UAV Images for Agriculture Land Parcel Delineation through Edge Detection Algorithm: A Case Study of Hilly and Terai Regions

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KEYWORDS

Parcel Delineation, UAV, GIS, Edge Detection, Segmentation, Agriculture

ABSTRACT

The use of unmanned aerial vehicles (UAVs) for remote sensing applications has gained significant attention in recent years. One important aspect of UAV-based remote sensing is the accurate delineation of parcels, which is essential for a wide range of applications, including land use planning, agricultural monitoring, and cadastral map preparation among several others. The on-screen manual digitization method can delineate parcels with great precision. However, the method is labor-intensive, time-consuming, and expensive. Alternatively, it can be achieved by utilizing automated algorithms. In this study, an edge detection algorithm is employed to delineate agriculture parcels using UAV images in the ENVI platform. The algorithm uses a pre-programmed algorithm to automatically detect and delineate field boundaries. The delineated boundaries were cleaned and refined by smoothing the polygon and the line vectors. The obtained parcel boundaries and their geometric parameters were assessed against manually digitized parcel boundaries using the same UAV ortho-mosaic. The method was tested on two scenarios: i) Terai farms having flat topography and small dikes and ii) Hill farms having undulated terrain in a terraced farming structure and crowded parcels. The mean of the percentage change in area for the land parcel was found to be 2.43% and 4.69% respectively for Terai and Hilly regions. Similarly, the mean of the percentage change in the perimeter of the land parcels were 8.82% and 2.43% respectively for Terai and Hilly regions. The study demonstrated the feasibility of using UAV images for agriculture land parcel delineation and highlighted the potential of an in-built edge detection algorithm as a time-efficient and reliable alternative to manual digitization if refinement and proper selection of algorithm and parameters are done. Thus, automated algorithms can be utilized to reasonably delineate agriculture parcels from UAV images.

1. INTRODUCTION

An agricultural land parcel is a specific piece or plot of land that is used for agricultural purposes such as farming, agroforestry, etc. It is demarcated and identified with natural and man-made features like roads, streams, bunds, walls, etc. Also, it can be defined as boundaries where a change in crop type, crop mixture, or farm management practice takes place, or where two similar cultivations are separated by a natural disruption in the landscape, like a bund or a ditch (Rydberg & Borgefors, 2001).

Due to human activities, natural calamities, and changes in seasonal vegetation in farmland, there is a frequent modification in agricultural land boundaries (Paul & Rashid, 2017). Farmland delineation is one of the first primary requirements for various parcel-based applications such as the estimation of agricultural subsidies, irrigation planning, fertilizers dose estimation, pesticide management, crop insurance, and establishment of agricultural policies and taxation (Ajayi & Oruma, 2022). Therefore, there is a high demand for accurate and up-to-date land parcel boundary information.

Parcel delineation is the process of identifying and demarcation of the boundaries of individual land parcels (Aung *et al.,* 2021). The delineation of land parcels on orthoimage is done on the basis of the shape and size of the parcels, color intensity, pattern, location, and presence of physical objects like roads, ditches, drainage, and spontaneous recognition (Ajayi & Oruma, 2022). It has wide use in downstream governmental policies of land allocation like cadastral mapping, agricultural planning, and taxation (Djordje, 2019). While ground-surveying methods are a decades-old practice, manual on-screen digitization using satellite, aerial or Unmanned Aerial Vehicle (UAV) images has been in practice in recent times.

Land parcel delineation using the ground survey method, such as with the use of a Total Station, involves physical inspection of various aspects of the land and measuring land boundaries' corners, followed by GIS (Geographic Information System) processing to delineate the parcel boundaries. Likewise, manual land parcel digitization records and converts land boundaries into a digital format using GIS software through an on-screen method. This can be used to manually identify and delineate the boundaries of individual land parcels utilizing satellite, aerial or UAV image mosaics. It allows for the creation of a comparatively accurate database and thus facilitates the preparation of detailed maps. However, these methods are labor-intensive, time-consuming, and expensive. Segmentation and edge detection algorithms, on the contrary, are computer programs that are designed to automatically identify and delineate the boundaries of fields based on certain criteria, such as the shape and size of the parcels, pixel intensity, and color (Khairee & Thakur, 2013).

The parcel size of Nepali farms is small with an average area of 0.24 hectares (CBS, 2006). Therefore, land parcel delineation using satellite imagery would be inappropriate in the Nepalese context. UAV, on the contrary, provides ultra-high-resolution images that could be utilized to obtain detailed information about farmland and land boundaries. It can precisely capture visible field boundaries of agricultural lands often marked by physical objects such as agricultural bund, water drainage, ditches, etc. Therefore, an inbuilt edge detection algorithm in Environment for Visualizing Images (ENVI) was used in this study to delineate agricultural land boundaries of a Terrain and a Hilly farm area using UAV images.

2. STUDY AREA

The case study areas were selected at agricultural farmlands in Lakshminiya Rural Municipality of Dhanusha District and Dhulikhel Municipality of Kavre District respectively representing Terai and Hilly farmlands. In addition, the two selected areas distinguish themselves in terms of agricultural bund and roads to indicate the farmland boundaries. Besides these, there are significant changes in the size and shape of the farmlands. Furthermore, different seasonal crops are grown in the two study areas. While potatoes and paddy are primarily grown in Dhulikhel, paddy, wheat, and lentils are mainly grown in Lakshminiya. The data was collected in June 2022 at the pre-paddy plantation stage in Lakshminiya while the UAV images from Dhulikhel were acquired in October 2022 when paddy was harvested from some portion of the fields (even crop was harvested from a part of the same field while those from the remaining area of the field was yet to be harvested). The study areas are represented in the map shown in Figure 1.

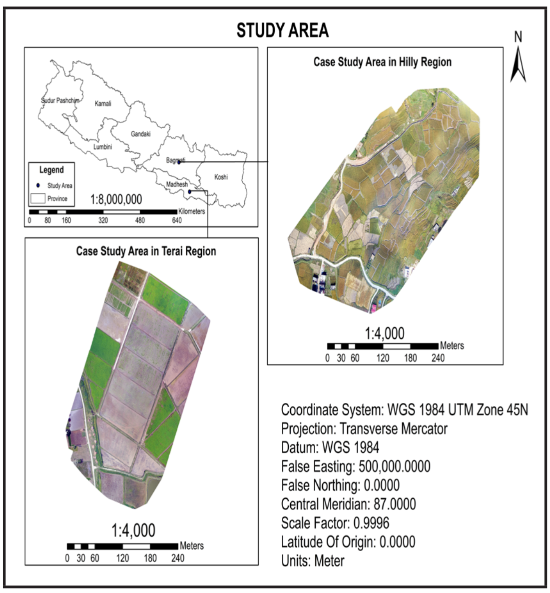

Figure 1: Study area map.

3. METHODOLOGY

Plans for Ground Control Points (GCPs) establishment and UAV flights to cover the entire study sites were prepared. GCPs were measured using Differential GPS in WGS84 Coordinates System and post-processing was done. UAV flights were conducted to capture ultra-high-resolution images of the areas. The images were processed with the input of GCPs coordinates to obtain orthophoto in centimeter-level accuracy. Land boundaries

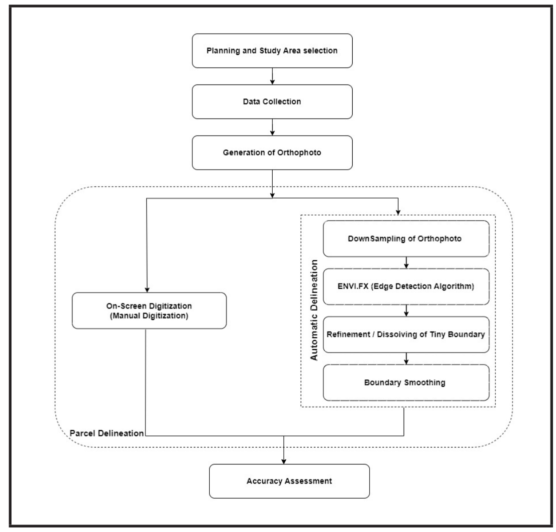

Figure 2: Methodology adopted.

using edge detection algorithms followed by a smoothing and refinement process. The parcel boundaries were manually digitized for accuracy assessment. After post-processing of the boundaries delineation using edge detection, the results were assessed against the manually digitized parcel data. The details of the methods adopted are discussed in the following subsections and are summarized in Figure 2.

3.1. Data collection

The location of GCPs was planned in such a way that the points are sufficient to cover the study area and variation in elevation (in the case of hilly terrain). These points were measured using STONEX S8 PLUS DGPS in static mode with a cutoff angle of 15 degrees, a time interval between the signals of 15 seconds, and a PDOP (Position Dilution of Precision) threshold of 3. In total, 6 GCPs were measured for both hilly and Terai areas. The measured coordinates were processed with TBC (Trimble Business Centre) software to obtain the resulting coordinates.

A 30cm by 30cm black and white GCP Marker was placed at each of the GCP locations before the UAV flight was conducted. A DJI Mavic 2 Pro UAV was flown to acquire the digital images of the areas. The images were captured with forward and side overlap of 80% and 70% respectively from a flying height of 70m above the ground. In total 160 images (acquired on 19^{th} October 2022) and 215 images (acquired on 20^{th} June 2022) were captured covering approximately 54,000 m^2 and 74,735 m^2 area on the ground from the Hilly and the Terai areas respectively.

3.2 Generation of ortho-photo

Pix4Dmapper software was used to process the UAV images. After the determination of the orientation and the position of camera stations, the coordinates of GCPs measured using DGPS survey were provided to re-optimize the orientation and the coordinates of camera stations, and thus the object space coordinates of the points in the images. Ultimately, an ortho-mosaic was prepared from the software.

3.3. Parcel delineation

3.3.1. Using edge detection algorithm

The original UAV ortho-image with a Ground Sampling Distance (GSD) of approximately 2 cm was resampled to lower resolutions with 5 cm and 10 cm GSD. The selected GSDs allowed the study of the impact of different GSDs on the results of automatic boundary extractions. In addition, extracting objects from a UAV ortho-image of lower spatial resolution smooths out the heterogeneity present in an individual field and is computationally less expensive.

ENVI Feature Extraction tool was used to delineate the parcel boundaries. The ENVI FX module uses two approaches: the edge method and the intensity method. The edge method works based on the gradient map calculated using the edge detection algorithm and modification of the gradient map defined by a scale level and a merge level parameter whereas the intensity method converts each pixel to a spectral intensity value by averaging it across the selected image bands. The intensity method is suitable for digital elevation models, images of gravitational potential and images of electromagnetic fields. The edge method is used for detecting features with distinct boundaries. Therefore, the Edge-Detection method was used for this case study.

The edge method consists of two parameters: Scale level and Merge level. The scale level is the relative threshold on the cumulative histogram from which the corresponding gradient magnitude can be determined. For example, the lowest 50 percent of gradient magnitude values are discarded from the gradient image at a scale level of 50. Increasing the scale level results in fewer segments and keeps objects with the most distinct boundaries. Likewise, merging aggregates over-segmented areas by using the ENVI FX default full Lambda schedule algorithms (Fetai *et al.,* 2019). The algorithm is meant to aggregate object outlines within larger, textured areas, such as trees and fields, based on a combination of spectral and spatial information. The merge level represents the threshold Lambda value. Merging occurs when the algorithm finds a pair of adjacent objects such that the merging cost is less than a defined threshold Lambda value. If the merge level is set to 20, it will merge adjacent objects with the lowest 20 percent of Lambda values. In this step, the selection of Texture Kernel Size (the size of a moving kernel centered over each pixel value) is optional. The ENVI FX default Texture Kernel Size is 3, and the maximum is 19. The final step was to export the object boundaries in the vector format.

The ENVI FX module was applied to the original as well as the down-sampled images. The detection of visible boundaries was based on the edge detection algorithm. The number of objects extracted varies accordingly with the scale and merge levels values of the algorithm used as well as the scale of the image. Thus, a combination of image scale (GSD), scale, and merge parameters of the used algorithm were applied to get the optimal combination. When a large change was detected in the number of extracted objects, the incremental value was slightly adjusted. To obtain the optimal scale and merge levels values and the image GSD, all possible ranges of scale level, merge level and GSD combinations were tested for both study sites.

After the delineation of boundaries using the edge-based method, the results were post-processing. This step consists of dissolving boundaries smaller than a pre-set area followed by the smoothing of the field boundaries. All extracted objects that were smaller than the minimum object area from the reference data were dissolved in the larger boundaries containing the smaller ones. The total number of remaining objects after dissolving were then smoothened using the Generalize Tool in ArcMap based on the Maximum Allowable Offset parameter.

3.3.2. Onscreen digitization

A single operator manually digitized the parcel boundaries using the On-Screen method based on the UAV image of the original scale. The operator visually identified the field boundaries using the original scale UAV image-mosaic. The single operator completed the digitization for the sake of maintaining uniformity in digitizing the parcel boundaries. The agricultural land parcels were flat, more of a regular shape, and large enough with the most recognizable agricultural bund width in the Terai region while the agricultural fields in Hilly terrain were small, more of an irregular shape, and crowded. However, the boundaries of the parcels were distinctly separable, and the parcel boundaries were recognizable in both cases.

3.4 Accuracy assessment

Finally, the extracted boundaries from the ENVI FX-edge algorithm were assessed against the manual digitization of land parcels based on spontaneous recognition. The assessment was made on the basis of the percentage change in the area and the percentage change in the perimeter of the delineated land parcels. First, the difference in area and perimeter of each parcel was calculated. Keeping the area and the perimeter of the parcels using the manual method as a reference, the percentage change in the parameters was obtained. Finally, the mean and standard deviation of the percentage change in these parameters were calculated.

$$\text{Percent Change in Area } (\% \Delta A) = \frac{Area_{manual} - Area_{edge}}{Area_{manual}} \times 100$$

$$\text{Percent Change in Perimeter } (\% \Delta P) = \frac{Perimeter_{manual} - Perimeter_{edge}}{Perimeter_{manual}} \times 100$$

Where,

$Area_{manual}$ represents the area of the parcels obtained using manual digitization.

$Perimeter_{manual}$ represents the perimeter of the parcels obtained using manual digitization.

$Area_{edge}$ represents the area of the parcels obtained using the edge-based method.

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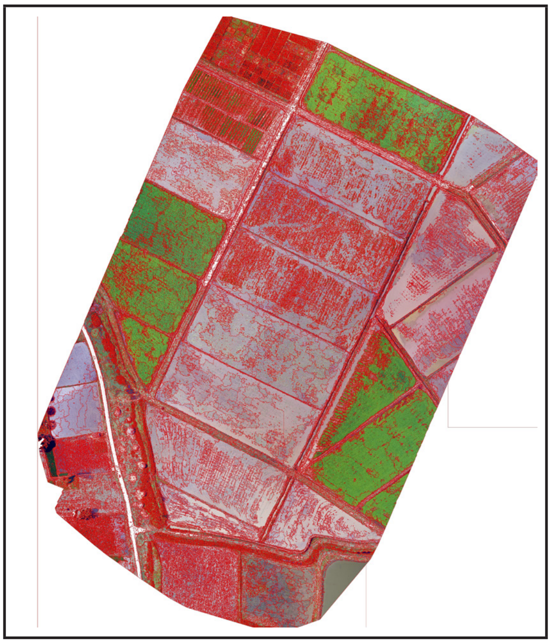
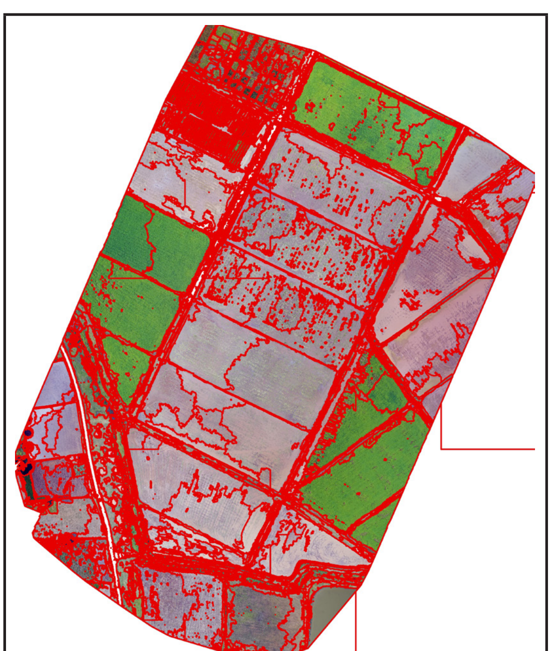
4. RESULTS

Resampling the UAV orthoimage to lower spatial resolution i.e., a larger value of GSD, resulted in the fewer and faster extractions of object boundaries. ENVI FX-edge detection algorithm was used for segmentation with the original scale as well as with the resampled Ortho-mosaic with 5cm and 10cm GSD.

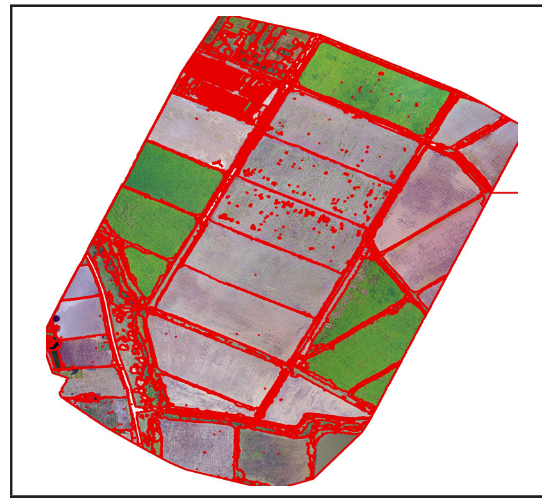
Scale level and merge level parameters were selected in the range from 30 to 60 and 80 to 99.9 respectively. The optimal results were obtained with a scale level parameter of 50 and a merge level parameter of 99.9. While the ortho-mosaic with the original GSD of about 2 cm resulted in many tiny field boundaries, those with the larger GSD (smaller image scale) reduced the number of such tiny boundaries (Figure 3). This improvement in the removal of tiny boundaries is because of the reduction of heterogeneity in image intensities due to spatial variation of crop characteristics within the individual fields.



(a)

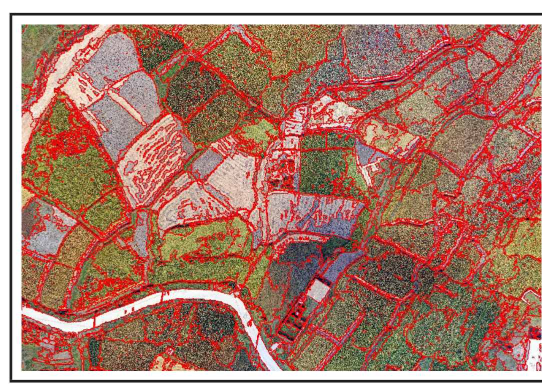


(b)



(c)

Figure 3: Extracted boundaries from the Terai region study area at original GSD of about 2 cm (a), at 5 cm GSD (b), and at 10cm GSD (c) with a scale level of 50 and merge level of 99.9. Many tiny boundaries were obtained at the original scale image which drastically reduced correspondingly at the image GSD of 5 cm and 10cm (c).



(a)

(b)

Figure 4: Extracted boundaries from the Hilly

region study area at 5 cm GSD and 10 cm GSD with a scale level of 50 and merge level of 99.9. Many tiny boundaries were obtained at the image GSD of 5 cm (a) which drastically reduced at the image GSD of 10 cm (b).

The dissolve operation was additionally performed to remove the objects under the minimum reference object area and dissolve them with the larger boundaries containing them. The boundaries smaller than 5 m2 were dissolved with the larger field boundaries containing them. Finally, the dissolved boundaries were smoothened using the Generalize tool of ArcMap with a Maximum Allowable Offset parameter of 0.5. A comparison of manually digitized boundaries, automatically segmented boundaries using the edge method, and smoothened boundaries after the edge method is shown in Figure 5.

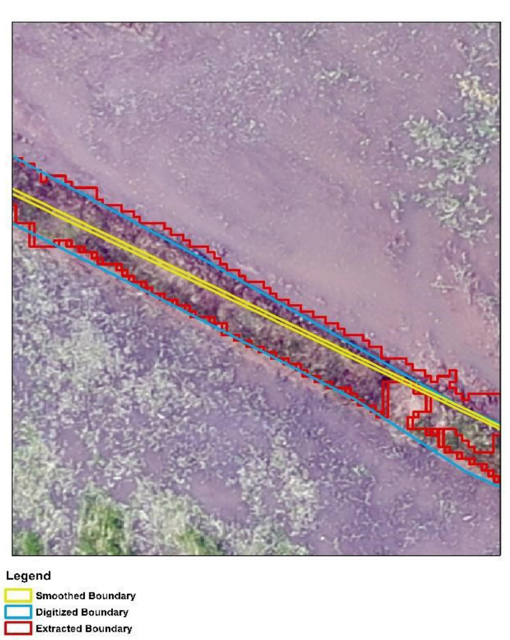
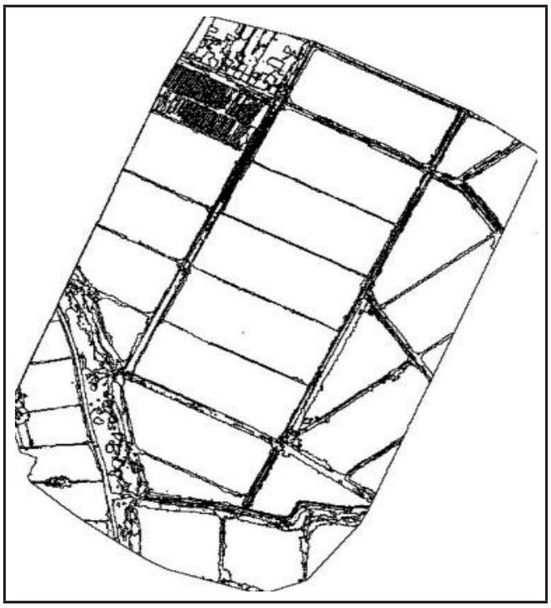


Figure 5: A comparison of manually digitized boundaries automatically detected boundaries from the edge method and smoothed boundaries after automatic detection.

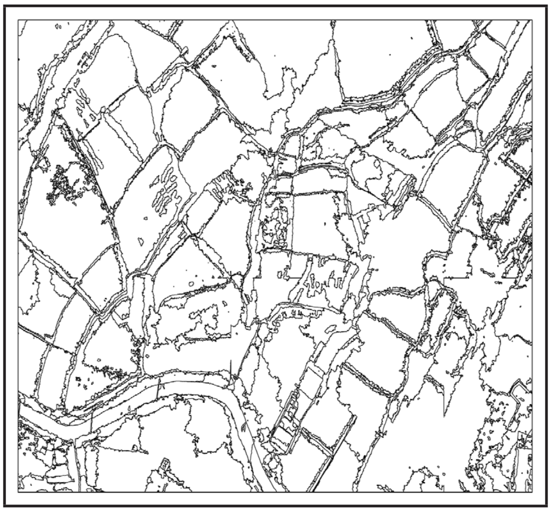
For accuracy assessment, all the parcels in the Terai region were taken whereas only the non-harvested parcels were considered for the Hilly region. The reason for choosing such parcels in the Hilly region was the non-uniformity of the harvesting process which result in unnecessary segmentation of land boundaries. The accuracy assessment resulted in the mean and standard deviation of the percentage change in the area of 2.43% and 1.65% for the Terai region study case and 4.69% and 1.04% for the Hilly region study case respectively (Table 1). In addition, the mean and standard deviation of the percentage change in perimeter of 8.82% and 8.85% for the Terai region study case and 2.43% and 2.91% for the Hilly region study case respectively were obtained. These percentage changes in area and perimeter for agricultural application are acceptable for agriculture planning, resource estimation, and taxation purposes. Therefore, the utilization of UAV images together with edge detection algorithms can provide agriculture parcel boundaries with a reasonable accuracy faster, cheaper, and requires minimum human interaction. The final delineated boundary is shown in Figure 6.

Table 1: Statistical results.

Parameter	**Statistics**	**Value**	
		Terai Region Case	**Hilly Region Case**
Parcels	Count	20	10
Percentage Change in Area (%)	Maximum	8.33	5.373
	Minimum	4.96	1.851
	Mean	2.43	4.69
	Standard Deviation	1.65	1.04
Percentage Change in Perimeter (%)	Maximum	5.84	6.377
	Minimum	4.35	0.94
	Mean	8.82	2.43
	Standard Deviation	8.85	2.91



(a)



(b)

Figure 6: Results of an automated delineation method of the Terai region (a) and that of the Hilly region (b).

5. CONCLUSION AND RECOMMENDATIONS

In this study, the land parcels from Terrain and Hilly sites were delineated from ultra-high-resolution UAV images using the Edge Detection in-built algorithm in ENVI. The obtained results were assessed against the manually digitized parcel boundaries from the same image mosaic. The results showed that the ENVI-Edge Detection algorithm can reasonably delineate the visible parcel boundaries like ditches, wider land bunds, and foot trails at a larger value of GSD. Similarly, variations in segmented results were studied under different values of scale and merge parameters which show the large deviations in results in small changes in the algorithm parameters. From this study, it is concluded that Scale level and Merge level algorithmic parameters, and the image GSD are key controls for the parcel delineation. The comparison of automated and manual land delineation of parcels shows that agriculture parcel boundaries can be delineated from UAV images using the Edge detection algorithm with reasonable accuracy, time, and cost which demands minimum operator interaction. Therefore, this approach could be utilized routinely to delineate field boundaries after crop rotation to estimate irrigation, pesticide, and fertilizers planning and management.

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REFERENCES

Aung, H. L., Uzkent, B., Burke, M., Lobell, D., & Ermon, S., (2021). *Farmland parcel delineation using spatio-temporal convolutional networks*.

Batić, D., (2019). *Deep learning for delineating farm boundaries.* Retrieved on August 2, 2022. https://datadragon.eu/2021/09/16/deep-learning-for-delineating-farm-boundaries/

CBS, (2006). *Land fragmentation. In agricultural census monograph: National Census of Agriculture 2001/02* (p. 12). Kathmandu, Nepal: Central Bureau of Statistics. Retrieved from http://old.cbs.gov.np/agriculture/agriculture_monograph_preface_and_contents

Fetai, B., Oštir, K., Fras, M., & Lisec, A., (2019). *Extraction of visible boundaries for cadastral mapping based on UAV imagery*. Remote Sensing, 11(13). DOI: 10.3390/RS11131510.

Gbenga, A. & Emmanuel, O., (2022). *On the applicability of integrated UAV photogrammetry and automatic feature extraction for cadastral mapping*, 71(1):1–24.

Khaire, A. & Thakur, N. V., (2013). An overview of image segmentation algorithms. *International Journal of Image Processing and Vision Science*, 1, DOI: 10.47893/IJIPVS.2013.1028

Paul, B. K., & Rashid, H., (2017). Land use change and coastal management. *Climatic Hazards in Coastal Bangladesh*, 183–207. DOI: 10.1016/B978-0-12-805276-1.00006-5.

Rydberg, A., (2001). Integrated method for boundary delineation of agricultural fields in multispectral satellite images. *IEEE Transactions on Geoscience and Remote Sensing*, 39.

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