Everest 1937 can be converted to WGS 84 using transformation parameters of 282 ± 10 (Delta X), 726 ± 8 (Delta Y) and 254 ± 12 (Delta Z). We used the transformation tool available within the ArcGIS software for transformation to WGS 84. The resulting map was still with a shift towards the east direction, therefore a value of -16.5 meters was used to realign the map with the image. This was determined through visual interpretation by matching the cadastral boundaries with forest boundaries and other visible features such as rivers and roads. However, there were still some shifts, which could be attributed to the heterogeneous errors during the creation (specifically in a mountainous terrain like presented in this case study) and digitalization of cadastral map (Figure 3).

3.2 Comparison of farms and mobile mapping

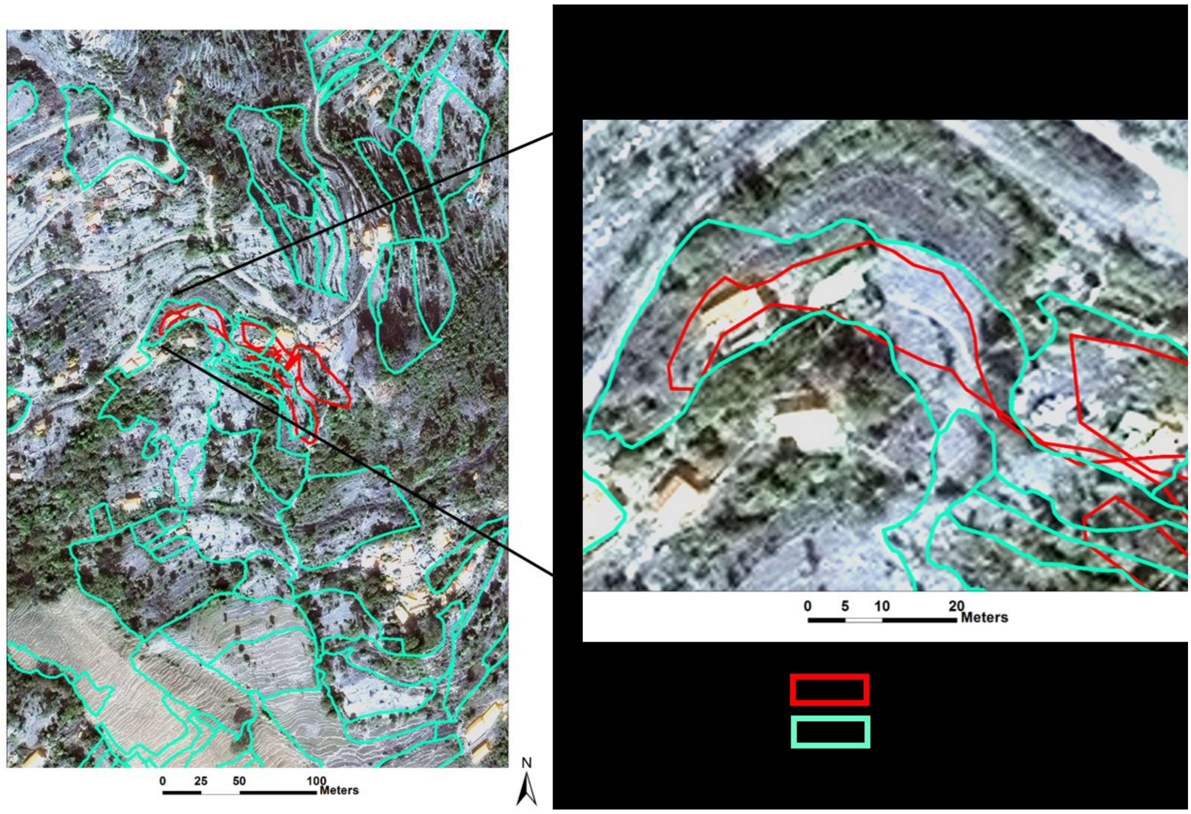

Figure 2 Farms collected by using mobile application MapIt in part of Phullapa area (red color) and the farm boundaries created by participatory approach (green color) overlaid on the satellite image with the magnified view showing the correspondence of boundaries.

Figure 2 shows the results of the mobile mapping overlaid on the image compared to the farm boundaries of PA. Mapping using a mobile app could prove to be fast and cost-effective. It was possible to organize the verification and comparison of a small set of farms with the situation in the field through the app. The project members including the first and the second authors of this paper were in the field for this purpose. There were many important observations made during the field visit. First, due to the fact that the participatory mapping project was underway, farmers had gathered to locate their farms on images. It was thus possible to arrange a visit to the farm where the farmer himself could guide and show the location of his farms. Whilst this approach could be potentially very useful in a relatively flatter terrain, the trial with the mobile mapping was challenging in the study area due to a number of reasons. Only few farms could be walked with the mobile application as shown in the figure due to the mountainous terrain. Firstly, the GPS accuracy within the app was not able to be reduced to below 10 m. Also, there were areas of significant vegetation in the area - tall trees etc., which obstructed the GPS signal. And finally, some of the terrain was so steep that carrying the phone in one's hand whilst climbing up a bank was both neither practical nor safe.

There are also logistical problems with the mobile approach for mapping farm boundaries. Some of the farms owned by a farmer were at great distances apart and with the type of terrain encountered in Nepal it would be extremely labour intensive and time consuming to have these mapped out on the ground by people using mobile GPS application.

Figure 3 Field photograph from Phullapa area in Dholakha district.

Moreover, with the standing (over 1 meter high) Millet crops (Figure 3), it was observed that the season of visit to the farms (October) was not the most optimal, as often it was almost impossible to walk the boundaries of farms. It was also difficult to get the corner points of the farm due to several reasons:

- In many cases, a farmer would be associated with several farms, the location of whom were not necessarily contiguous.
- Sometimes the constituent farms were on very high slope, and that made it difficult to walk up to draw boundaries.
- Communication with the farmers was difficult due to language barrier.

All the farms had Millet planted, which according to the farmers, would be harvested in December. In April, they plant maize which then is harvested in September. The best time, thus, to use mobile mapping may be from December to March when there are no standing crops. Its supposedly bare after the harvest till Maize is planted. This observation also proves that the season close to harvest is not the optimal time for such mapping. Thus, if an actual cadastral survey has to be done, the time of survey could be very limited. Factors as mentioned above should be seriously considered before planning a survey.

3.3 Comparison of parcels, farms and plots

Figure 4 shows the comparison of the cadastral map with PA and automatically extracted boundaries. With visual assessment, it is clear that the automatically extracted boundaries partially coincide with the PA-boundaries. If there is sufficient contrast between adjoining farms, the boundaries were detected.

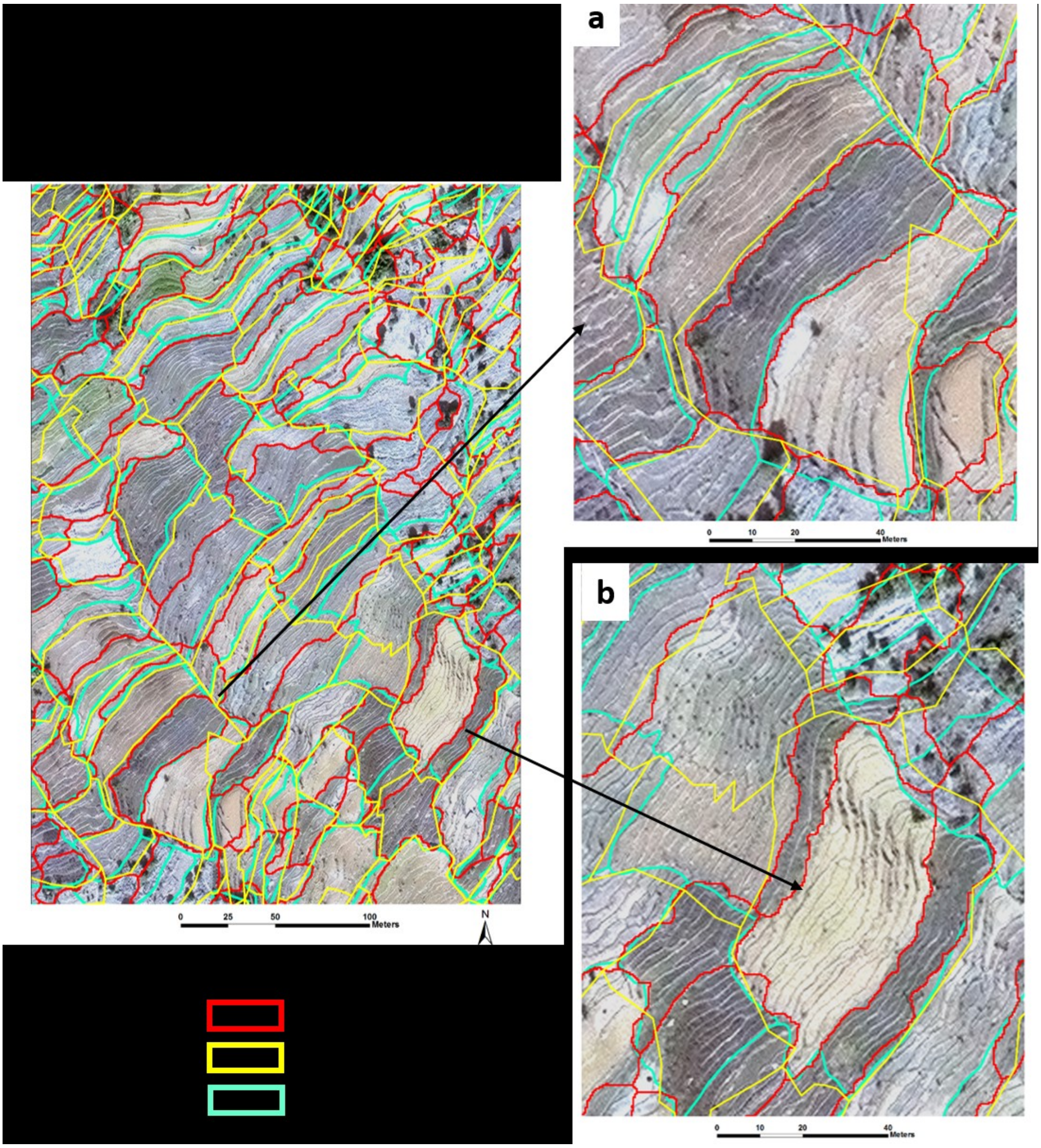

Figure 4 The output of automatically extracted boundaries (red), parcels from the cadastral map (yellow) and the farm boundaries created by participatory approach (green) overlaid on the satellite image : (a) and (b) show the magnified view displaying the correspondence between the boundaries.

Figure 4a shows the correspondence between the cadastral, PA and automatically extracted boundaries. Here it should be noted that, except the heterogeneous shift in cadastral map, many parcel boundaries align with the farm boundaries. There are many deviations that could be attributed to the change in tenure status resulting from subdivision due to inheritence. There could also be cases of parcels being merged into bigger farm, as seen in figure 4b. Alternatively, there could be farms being merged to bigger units as a result of change in tenure status. The fact that the cadastral map was created almost three decades ago and the farm boundaries are recently collected, can also explain the changes on the ground over this time.

Inherent challenge is that not all visible boundaries are farm or parcel boundaries. The software identifies the boundaries that have contrast with adjoining areas, these are not necessarily cadastral boundaries. Though, there seem to be a promising pattern where a relatively different texture of parcel (comprising of a number of farms) may be identified (figure 4) and that may result in identifying a parcel. The way forward would be to find editing tools that could be used easily on a tablet/phone and taken to field together with the results. The polygons could then be edited and related tenure information be added to a parcel.

With the current status of reference map, which is the cadastral map in this case, it is very difficult to make conclusions on the quality of automatically extracted boundaries. A clear recommendation on the use of automated methods for parcel boundaries extraction can be made once the reference data is corrected. However, the results of recently captured participatory mapping approach may potentially give an insight on the usefulness of the automated method approach. The validation of the results of the method is underway and can potentially be used as a reliable baseline for such comparison.

4. CONCLUSION

This work presents the initial results of comparison of boundaries, generated by different methods. When comparing the output of the automatic feature extraction with an existing cadastral map, remarkable shifts in the official map were noticed. Efforts are being made to improve the quality of the map as it has heterogeneous errors as seen in Figure 1. In addition to the cadastral map, the results were qualitatively compared with the farm boundaries recently collected by participatory methods. These farm boundaries seem to be a good alternative as baseline data as they are more accurate and show the recent situation. Further, the results of farm boundaries acquired by using a mobile application were also presented and the challenges for the approach were discussed. When compared with the boundaries of the participatory method, these don't look accurate but the output does reflect upon the challenges of using this approach in such difficult terrains. The automated feature extraction method is fast and can be used to extract plot boundaries. However, it still needs to be optimized to avoid false positives. Visual interpretation shows deviations among the results of different methods. Current research is focusing on quantifying the deviations and finding the optimal approach where feature extraction methods could best assist in cadastral map creation. Further research will give an insight on the potential of the methods for fit-for-purpose application for large-scale cadastral mapping.

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BIOGRAPHICAL NOTES

Divyani Kohli is currently working as a Post-doctorate researcher at the Faculty of Geo-information Science and Earth Observation (ITC), University of Twente, The Netherlands. She completed her doctorate from the same university in 2015. Her past assignments have included a range of topics such as the use of GIS/Remote sensing in urban mapping, automated feature extraction, spatial analysis, spatial metrics, uncertainty analysis and advanced image processing techniques. Currently, her research focuses on exploring the use of Remote Sensing based methods, specifically object-based image analysis, for cadastral boundaries extraction from very high resolution satellite images. The methods being developed for this research are aimed at expediting and supporting cadastral mapping of areas where no reliable data exists.

Eva-Maria Unger is currently a PhD researcher at the Faculty of Geo-information Science and Earth Observation (ITC), University of Twente, The Netherlands. Her research focuses on Responsible Land Administration and Disaster Risk Management. She completed her Master (Msc) at the Vienna University of Technology (TU Wien) in 2011. She is Geodetic Advisor at Kadaster International working on projects in Mozambique, Indonesia and Nepal. Further, she is working in close collaboration with UN-Habitat GLTN and UNGGIM. Eva-Maria is chair of the International Federation of Surveyors (FIG) Young Surveyors Network. In 2015, she was listed by XYHT Magazine as a Top 40-under-40 Remarkable Geospatial Professional.

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