Development of a Free Open-Source Hybrid Segmentation Plug-In to Extract Agricultural Field Boundaries in a Heterogeneous Land System

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Abstract. Accurate representation of agricultural field boundaries is a prerequisite to perform crop classification, evaluating sustainable strategies, and implementing agricultural policies. However, this is an elusive task in the Indian agro-economic setting due to land fragmentation, and small and irregular farm boundaries. In spite of significant advances in the development of efficient segmentation algorithms, their application is limited due to a lack of implementation tool/software, resulting in a wide gap between research and practice. An open-source tool is developed to automatically extract the agricultural field parcels using Red channel (R), Green channel (G), Blue channel (B), and Near Infrared Region (NIR) spectral channels. The tool will work based on Object-based Image Analysis (OBIA) methodology, i.e., the Sobel edge extraction operator will obtain the edges from each band and the edges were added from RGB, and NIR bands to obtain the final edge map. Watershed Segmentation is used to form the regions from the edges. The correctness of the segmentation is computed by using Quantitative completeness (QC) measure. The effectiveness of the plugin was explained on the marginal land system in India using Sentinel-2A and Cartosat-2E imagery. While Sentinel-2A has resulted in under-segmentation (QC = 0.84) with an overall accuracy (OA) of 37.05%, Cartosat-2E has resulted in over-segmentation (QC = 1.49) with an OA of 76.67%. Field boundary extraction with Cartosat-2E imagery performed well in extracting the field parcels relative to ground truth samples.

Keywords: Hybrid segmentation · Sentinel-2A · Cartosat-2E

1 Introduction

Despite a huge arable land and availability of resources, yield per unit of cultivated area for most of the Indian crops is much lower than corresponding world averages [1]. One reason for this low productivity is land fragmentation. The success of an agricultural system largely depends on the accuracy in delineating the boundaries and extent of the

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field parcels, as these are the fundamental units on which soil-water-crop simulations and decisions are made with regard to crop classification and yield prediction [2]. Representing the agricultural parcels of a region at high spatial resolution is quite challenging in Indian context due to highly fragmented and heterogeneous nature of the land systems. Hence, mapping of Agricultural Field Boundaries (AFB) is of utmost importance in order to implement the best land management practices. The spatiotemporal patterns of the AFB could be best represented with the help of Earth Observatory (EO) satellite images, having high spatial and temporal resolution [3]. The current study focuses mainly on the usage of open-source tools, algorithms, and satellite images for delineating AFB. The algorithms used for segmenting AFB are implemented in the open-source tools including Geospatial Data Abstraction Library (GDAL), Geographic Resources Analysis Support System (GRASS), and System for Automated Geoscientific Analysis (SAGA) in Quantum Geographic Information Systems (QGIS) platform. A plug-in has been developed for the same using python 3.7 and QGIS Application Programming Interface (API).

Field boundary delineation using remotely sensed imagery can be categorized into edge-based, region-based and hybrid methods. Edge-based algorithms detect the discontinuities within the image, while region-based algorithms group pixels with similar spectral properties [4]. Region-based approaches use regions as basic units. Region-based segmentation is a technique for determining the region directly and it groups pixels with similar spectral or textural properties [5]. Hybrid segmentation approaches have successfully attempted to combine the advantages of edge-based (exact boundary edges) and region-based (closed boundary parcels) segmentation techniques. Hybrid methods generally provide superior results in comparison to edge-based or region-based methods.

Hybrid segmentation approaches added the combined advantages of both edge and region-based methods [6]. [11–14] used hybrid segmentation algorithms to delineate AFB using commercial tools and single-date satellite imagery. [9] extracted AFB using hybrid segmentation methods and multi-temporal Sentinel-2A (S-2A) imagery in eCognition tool. From the literature, Watershed Segmentation (WS) algorithm is preferred to segment AFB from a gradient image. The gradient image can be obtained by using Sobel edge detection operator for multi-band images of S-2A satellite imagery [7]. The implementation of Sobel edge detection operator and WS algorithm in open-source platforms has not been explored for segmenting highly fragmented land systems using Cartosat-2E (C-2E) & Seninel-2A (S-2A) images. Hence, the proposed study aims at developing an open-source QGIS plug-in for segmenting AFB using Hybrid (Sobel and WS) segmentation methods. The accuracy of the segmentation obtained from commercial C-2E Very High-Resolution multispectral images of 1.6 m resolution and S-2A images of 10 m resolution was evaluated by comparing the segmentation metrics with the ground truth data, manually delineated from google earth engine [10]. The entire process of segmentation is demonstrated with the help of plug-in in QGIS. A plug-in is a software add-on that is installed on a program. Plug-ins in QGIS add useful features to the software [14]. There are several tools, technologies, or systems such as GIS (Geographic Information Systems), RS (Remote Sensing), and SDSS (Spatial DSS) available to support spatial decisions and could be best represented with the help of plugins.

2 Materials and Methodology

2.1 Area of Interest and Satellite Data Acquisition

The segmentation algorithms were implemented in fragmented landscapes located in agricultural areas of Kandi area, Sanga reddy district, Telangana state, India. The area of interest of the proposed research is 10.66 km2 (1,072 ha), which falls under tropical savanna climate zone (Aw) characterized by lengthy dry and short wet seasons, from the Köppen-Geiger approach [15]. The area of the latitudes and longitudes are 17°37′33″N – 17°38′42″N, and 77°59′06″E – 78°00′29″E, as shown in Fig. 1. Annual average rainfall in the study area is about 950 mm and greater than 75% of the rainfall received during the months July-September. Very High-Resolution multispectral images (MS) of commercial Cartosat-2E (C-2E) were collected from NRSC (National Remote Sensing Centre), Hyderabad. The spatial resolution of C-2E is 1.6 m and spectral resolution of four bands (Blue, Green, Red and Near Infrared Region). The images were orthorectified before processed by proposed classification models. The freely available Sentinel-2A of 10 m spatial resolution cloud free datasets were downloaded from sentinel scientific data hub, European Space Agency (ESA). One cloud free image from both C-2E and S-2A were collected in an agricultural year (2019–20).

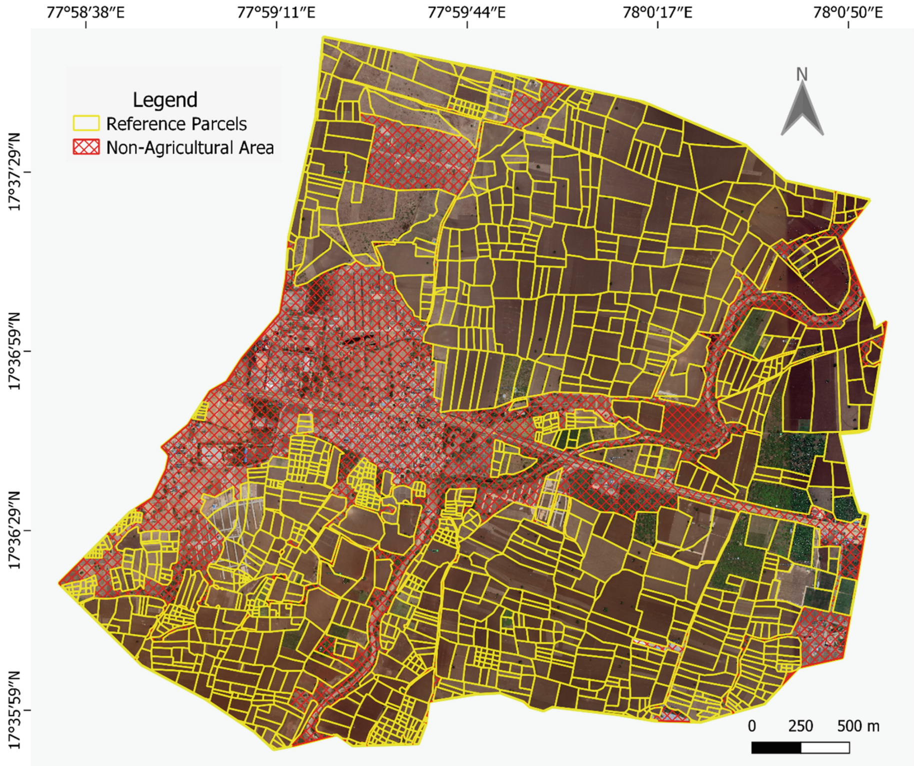


Fig. 1. Map of the study area

2.2 Image Segmentation

The image segmentation methodology is used in extracting edges and then to form the parcels(regions) using watershed segmentation algorithm. The first step in the process is to eliminate the non-agricultural areas from the area of interest (AOI). Then, all four bands have to mask with the agricultural land parcels of the AOI. The Sobel edge detection algorithm has to perform on induvial image bands [9]. Single edge image is obtained by aggregating all four edge layer bands. Region-based Watershed segmentation is performed on aggregated edge image i.e., obtained from the Sobel operator [8]. Based on the Visual interpretation of boundaries and Trail & Error method, Threshold 20 has better detection of field boundaries compared to other thresholds.

2.3 Tool Development in QGIS Interface

Python supports modules and packages, which encourages program modularity and code reuse. Often, programmers fall in love with Python because of its increased productivity. Python supports various libraries with which we can develop GIS applications or plugins such as 'qgis.PyQT, osgeo, processing, gdal, etc.'. "Qt designer studio" is used to design the user interface. The process of the entire segmentation methodology, including custom widgets will be developed in python script. The developed QGIS tool is shown in Fig. 2.

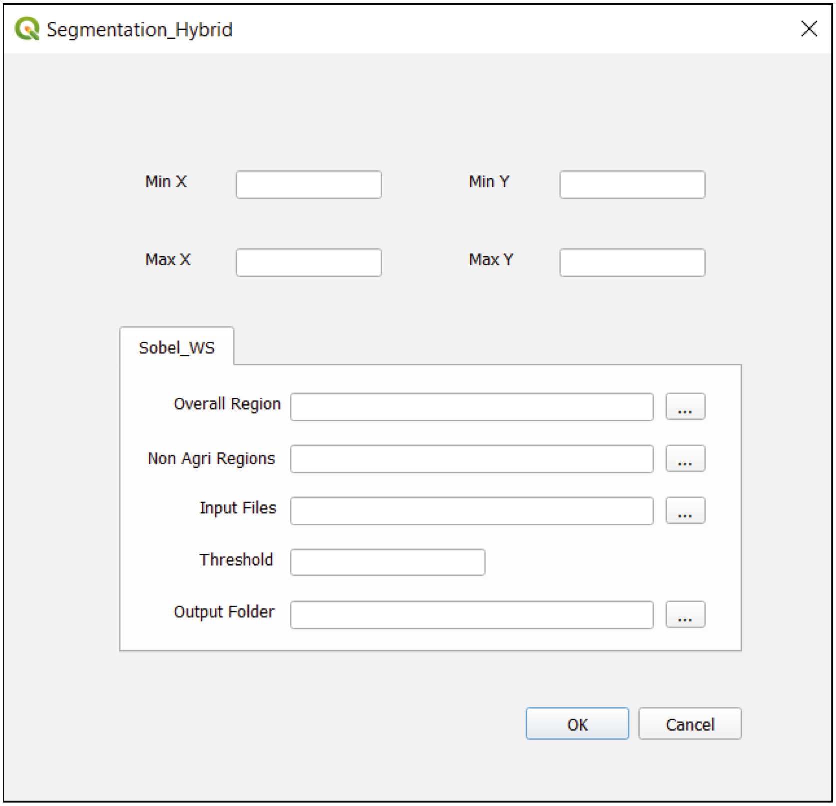


Fig. 2. Segmentation Plug-in developed in QGIS interface

Paths and directories given in the input dialog box will be read into the program. Non-agri region is subtracted from the overall region by running the 'native:difference' algorithm with appropriate parameters output is stored in 'difference.shp'. Each input raster is clipped to the 'difference.shp' polygon using 'gdal:cliprasterbymasklayer' algorithm and generated rasters will be stored as 'masked#.tif' in output directory. Each masked raster is then used to generate an edge map and generate edge layer rasters using 'gdal:slope', which will be stored as 'output#.tif'. These raster layers of different bands are combined and sent to 'saga:watershedsegmentation' algorithm to apply region based segmentation which separates the segments in the given input raster region and produces rasters containing estimated segmented regions in 'segment.sdat' raster file. This 'will be converted into a vector polygon with these segments as features using the 'grass7:r.to.vect' algorithm. All the files will be generated into the 'Threshold_#' directory in the given output directory.

3 Results and Discussions

The tool was evaluated by considering two satellite imagery S-2A (10 m resolution) and C-2E (1.6 m resolution) for extracting marginal fields. The obtained field boundaries from the Cartosat-2E and Sentinel-2A from the proposed hybrid segmentation algorithm are shown in Fig. 4.

Segmentation is evaluated by the ratio of the number of regions in the segmented image to the number of regions in the reference segmentation. Which is called as the *generalization*, and given by:

$$\mathrm{Gen} = \mathrm{N_s} / \mathrm{N_{ref}}$$

where, N_s is the number of parcels in the extracted scene and N_{ref} is the number of parcels in the reference segmentation. This measure allows for evaluation of the over-segmentation (OS) (*Gen more than* 1) or the under-segmentation (US) (*Gen* less than 1). Completeness Accuracy evaluation is performed on Area of Interest (AOI) and five different Region of Interests (ROI) as shown in Fig. 3. The five regions of interests (ROIs) were selected uniformly covering the entire ROI. The accuracy metric of completeness for selected ROIs of C-2E and S-2A delineated field boundaries are shown in Table 1 (Fig. 4).

The results depicts that the segmented boundaries delineated from C-2E imagery are falling under "Over-Segmentation" category as '*generalization*' ratio is more than one. i.e., more number of segments are forming than the actual number of fields because, VHR (Very High Resolution) multi-spectral images will delineate highly fragmented agricultural land parcels. While S-2A results are falling under "Under-Segmentation" category. i.e., less number of segments are forming than the actual number, which is due to coarse resolution of the satellite. Results are in agreement with the effectiveness of very high-resolution satellite imagery for an accurate demarcation of fragmented/heterogeneous croplands.

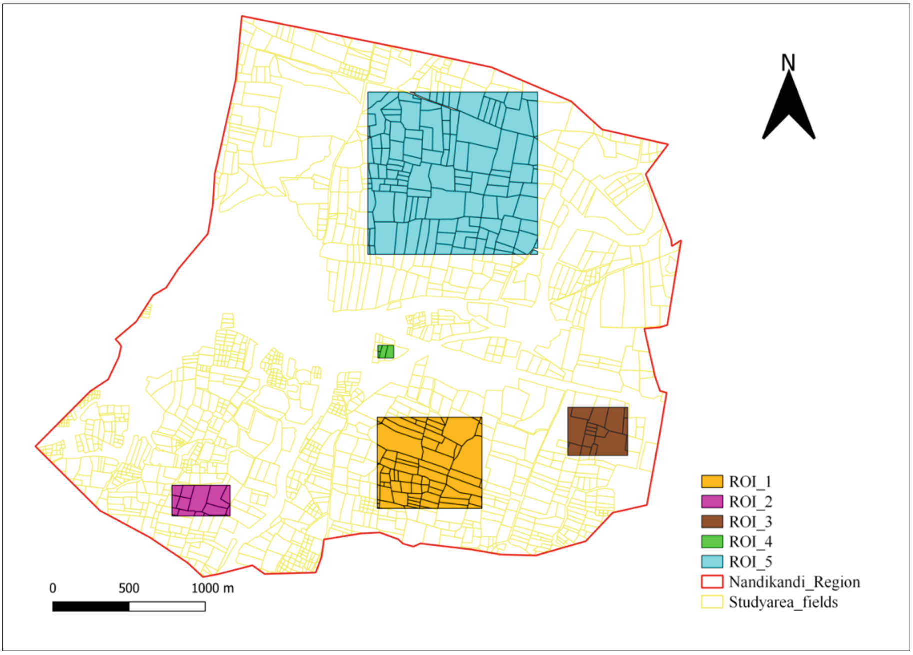


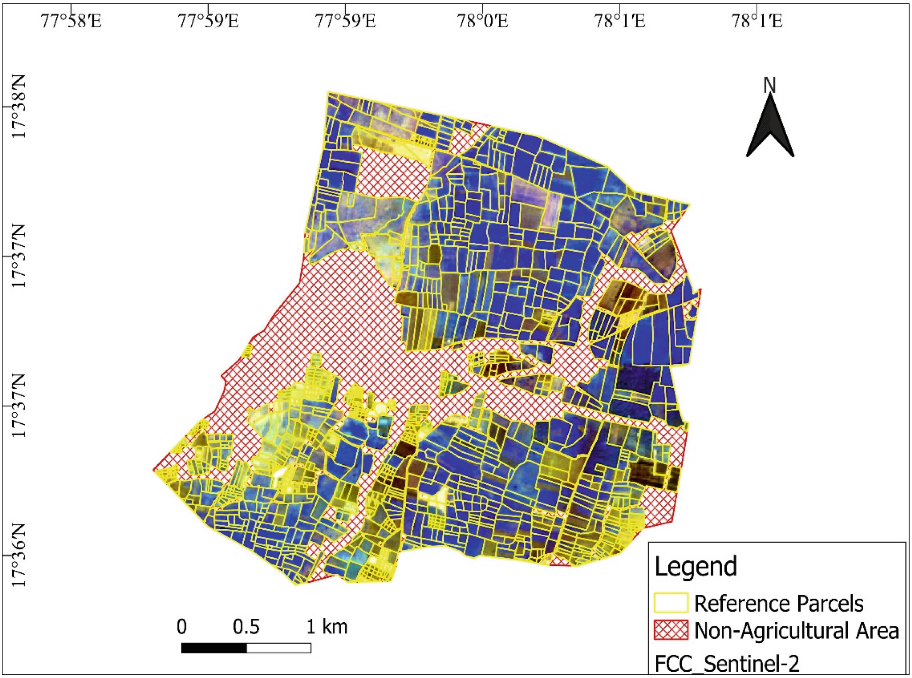
Fig. 3. ROI's for Accuracy Metrics of completeness

Table 1. Generalization (Quantitative Completeness) for the different regions of interest of Sentinel-2A and Cartosat-2E

Region of Interest (ROI)	Area (Sq.m)	Ground-truth Parcels	Sentinel-2A		Cartosat-2E	
			Extracted no. of parcels	Quantitative completeness	Extracted no. of parcels	Quantitative completeness
ROI-1	8,445	4	1	0.39 - US	6	1.39 - OS
ROI-2	75,223	16	13	0.83 - US	17	1.04 - OS
ROI-3	1,23,127	16	19	1.17 - OS	28	1.69 - OS
ROI-4	4,07,003	73	86	1.16 - OS	74	1.08 - OS
ROI-5	10,75,112	129	241	1.85 - OS	137	1.09 - OS

4 Conclusion

CARTOSAT-2E with 1.6 m spatial resolution got better results (Over-segmentation) compared to SENTINEL-2A with 10m spatial resolution (Under-segmentation) for the entire area with respect to quantitative completeness (generalization) accuracy, this is due to the differences in spatial resolution and factors like cloud cover, noise effect etc., For better understanding, the Region of interests are selected uniformly throughout the study



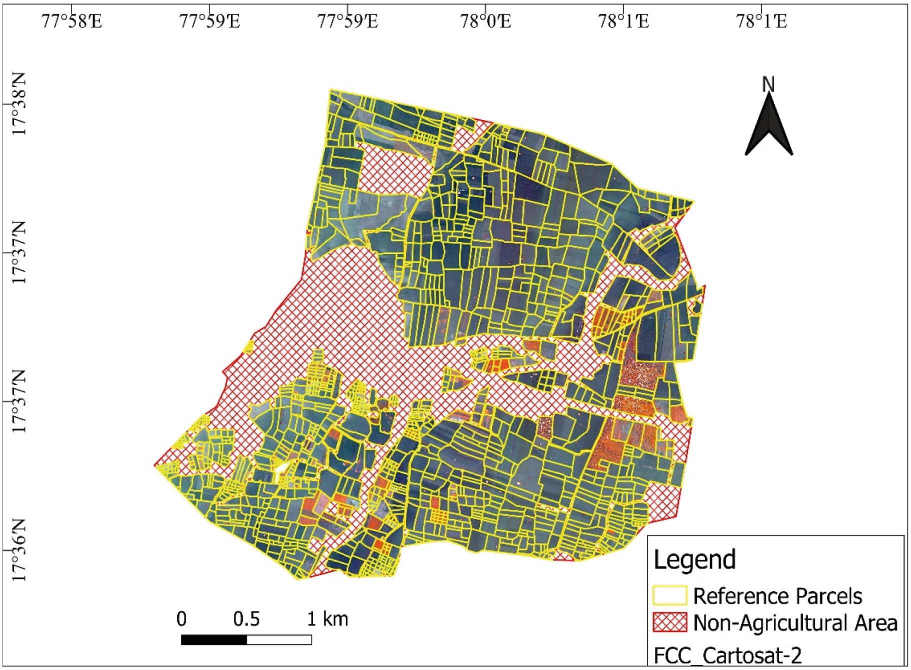


Fig. 4. Field boundaries overlaid on (a) Sentinel-2A (b) Cartosat-2E imagery. The shaded area corresponds to non-agricultural regions of the study area

area for evaluation. The combination of edge and region-based algorithms yields better results for agricultural parcel extraction. Overall, the Cartosat-2E gives the best results in comparison with the Sentinel-2A dataset with the proposed Hybrid segmentation algorithm. The entire methodology is built in the form of a plugin in QGIS interface in the form of effective user-friendly tool. The developed tool is suitable to apply for any kind of topography. The results from the automatically delineation of agricultural land parcels could be further used for Object Based Image Analysis for the classification of crops; thereby the yield of the crop can be computed.

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