OBJECT-BASED IMAGE ANALYSIS APPROACH TO DETERMINE THE FALLOW PERIODS FOR SHIFTING CULTIVATION IN INDIGENOUS COMMUNITIES IN GUYANA

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ABSTRACT:

Shifting cultivation is an agricultural practice that is the basis of subsistence for the Indigenous population in Guyana and has impacted on a total forest area of 13,922ha to varying degrees of impact on forest carbon. Generally, within these communities, there are two types of shifting cultivation: pioneer and rotational. Pioneer shifting cultivation involves the cutting of primary forest and subsequent cropping and then abandonment. Rotational shifting cultivation involves revisiting areas on a rotational cycle. In Guyana, shifting cultivation is not included in the sustainable land use system since no work has been done to understand the rotational cycles. This study utilized an Object-based image analysis (OBIA) of time-series satellite data (Landsat TM5 and OLI) for the period 2004 to 2017 to determine the dynamics of land cover, time-series changes, and prevailing shifting cultivation cycle in the indigenous communities of Jawalla and Phillipai in the western section of Guyana. OBIA proved to be an efficient method for shifting cultivation and sustainable forest management analyses in Guyana. The findings of this study indicate that short fallows are associated with shifting cultivation in Guyana and the size of the patches cleared each year has been increasing. These trends have potential ecological and livelihood implications that can impact the flow of ecosystem services and the sustainability of livelihoods.

1. INTRODUCTION

1.1 Background

Shifting cultivation is an integral land use activity for the Indigenous population of Guyana. Malmer *et al.* (2005) define shifting cultivation as a form of “non-sedentary” agriculture that involves the clearing and burning of patches of forest for the purpose of cultivation. It is a type of agricultural system carried out extensively in the tropical regions under other terms such as swidden farming or slash and burn farming (Gleave, 1996).

The practice of shifting cultivation is characterized by a subsequent return to the once-cultivated lands to restart the process (Gleave, 1996). The period between cultivations is referred to as the fallow period, the duration of which determines soil and vegetation (forest) replenishment in the area (Erni, 2015). There are many variations of this form of agriculture across the world (Erni, 2015), and even more opinions on the level of sustainability it entails (Erni, 2015). While it is argued that shifting cultivation is an ideal form of agriculture for the tropics, it is important to note that this is dependent on tolerable human population densities and long fallow periods (Erni, 2015).

A range of factors, inclusive of population growth, influences the length of fallow (Gleave, 1996). Studies (Erni, 2016; Gleave, 1996) show that fallow periods are increasingly becoming shorter in tropical regions, resulting in grim degradation and deforestation issues. In Guyana, shifting cultivation is categorized as either Pioneer Shifting Cultivation or Rotational Shifting Cultivation (Brown *et al*., 2014). Pioneer shifting cultivation refers to the burning of primary forests for the purpose of cultivation, while rotational shifting cultivation refers to the cultivation of areas that have already been burnt and cultivated before (Brown *et al*., 2014). Over the years, Guyana has seen an increase in the total forest area degraded as a result of shifting cultivation. Further, community surveys conducted in Indigenous communities in Guyana indicate short fallow periods and long cultivation periods (Brown *et al*., 2014).

Against this backdrop, this study is conducted to determine the fallow periods for shifting cultivation in Guyana and to assess the ecological and livelihood implications of such, using remote sensing technologies.

The study is confined to two Titled Indigenous areas in Guyana; i.e. the communities of Jawalla and Phillipai in Administrative Region seven of Guyana.

1.2 Remote Sensing for Land Use and Land Cover Analysis

Remote sensing methods are tremendously useful for a range of land use and land cover analysis. Analyzing and monitoring land cover change using multi-temporal satellite imagery and advanced remote sensing techniques presents an efficient means of understanding the landscape dynamics of the earth. Guyana, for the past decade, has employed the use of this dynamic technology to map land use and land cover change under its REDD+ Monitoring Reporting and Verification System (MRVS). Shifting cultivation, in particular, has been mapped using modern satellite imagery such as Rapid Eye, Landsat, and Sentinel (GFC, 2018).

1.3 Object-based Image Analysis

This study adopts the object-based approach to image classification to determine the length of the fallow period of shifting cultivation in Indigenous communities of Guyana. This brand of image analysis has become popular for its ability to classify imagery beyond pixels (Blaschke, 2010). Blaschke *et al.* (2004) and Hossain & Chen (2019) explain the main shortcomings of pixel-based image analysis, highlighting its inability to consider the shape and contextual characteristics of the imagery.

The difference with object-based analysis is that it focuses on image-objects instead of pixels. Image-objects, according to Blaschke *et al*. (2004) are groups of pixels that translate to features in the real world. Moreover, as discussed by Hossain & Chen (2019), pixel by pixel analysis fails to consider the spatial variation of land covers in high-resolution imagery.

Object-based image analysis is built on image segmentation and involves the development of automated methods to generate meaningful objects from imagery (Hay & Castilla, 2008). Image segmentation refers to the partitioning of an image into sections (objects) that vary based on properties such as colour, size, shape, etc. (Hossain & Chen, 2019).

2. STUDY AREA

This study was conducted in Jawalla and Phillipai, two Titled Indigenous villages in Western Guyana, geographically, the area is located between 5.231 to 5.753°N latitude and 60.117° to 60.675°W longitude (Figure 1). Together the villages occupy an area of 120,595.92 hectares (1,205.96 Km^2). The villages are populated with the Akawaios indigenous sub-tribe who are thought to be the linguistic descendants of the Karinya and are mainly found in the Upper Mazaruni area, Barama, Upper Pomeroon, Demerara, Wenamu and Upper Cuyuni Rivers.

The adjoining villages, both located in remote locations of the Pakaraima Mountains, Region number 7, Cuyuni – Mazaruni. The main economic activity in this area is alluvial mining with a combined population of approximately 2,370 individuals. The area experiences year-round heavy rainfall. The mean precipitation within the last decade is 22.86 mm/pentad and ranges between 1.71 mm/pentad (low) and 137 mm/pentad (high). The daily surface temperature is around 17.3°C and 28.7°C with an average within the last decade of 22.73°C. The topography is extremely irregular and comprises of mountains, highlands, small basins, and valleys. The vegetation in this area is characterized as a moist, evergreen forest of mixed species types.

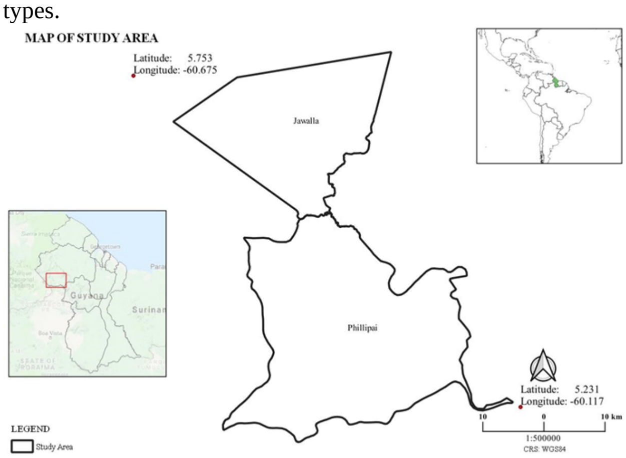

Figure 1. Location map of the study area

3. MATERIALS AND METHODS

3.1 Satellite data acquisition

The present study involves the collection and analysis of 14-years Landsat satellite images (TM and OLI). The required satellite imageries were acquired and processed utilizing the services of Google Earth Engine (GEE) for the development of the land cover change maps.

The processing sequence included the pre-processing of the satellite data after which the cloud/shadow mask was applied, subsequently, the sub-setting of satellite images was performed for extracting study area from all images, taking the geo-referenced outline boundary of Jawalla and Phillipai as AOI (Area of Interest).

Vegetation indices in the form of Normalize Difference Vegetation Index (NDVI) and Enhance Vegetation Index (EVI) were calculated and subsequent band stacking was performed. The stacked images were then downloaded after which Geometric corrections and the segmentation process were performed.

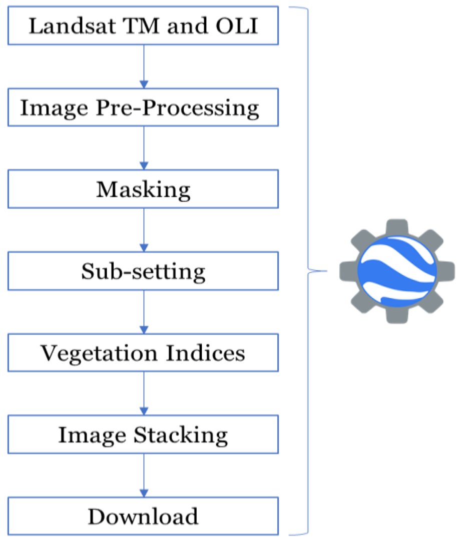

Figure 2: Diagram of the image processing steps

3.2 Object-based image analysis

3.2.1 Image Segmentation: Object-based image analysis requires the creation of objects or separated regions in an image. The pre-processed images were subjected to image segmentation in ENVI. This involved the breaking up of each image into small segments, i.e. objects, based on the unique image properties such as texture, shape, and colour so that the characteristics of the image objects within each region have high homogeneity and strong statistical correlations.

3.2.2 Image classification: Subsequent to image segmentation, image classes were created and matched with the objects created in the previous step, i.e. creating examples for image classification (see figure 2). These image classes were used as examples for the classification of the entire images. Seven Land Use Land Cover (LULC) classes were considered for this purpose (figure 2). Considering the power of object-based methods, an attempt has been made to separate each class, e.g., new cultivation, under cultivation, regrowth, high and low forest, etc., in the classification schemes.

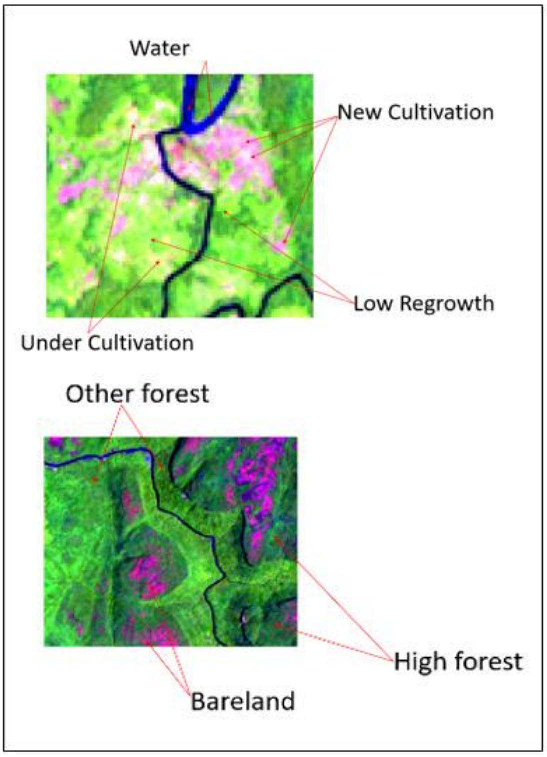

Figure 3. Classes delineated for classification

3.3 Post-classification sieving

The results from the classification were further screened to remove isolated pixels based on a size (number of pixels) threshold and generalize classification of the images through a sieving process. Normally classified images often manifest a salt-and-pepper appearance due to the inherent spectral variability encountered by a classifier. In such situations, it is often desirable to smooth the classified images to show only the dominant presumably correct classification. Thus, post-classification processes were applied over a classified image to eliminate isolated pixels and to generate an apparently less noisy image. In this study, the post-classification process applied was sieving. Once this process was completed quality checks were done to verify the integrity of the image classification. This step was performed in QGIS 3.8 software.

4. RESULTS AND DISCUSSION

The results obtained through the analysis of multi-temporal satellite imageries are diagrammatically illustrated in Figure 3. The seven land cover classes identified previously were analyzed, and a year by year account of the annual area under shifting cultivation within the study area was identified continuously for the entire study period. This analysis gives a fair idea about the prevailing condition of the practice within the communities. Figure 3 shows the spatial distribution of burnt areas for each year under analysis. These results demonstrate that the shifting cultivation plots are concentrated (more or less) in a common area, i.e. following the path of a river that passes through the study area.

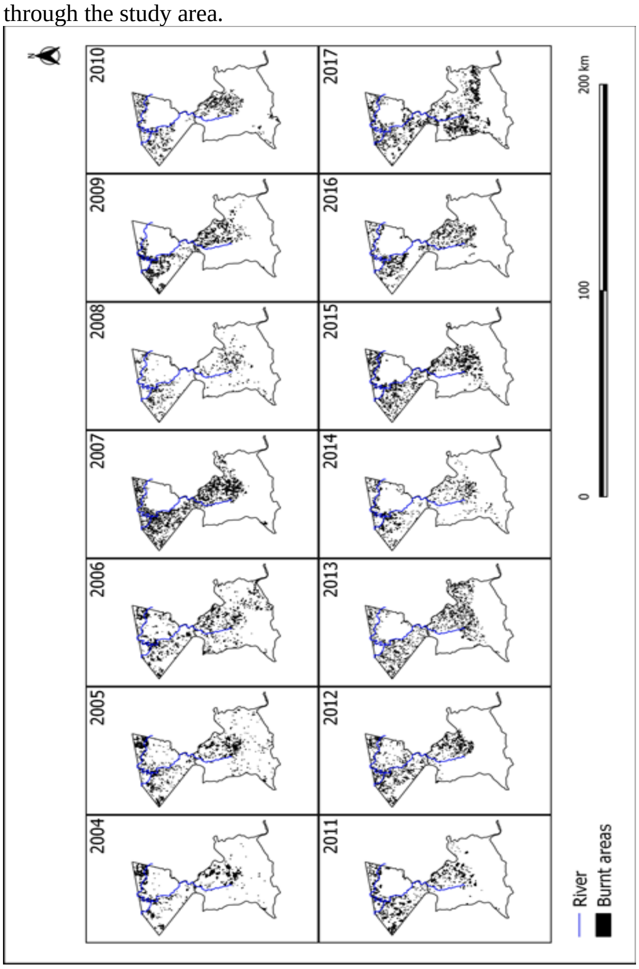

Figure 4. Map showing the spatial distribution of burnt areas each year 2004-2017

The percent of the total cultivated area under varying fallow cycles is observed in figure 4. The results of the classification were simplified and grouped into five principal groups, areas that were identified as single period cultivation, and areas with fallow years of 1-3 years, 4-6 years, 7-9 years and ≥ 10 years.

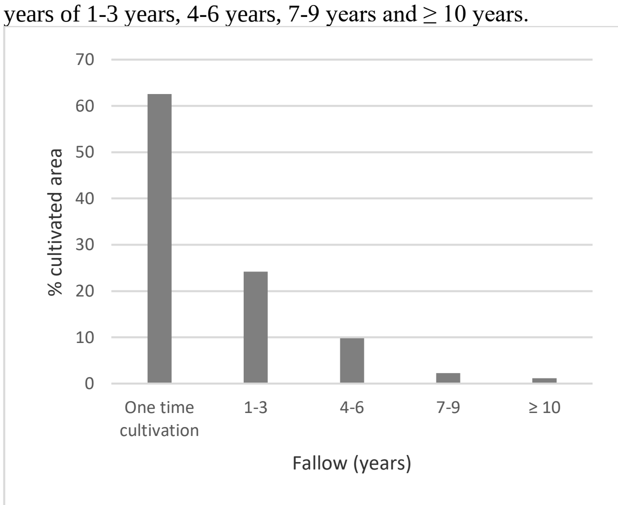

Figure 5. Chart showing the percent of area cultivated under various fallow periods

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As illustrated in figure 4, most of the cultivated area consists of a one-time instance of burning (62.6%) while the remaining 37.4% was distributed among the longer fallow periods. The fallow periods and their respective values are represented in table 1.

Fallow period (years)	% area cultivated
One time cultivation	62.59
1-3	24.20
4-6	9.78
7-9	2.30
≥ 10	1.14
Fallow period (years)	% area cultivated
One time cultivation	62.59

Table 1. Fallow periods and their respective % area cultivated

A comparison of the total area in hectares cultivated under each fallow period (1-13 years) 2004 -2017 showed that the maximum area of two thousand three hundred and ninety-eight hectares (2,398 ha) were cultivated under a 2 year fallow, while the least area cleared for cultivation was eleven hectares (11 ha) under a 13 year fallow as illustrated in figure 5 and table 2. The total area cultivated over the 13 years fallow period within the communities was eight thousand five hundred and nine hectares (8,509 ha).

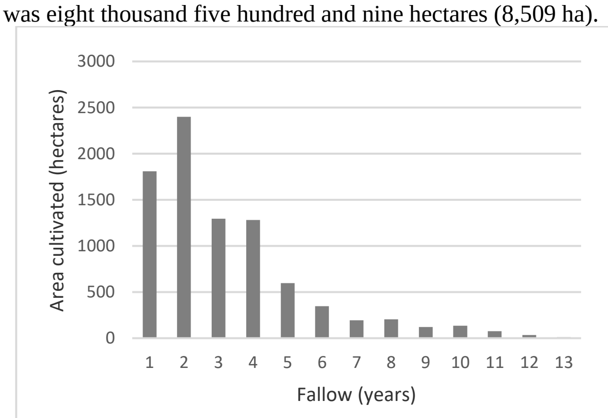

Figure 6: Chart showing the total area in hectares cultivated under various fallow periods

Fallow period (years)	Area cultivated (hectares)
1	1808.74
2	2398.31
3	1296.2
4	1280.36
5	597.92
6	346.35
7	194.77
8	205.43
9	122.08
10	136.28
11	77.7
12	33.45
13	11.17

Table 2. Fallow periods and the respective total area cleared

An analysis of the total area of land cleared each year for shifting agriculture each year is illustrated in figure 6. The mean land area cleared during the 13 year analysis period was one thousand six hundred and thirty-three hectares (1,633 ha). In 2017, the largest area was cleared amounting to two thousand six hundred hectares (2,600 ha). The smallest observable areas cleared was seen in 2008, the total area cleared in that year was five hundred and forty-four hectares (544 ha) (table 3).

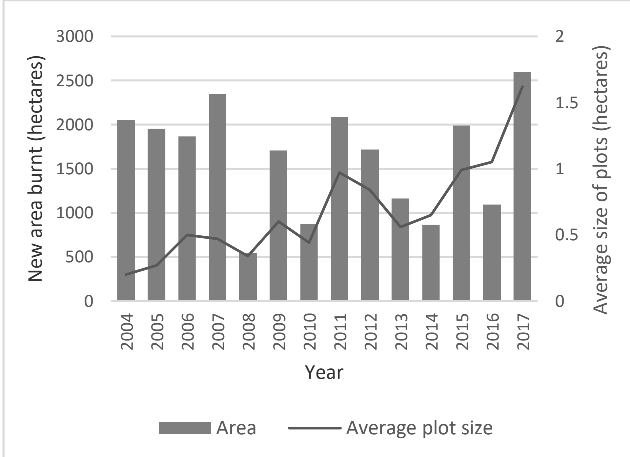

Figure 7. Total area cultivated each year along with the average size of plots burnt

Year	Area cultivated (hectares)
2004	2051.86
2005	1954.59
2006	1866.29
2007	2349.97
2008	544.02
2009	1707.92
2010	871.45
2011	2086.54
2012	1717.97
2013	1161.5
2014	865.78
2015	1991.16
2016	1092.36
2017	2599.35

Table 3. Total area cultivated each year

The areas cleared over time fluctuates, the average size of the plots cleared per year was 0.68 hectares. While there is no observable trend in the total area cleared, the results indicate that there has been a gradual increase in the size of plots burnt each year.

4.1 Fallow periods for shifting cultivation in Guyana

The length of time that an area previously burnt and cultivated is left to replenish is referred to as the fallow in shifting cultivation practices (Erni, 2015). In many tropical countries, where this type of agriculture is readily practiced, fallow periods are becoming significantly shorter owing to a variety of reasons (Dalle & Blois, 2006). Shorter fallows are concerning because this type of agriculture is sustainable only if the soil and natural vegetation are left to recover; the alternative is permanent cropland (Yadav *et al*., 2012).

The results of this study show that Guyana's case is similar to many other tropical countries, i.e. short fallow periods are associated with shifting cultivation. The results depicted in figures 1 and 2 show a significant disparity between the total area cultivated under fallow cycles less than 5 and that over 5 years. This can be attributed to an increasing population in these communities, thereby an increased demand for food; proximity to farmlands; changes in land tenures (Dalle & Blois, 2006).

In addition to short fallows, the results indicate significant instances of one-time cultivation. This implies that, in many cases, burnt croplands are not returned to; rather new areas are being burnt and cultivated. Figure 1 indicates the high percent of burnt land which has been cultivated just once within the 13- year period of this study. Further, the results depicted in figure 6 show the large areas which are newly burnt every year (pioneer shifting cultivation). This indicates that old burnt areas are not often returned to for subsequent cultivations. This trend is indicative of arbitrary agricultural practice which can have substantial ecological consequences. Also concerning, is the increasing size of patches cleared for agriculture. Figure 6 shows that the average sizes of the patches cleared have been steadily increasing since 2013. This practice can potentially change the ecological conditions at the level of the farmlands, as well as, at the landscape level (Dalle & Blois, 2006).

4.2 Ecological and livelihood implications of shifting cultivation practices in Guyana

Based on the results of this study, the practice of shifting cultivation in Phillipai and Jawalla is associated with short fallows, large areas being newly burnt each year and larger sizes of plots being burnt. These results are concerning given the potential impacts on the ecology and livelihood sustainability of people.

Short fallows can potentially reduce species diversity and can alter the vegetative composition of forests. Yadav *et al.* (2012) find that frequent cycles of burning and cultivation have directly affected tree species diversity and have led to the degradation of forest land in parts of India. Further, studies (Dalle & Blois, 2006) show that shorten fallows are closely associated with an increase of pioneer species, thus altering the natural vegetative composition of forest landscapes (Delang *et al*., 2016).

In addition to vegetation impacts, short fallows do not permit complete recovery of soil nutrients and can result in poor soil properties. Further, the clearing of large patches of primary forest creates fragmented landscapes; modifies ecosystems, thereby affecting the flow of ecosystem services and displaces wildlife (Dalle & Blois, 2006).

While these issues associated with shifting cultivation are as a result of increasing population pressures, the very sustainability of people's livelihoods can be affected by short fallows and arbitrary burning. Forest degradation and soil depletion at current rates would create a landscape that can no longer support livelihood activities such as shifting cultivation (Delang *et al*., 2016).

The view that shortened fallows in shifting cultivation equate to yield declines has been challenged by Mertz (2002) on the premise that this might not be the case for many locations as yields vary based on site-specific conditions, such as soil type, vegetation type, and climate. Nonetheless, while the connection between yields and length of fallow is not straightforward, the ecological implications of short fallows are unquestionable.

4.3 Object-based image analysis for shifting cultivation analysis in Guyana

This study employed the use of a contemporary remote sensing technique, i.e. OBIA. This technique proved efficient in achieving the objectives of this research and provided accurate results due to the flexibility and thoroughness associated with image segmentation and classification. Further, due to the automation aspect associated with the use of the ENVI software, all burnt patches were detected as opposed to only considering those areas that are of a certain size. This is helpful as it gives a holistic view of the shifting cultivation scenario in the interior regions of Guyana. Moreover, this study is evidence that new and efficient remote sensing techniques can be applied to a range of land and forest management issues in Guyana to guide decision making and contribute to sustainable forest management.

5. CONCLUSION

Shifting cultivation is an important aspect of the livelihoods of indigenous communities in Guyana. For many years, it has been practiced in the interior regions of Guyana with minimal negative impacts. However, with increasing population pressures, this agricultural practice has changed. This paper analyzed the trends associated with fallow periods of shifting cultivation in the communities of Phillipai and Jawalla. It was found that most of the area under shifting cultivation experiences short fallows and each year, large areas are being burnt for agriculture. Further, the size of the patches burn each year has been on the rise for the past years. These practices have both ecological and livelihood implications.

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