A Hybrid Approach to Improve Classification Accuracy of Mapping Perennial Crops in Bảo Lâm District, Lâm Đồng Province

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Abstract
Perennial crops deliver strong economic, social and ecological benefits to many tropical countries. Accurate maps acquired through the remote sensing of the perennial crops are not yet available in the Central Highlands. The main objective of this study is to improve classification accuracy when mapping perennial crops in Bảo Lâm district with a hybrid approach and pixel-based classification. The results suggest improvements in the coffee and tea crop classification accuracy as compared to earlier work, and the overall accuracy increases from 71% to 75% and the Kappa coefficient improves from 0.66 to 0.71. The input parameters that most strongly impact the classification accuracy are NDVI and slope. This paper offers a comprehensive study on the accuracy gains through using a hybrid approach.

1. Introduction

Perennial crops deliver strong economic, social and ecological benefits to many tropical countries. Over the recent decades, agricultural expansion to produce commodities for global markets became an increasingly important factor of tropical deforestation (DeFries et al., 2010 and Lambin and Meyfroidt, 2011). The Central Highlands of Vietnam (Tây Nguyên in Vietnamese) hold most of the remaining forests with high biomass and biodiversity value in Vietnam (Meyfroidt and Lambin, 2008). In the context of socio-economic developments in the Central Highlands, the expansion of perennial crops is challenged by forest protection and biodiversity conservation as well as the increasingly severe effects of drought on agriculture in the region over the past 10 years.

Alongside the increased availability of Earth Observation data, in particular from the Landsat archive and Sentinel-2 data, researchers and practitioners have become increasingly interested in integrated time-series and multi-sensor remote sensing data for vegetation mapping (Yichun et al., 2008) including perennial crops. The general classification methods are based on the original digital number of all spectral bands and dominated by pixel-based classification methods. Based on these methods, the spectral confusion commonly occurs between perennial crops with young woodland and mature woodland (Langford and Bell, 1997, Cordero□Sancho and Sader 2007, Gomez et al., 2010 and Ortega-Huerta et al., 2012). The high similarity in spectral signatures of the different canopies challenges an accurate discrimination between the different classes. For example, the sun-grown (non-shaded) coffee was spectrally confused with crops/pasturelands and low-density woodland classes and most of the classification errors for this class occurred with shade coffee plantations, especially those having low-density tree cover. (Cordero-Sancho and Sader, 2007).

Despite the growing body of literature on vegetation mapping, systematic attempts to map specific perennial crops from remote sensing data remain limited i.e. mapping coffee plantations (Lelong and Thong-Chane, 2003, Vieira et al., 2006, Cordero-Sancho and Sader, 2007, Bernardes et al., 2012, Ortega-Huerta et al., 2012 and Mukashema et al., 2014), spectral characteristics of some species of tea plantations (Li and He, 2008 and Singh et al., 2012) and mapping tropical rubber plantations (Suratman et al., 2004, Zhe and Fox, 2011, Dong et al., 2012, 2013 and Chen et al., 2016). One of the problems while mapping perennial crops is the low accuracy of the final classification results. Regarding to the mapping of coffee plantations, consensus seems to exist that low classification accuracy is achieved when using Landsat data without ancillary data (Langford and Bell, 1997, Vieira et al., 2006, Cordero-Sancho and Sader, 2007, Gomez et al., 2010, Ortega-Huerta et al., 2012 and Mukashema et al., 2014).

In recent decades, a research trend can be observed in which ancillary data based on expert knowledge is integrated to improve classification accuracy, for example: modeling for mapping coffee plantation (Gomez et al., 2010, Bernardes et al., 2012 and Ortega-Huerta et al., 2012). Cordero-Sancho and Sader (2007) have examined spectral band combinations and ancillary data in the CSEM model for evaluating the classification accuracy and the nature of spectral confusion between coffee and other cover types with original spectral bands had significantly lower classification accuracy compared to datasets that included more spectral bands and ancillary data (Cordero-Sancho and Sader, 2007). Mukashema et al., (2014) show that the combined use of spectral and ancillary data (DEM and a forest map) allowed mapping of coffee fields with an overall accuracy of 87% (Mukashema et al., 2014). The hybrid classification approach was applied successful for distinguishing non-mangrove natural forest with 'open-canopy' from 'close-canopy' coffee plantations (Ortega-Huerta et al., 2012). Using the moderate spatial resolution, the hybrid approach can be produced land use/cover maps with higher accuracy from satellite images (Lo and Choi, 2004).

The main objective of this study is to improve classification accuracy when mapping perennial crops (coffee and tea plantation) in the Bảo Lâm district, Lâm Đồng province. This objective can be subdivided in two sub-goals: 1.1: testing the role and importance of each selected input parameters in a hybrid approach; 1.2: the overall classification accuracy improves significantly when using a hybrid approach in Bảo Lâm district.

2. Study Area

Bảo Lâm district area covers 146,344 ha (Figure 1) which comprises of around 19% of the total area of Lâm Đồng province. Lâm Đồng is one of five provinces of the Central Highlands (Tây Nguyên in Vietnamese). Natural vegetation over the Central Highlands is mainly composed of evergreen to semi-evergreen broadleaf forest, except in the northwestern part where dry and open deciduous forests dominate.

Bảo Lâm district has the largest tea plantations and is second in coffee plantations area when compared with all districts of Lâm Đồng province. The coffee and tea tree are the main perennial crops in the Central Highlands. In 2014, Bảo Lâm has had 48,947ha of perennial crops including 29,774ha coffee; 11,912ha tea; 251ha cashew and 87ha pepper (Lam Dong Province Department of Statistics, 2010). The Central Highland of Vietnam agro-ecosystems are dominated by small-scale agricultural fields that often contain a mix of annual and perennial crops with natural vegetation.

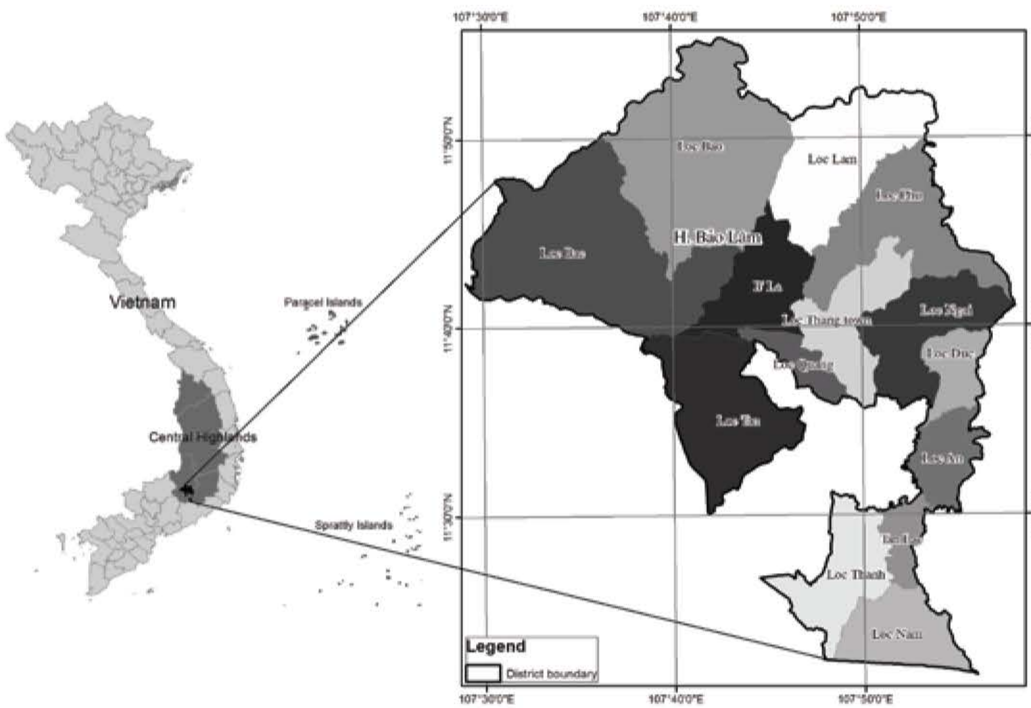

Figure 1: Bảo Lâm district, Lâm Đồng province

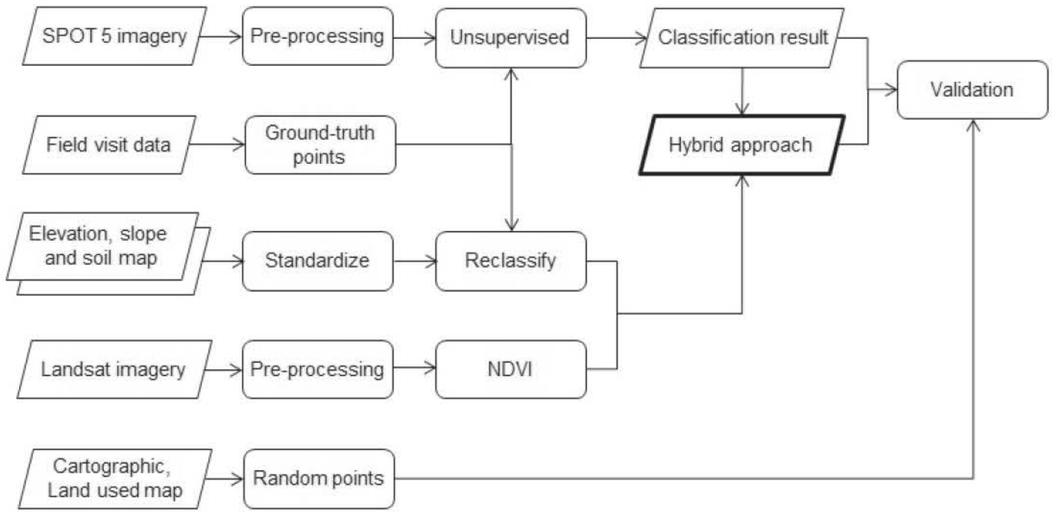

Figure 2: Flowchart of the methodology

This landscape can also be found in Bảo Lâm. The dry season lasting from November to April constrains coffee cultivation. By imposing irrigation, the growing season can be initiated earlier. The geomorphology, with 900m medium altitude, basaltic soils and flat or gently hilly relief, creates favorable conditions for agriculture especially for perennial crops (UN-REDD Vietnam, 2011).

3. Data and Methods

A general flowchart of the methodology applied in this work is shown in Figure 2. The various sub-tasks will be outlined in appropriate sub-sections.

3.1 Data Acquisition

Imagery of the SPOT 5 satellite has a relatively high spatial resolution which is expected to allow for increased accuracy in vegetation cover discrimination as compared to Landsat imagery. The higher resolution of SPOT improves the capacity to distinguish vegetation cover types (non-forest) and overall achieves a higher accuracy than Landsat images, especially in flat areas integrated with ecological conditions of perennial crops (Iverson et al., 1989, Gao, 1996 and Lillesand and Kiefer, 2000).

In order to detect the perennial crops in the study area, we used SPOT 5 satellite image acquired on the 10th February 2011, which is in the middle of dry season, and two Landsat5 images. The dates of the SPOT imagery are in the dry season which allows an easier discrimination between perennial crops and annual crops, grass land and other vegetation. The Landsat satellite images are acquired on the 21st December and 11th May which coincide with the planting and harvesting time of some annual crops in the case study.

Based on analyzing the crop calendar, from December to April is the optimal time to collect the satellite image for mapping perennial crops in the study region. Peanut, corn and potato crops are planted in April. For those periods, the land cover will look similar to bare soil. The purpose of this selection will be to remove the annual crops area from the perennial crops. In the Central Highland, in the first three years while the perennial crops are still young, they have planted the alternated of perennial crops and soybean, peanut, corn, cassava etc. The SPOT image is higher resolution and can distinguish land cover with more detail than Landsat image. However, SPOT imagery is not free of cost or publicly accessible. The available imagers do not correspond with the time-resolution based on the crops calendar. Thus, remote sensing data acquired in the harvesting time will be employed to remove the annual crops area from the perennial crops area of classification result. So, the Landsat images acquired in harvesting time were employed to extract NDVI to identify the non-vegetation area which will be used to remove the annual crops area from the perennial crops in the pixel-based classification result (Table 1).

3.2 Classification of Land Cover

The choice of classification algorithm requires considering multiple aspects of the problem: type of data, statistical distribution of classes, target accuracy, ease of use, speed, scalability, and interpretability of the classifier. A general pixel-based classification method was employed to compare with the results of classification when using the hybrid approach integrated spatial analysis in the post-classification stage.

Table 1: Remote sensing and ancillary database description and sources

Dataset	Description	Source
SPOT 5 (XS); 278-327	Spatial resolution 10 by 10 m, Acquired on 10 February 2011	STI-VAST*
Landsat 5: LT51240522010131BKT01 and LT51240522010355BKT00	Spatial resolution 30 by 30 m, cloud cover less than 10%	USGS
DEM	Spatial resolution 10 by 10 m	MONRE**
Land use map of Bảo Lâm district in 2010	Format in vector, scale 1:25000	MONRE
Soil map of Lâm Đồng province	Format in vector, scale 1:100.000	MONRE
Ground truth points (GTPs) in 2011	GTPs collected in Bảo Lâm district	STI-VAST
Photomap (high resolution): C-48-12-A; C-48-12-B; C-48-12-C; C-48-12-D; C-48-24-B;	Spatial resolution 2.5 by 2.5 m; included 5 pieces based on Vietnamese topographic map ID	MONRE
Crop calendar	Time for: planting, harvesting of some crop plantations in Bảo Lâm district	DARD Lâm Đồng***
Growing Cycle f Perennial Crops	Growing conditions of some perennial crops: elevation, soil, precipitation, temperature and life cycle	DARD Lâm Đồng

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Table 2: Statistical classification error of coffee and tea area when intersected with each input layer of spatial analysis in the hybrid approach

Layers name	Coffee (ha)	Tea (ha)	Coffee (%)	Tea (%)
NDVI	3,602	752	9.7	11.8
Slope 18	-	1,090	-	17.0
Slope 22	2,011	-	5.4	-
DEM 560_960	1,276	364	3.4	5.7
Soil	1,393	276	3.8	4.3
Total classification error area	7,038	1,983	19	31
Total area not applied hybrid approach	29,979	4,412	81	69
Total area applied hybrid approach	37,017	6,396	100	100

When classifying complicated classes, the unsupervised approach appears to be more effective than the supervised algorithm (Rozenstein and Karnieli, 2011). Limited research thus far has been conducted in applying pixel-based classification methods to map perennial crops using Landsat image (Cordero-Sancho and Sader, 2007 and Meyfroidt et al., 2013). The few studies conducted obtain low overall accuracies; 64% as conducted in Tây Nguyên (Meyfroidt et al., 2013) and 56% as conducted in Costa Rica (Cordero-Sancho and Sader, 2007).

The time series of remote sensing data consists of Landsat TM images – path/row 124/52 in 21st December and 11th May 2010 and SPOT 5 satellite image acquired in 10th February 2011, which were co-registered and geo-referenced. 124 ground-truth points (GTPs), collected by fieldwork in October 2011, were used in combination with Google Earth images, and expert knowledge to train unsupervised classifications of land cover by the "Isodata" algorithm with 150 classes. Maximum Iterations = 15; Convergence = 0.98. Classifications with 150 classes, which were subsequently aggregated into eight classes: (i) coffee plantation, (ii) tea plantation, (iii) annual crops and bare land, (iv) closed forest, (v) open forest and shrub, (vi) residential land, (vii) water body and (viii) pine forest.

3.3 A Hybrid Approach of Image Analysis

Post-classification comparison of a time series of land cover maps can aid in identifying illogical land cover transitions in space and time (Liu and Cai, 2012), which, in well-registered maps of the same spatial resolution, can be indicative of classification error (Townsend et al., 2009). The studied perennial crops are known to grow best within specific environmental zones (Table 2). In the Central Highlands, the coffee trees are growing optimally within the temperature range of 19^{0}C - 23^{0}C (Nguyen et al., 1996 and Van and Thuy, 2002), with rain fall ranging from 1200 to 1500 mm/year and a humidity of between 80 to 85% (Phong, 2000). In general, coffee trees are optimally adapt to scattering light (Sung, 1998). In the study area, basalt soil is the best suitable soil for planting coffee tree (Nguyen et al., 1996 and Van and Thuy, 2002). Similarly to coffee trees, tea trees are growing better in temperature from 12^0C to 35^0C, with annual rain fall of more than 1500 mm/year and humidity between 80% and 85%. Tea trees are less selective in soil type compared to coffee trees, but in this study area, the basalt soil is most suitable for planting high quality tea (Dat and Nhuong, 1999). The hybrid approach prepared to define the specific perennial crops (only coffee and tea in Bảo Lâm district) based on ecological conditions of perennial crops and extracted point value data from 34 coffee GTPs and 30 tea GTPs (of 124 ground truth points, collected by fieldwork in October 2011).

- The slope constraint was excluded from the integration of spatial analysis because some coffee and tea plantations were located on slopes greater than 15 degrees. Furthermore, the slope variable proved to be a poor predictor of coffee location in earlier studies (Cordero-Sancho and Sader, 2007). The slope layer is included: less than 15 degree based on ecological conditions of perennial crops and extracted slope value from 34 coffee GTPs and 30 tea GTPs. The range of slope was selected from zero to maximum slope value with each perennial crop type: (i) tea plantation: slope range from 0 to 18 degree; (ii) coffee plantation: slope range from 0 to 22 degree;

- Elevation range found ranges between 500m to 1500m. The elevation extracted from GTPs with DEM range from 560m (minimum) to 960m (maximum) for both coffee and tea plantations in the Bảo Lâm district;

- Soil types: most GTPs of coffee and tea plantation are located in basalt soil type (about 95% of the 64 GTPs). The soil type layer will be reclassified: basalt and others soil type.

- NDVI layer: based on crops calendar and growing cycle of perennial crops, in the first three years, the coffee and tea plantations are still open-canopy and the annual crops such as: corn, soybean, peanut, cassava, potato will be planted alternatively to the perennial crops. The NDVI index calculated from Landsat TM images – path/row 124/52 in 21st December and 11th May 2010 will be reclassified: vegetation and non-vegetation due to visual interpretation. The coffee and tea plantation area in classification result will be change to annual crops and bare land class if overlay the non-vegetation class.

The eight classification results (two classes: coffee and tea plantation with and six classes without applied hybrid approach) were evaluated. Majority filters (3x3) were used to remove noise and speckle.

3.4 Classification Accuracy Assessment

The accuracy of a classification is usually assessed by comparing the classification result with reference data, such as ground truth points, higher resolution satellite images, maps derived from aerial photo, in which ground truth collected through ground truth points (GTPs) from field survey is the best. To validate the image classification, it is preferable to conduct fieldwork or to use another source of data, such as an image or aerial photo that has finer resolution than SPOT images. Thus, we conducted a visual interpretation of high resolution imagery which were used in combination with land used map, Google Earth images, and expert knowledge to validate the classification. The accuracy assessment employed 443 random points in study area that were not included in the training site selection: 65 for coffee plantation, 64 for tea plantation, 81 for annual crops and bare land, 77 for close forest, 70 for open forest and shrub, 25 for residential land, 37 for water body and 24 for pine forest. Error matrices were created and evaluated for each of the eight classes. The error matrix compares the accuracy between sample points from the classified result and the random point from photomap interpretation data (Congalton and Green, 1998 and Stein et al., 2002). To facilitate comparison of classification results, the following accuracy terms were derived from each error matrix (Congalton and Green, 1998).

The error matrices for the six classification outputs were evaluated by computing the kappa statistic for each matrix. Kappa analysis allows the analyst to determine if one error matrix is significantly different from another. Kappa analysis produces the KHAT statistic (K) that is a measure of the overall agreement between the image classification and reference data, excluding chance agreement. Values of K can range from zero (no agreement) to one (perfect agreement) (Congalton and Green, 1998 and Stein et al., 2002). Congalton and Green (1998), proposed three agreement levels: $K > 0.8$ indicates strong agreement; $K > 0.4$ and $K < 0.8$ suggests moderate agreement; and $K < 0.4$ indicates poor agreement (Congalton and Green, 1998).

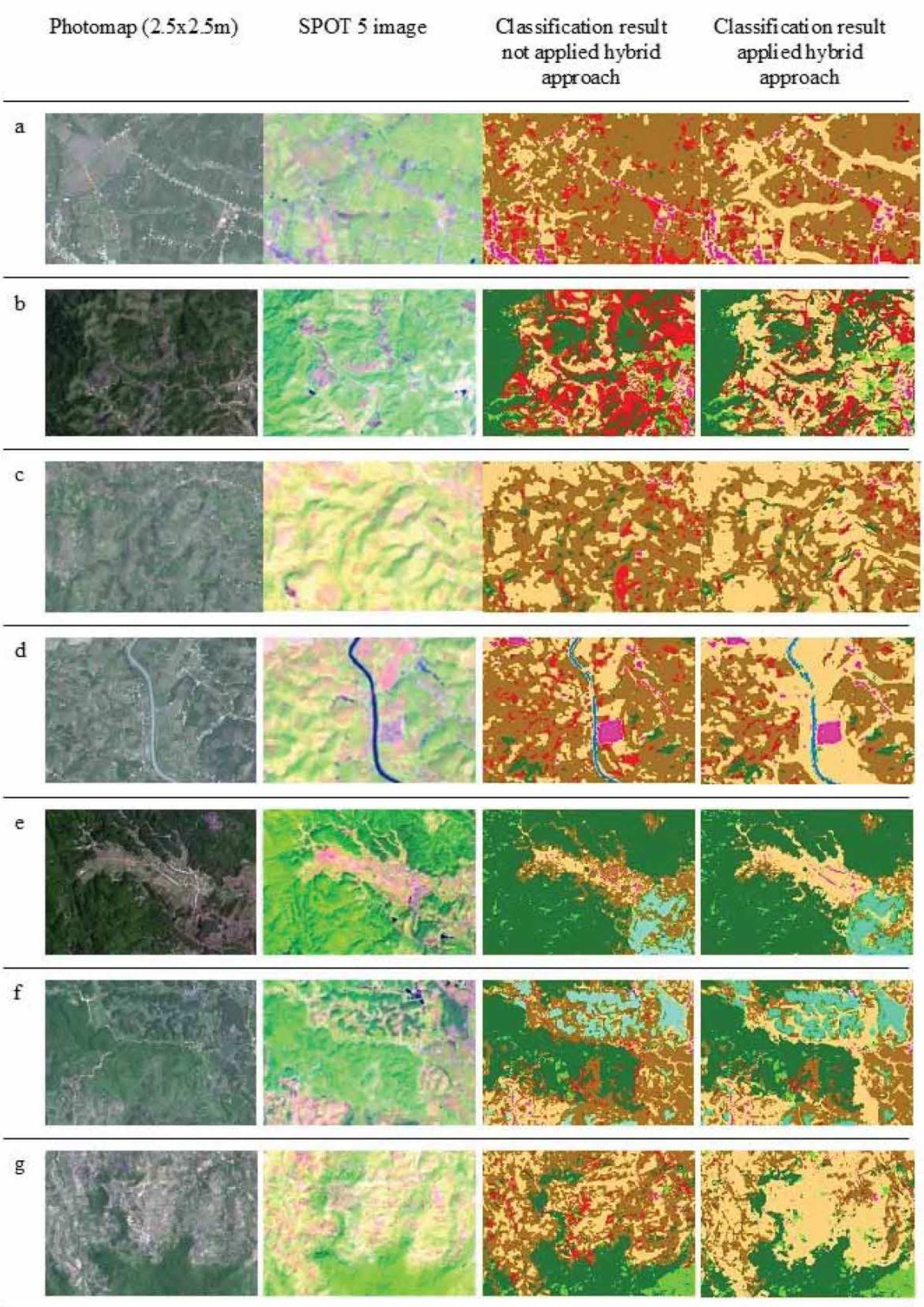
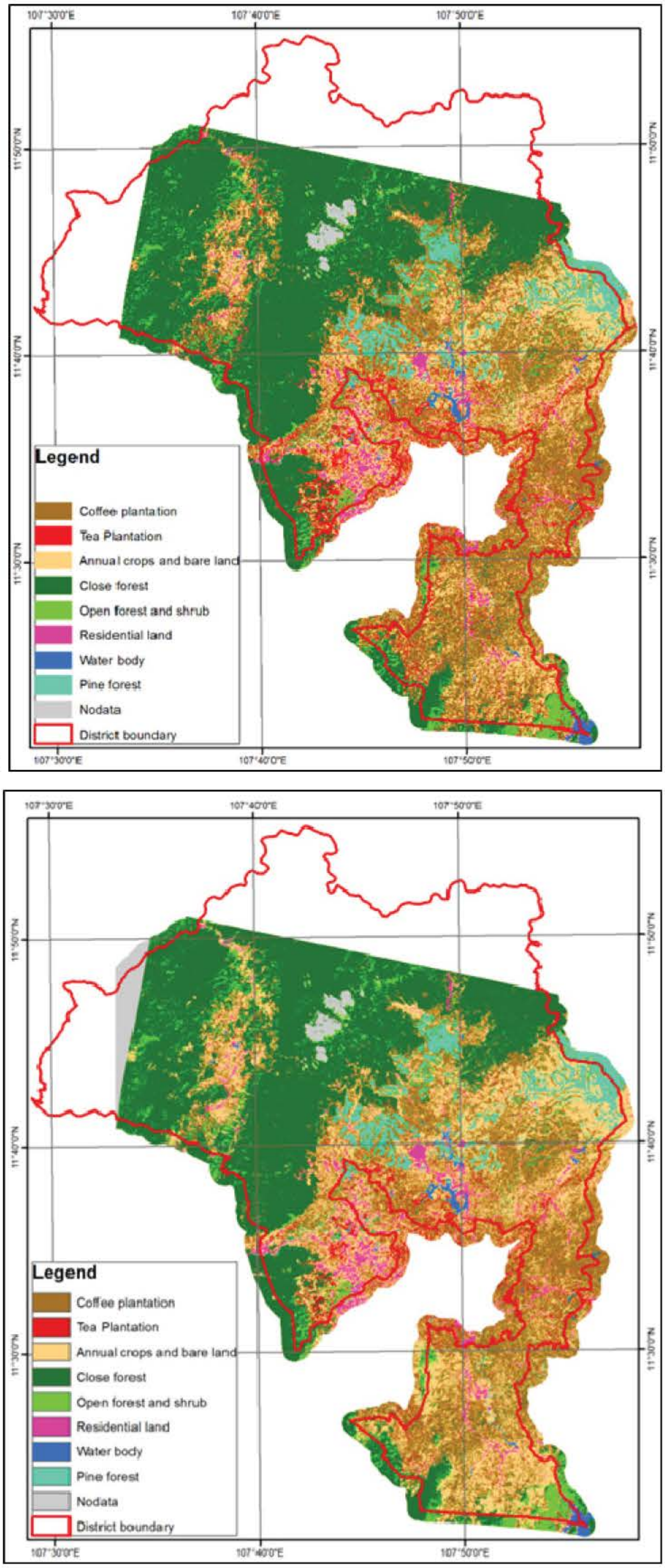


Figure 3: Comparison of classification result with/without applied the hybrid approach

(a)



(b)

Figure 4: Classification results: (a) pixel-based method; (b) hybrid approach, in 2011

4. Results and Discussion

4.1 Perennial Crops and Land Cover Classification

In the classified result with pixel-based method (applied Isodata algorithm, Figure 4a) mostly, coffee and tea plantation were confused with annual crops and open forest and shrub. Other classification errors occurred among annual crops and residential land. Also, young coffee and tea plantations were spectrally confused with shrub and annual crops, while the old tea plantations were confused with close coffee plantations, the same with preview research (Langford and Bell, 1997, Cordero-Sancho and Sader, 2007, Gomez et al., 2010, Ortega-Huerta et al., 2012). The causes of spectral confusion with open forest and shrub may be attributed to the age of the coffee and tea plantation. The young coffee conditions have high spectral similarities with other crops.

The classified result applied hybrid approach (Figure 4: row: b) show that the classification errors are 19% of total coffee area and 31% of total tea area reclassified in a different class than initially (Table 2). This result demonstrated the sub-hypothesis 1.1. In the coffee class, if compared of each spatial analysis inputs, the NDVI layer can be detected the highest classification error is 9.7% about 3,620ha. Almost all this area is located in the nearest forest land cover (Figure 3, row: g, c) where the annual planted in the open-canopy coffee. The remainder of the coffee classification error has the changing from vegetation to non-vegetation caused in the trim a branch time or replaced old coffee trees by other trees. The slope layer can be only found the classification error about 5.4% of total coffee area (Figure 3, row: f) and the remainder elevation and soil type inputs detected coffee classification error about 3.4% and 3.8% (Table 2) of total coffee area, respectively. The annual crops planted in the alluvial soil (Figure 3: row: a, d) and the other exhausted soil (Figure 3, row: e) will be removed from coffee area by soil type input layer. This result demonstrated that the coffee area was confused with annual crops when not integration of spatial analysis. Differ from coffee class, if compared of each spatial analysis inputs, the slope layer can be detected highest classification error of tea area is 17.0%, about 1090 ha. Almost this area located in the high mountain, and in fact that area is the open forest and shrub class (Figure 3: row: g, b). NDVI can be detected tea classification error about 11.8% of total tea area (Figure 3, row: c) and the remainder elevation and soil type layers can be detected classification error about 5.7% and 4.3% (Table 2) of total tea area, respectively. The NDVI and slope layers play an important role to remove the erroneously classified results when initial classification was based solely on the DN values from all spectral bands of high resolution remote sensing data. Based on the spatial analysis in the hybrid approach, the coffee and tea plantation area could be reclassified to the annual crops (Table 3). To demonstrate the useful of hybrid approach, the total classification error have been overlaid by the three type forest map in 2010 to assess of the classification error. The statistical results are depicted in the main classification error of coffee and tea class was addressed in protection forest about 50% and 42%, in the agriculture and other land with 45% and 50%, respectively. That is also to consolidate the main with confused occurred perennial crops being un-correctly classified as annual crops and open-forest and shrub (protection forest in three type forest map) when not applied spatial analysis.

So when compare with statistical data (Lam Dong Province Department of Statistics 2010), in 2010 Bảo Lâm district has more than 27,000ha coffee inside about 10% young coffee and 90% mature coffee. The young coffee approximately 2,700ha about 74% area of total coffee classification error (3,616ha), and almost can be detected when applied spatial analysis. Because in the first three years, the coffee plantation still open-canopy (young coffee) and the young coffee area be classified annual crops class. Almost all coffee classification error is young coffee (74%) which was classified erroneously into annual crops.

Table 3: Statistical classification error intersected with three type forest map in 2010 (FIPI)

	Annual crops and other land	Production forest	Protection forest	Total in study area
Classification error of coffee class (ha)	3,179	367	3,492	**7,038**
Classification error of tea class (ha)	998	148	837	**1,983**
Classification error of coffee class (%)	45	5	50	**100**
Classification error of tea class (%)	50	7	42	**100**

Table 4: Accuracy comparisons of classification results when applied or not hybrid approach

Class name	**Not integration of spatial analysis**		**Integration of spatial analysis**	
	PA	**UA**	**PA**	**UA**
Coffee	63	80**	85*	77
Tea	77	67	91*	67
Annual crops and bare land	79*	60	74	78**
Close forest	68	85	68	91**
Open forest and shrub	59*	53	57	64**
Building land	65	68	65	68
Water body	100	84	100	84
Pine forest	86	75	86	75
Overall accuracy	**0.71**		**0.75**	
Kappa	**0.66**		**0.71**	

**Highest scores for producer's accuracy (PA); **Highest scores for user's accuracy (UA)*

4.2 Accuracy Assessment Comparisons

The overall classification accuracy marginally improved when with/without integration of spatial analysis. The highest overall accuracy achieved was 75% and higher than preview research. Overall accuracy increased 4% when applied hybrid approach. The Kappa also increased from 0.66 to 0.71.

User's accuracy (Table 4) indicated that coffee and tea classes have highest accuracy after applied spatial analysis. In addition, both the producer's accuracy of the coffee and tea classes increase, as well as the user's accuracy of annual crops and bare land; open forest and shrub and closed forest area increases suggest that the main confused, occurred perennial crops with annual crops and forest classes when integrated spatial analysis. Almost he user's accuracy of the coffee and tea classes and the producer's accuracy of annual crops and bare land; open forest and shrub and close forest have no change when integrated spatial analysis. So the both overall accuracy and Kappa increase suggest some improvement in coffee and tea crop classification accuracy compared to earlier work and demonstrated the sub-hypothesis 1.2.

5. Conclusions

This research has been the most comprehensive to date to examine the spatial analysis of ancillary data in the hybrid approach that includes the human knowledge of nature and social conditions of perennial crops to improve the classification accuracy of perennial crops (coffee and tea plantation) mapping in the Bảo Lâm district, Lâm Đồng province. Spectral separation between coffee, tea crops and annual crops, shrub and open forest were only moderately successful in the Bảo Lâm district. When applied pixel-based classification method, the classification errors were highest between coffee class with annual crops and tea classes with open forest and shrub class. The overall accuracy, when applied spatial analysis was high that attempted to distinguish coffee and tea crops from open forest, shrub and annual crops. The pixel-classification with all spectral bands of SPOT image had significantly lower classification accuracy compared with applied spatial analysis in the hybrid approach in Bảo Lâm district, Lâm Đồng province.

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