A comparison of Sub-Pixel and maximum likelihood classification of Landsat ETM+ images to detect illegal logging in the Tropical Rain Forest of Berau, East Kalimantan, Indonesia

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Abstract

Selective logging is currently a widely adopted management practice throughout the tropics. Monitoring of spatial extent and intensity of such logging is, therefore, becoming an important issue for sustainable management of forest. In spite of successful use of RS in various field of forestry, detection and quantification of selective logging is still a problem. This study explores the possibility of using various approaches and Landsat-7 ETM+ image for the purpose. Two dataset of Landsat-7 ETM+ acquired on 16 August 2002 and 26 August 2000 of Labanan concession area East Kalimantan, were used. Field data of newly logged points, unlogged forest etc were collected during a fieldwork in September 2002. Maximum likelihood (ML) classification of original dataset of ETM+ 2002 and fused dataset with panchromatic were carried out. Sub-pixel classification approach was also tested. The results showed that the ML classification of fused image and sub-pixel classification approaches were found reasonable with overall accuracy and kappa 84%, 0.75; 86%, 0.71.

1. Introduction

Forests are one of the world's most important renewable natural resources that serve various economical, social and environmental functions. Tropical forest, which comprises 47% of the worlds total forest area, has the highest economic and environmental value. Although, tropical forests have high importance due to its values, they are decreasing quantitatively as well as qualitatively because of various problems. Deforestation and forest degradation have been emerging as more and more important issues of the world's forestry sector. An area of 16.1 million ha of forests was lost every year during the 1990s, of which 15.2 million ha were in the tropics. The continuous depletion of forest resources is not only creating a serious threat to the regular supply of forest products but also resulting in a lot of negative environmental impact e.g. global warming, biodiversity loss etc. However, the world community has already realized the consequences and started to emphasize the sustainability of forest resources. United Nations Conference on Environment and Development (UNCED) held in June 1992 in Rio de Janeiro was the significant milestone in this regard.

Indonesia is rich in its forest resources. About 60% of country's total land area is covered by forest representing approximately 10% of the world's total tropical forest area. Timber has been an important source of national income since commercial logging started in the early 1960s. Concession holders carry out most of the management and harvesting activities. Selective Cutting and Planting (TPTI) is the commonly used silvicultural system in natural production forests of Indonesia. A series of activities has been established by the national guidelines for the implementation of the system to achieve the goal of sustainable forest management.

But, there are a lot of problems toward achieving the goal of sustainable forest management in Indonesia. Massive deforestation due to transmigration and illegal felling is one of the big problems. It has been estimated that about 50% of Indonesian total timber production comes from illegal means. The situation is worsening these days due to the change arising from the economic crisis, a decline in law and order, legal change arising from a movement calling for democracy, reform and change (popularly known as *reformasi* locally) and new decentralization law. The new laws have empowered the district government to issue the small forest concession and even to collect some revenue on their own decision

The importance of remote sensing to generate information for forest management has been widely recognized. It is the only way to acquire repetitive biophysical data for large geographic area at reasonable cost, accuracy and effort

Many studies have been carried out on the use of RS products to detect tropical deforestation. These studies mainly concentrated with land cover change from forest to non-forest etc and have been proved very useful for that purpose. But the possibility of using RS data to detect selective logging is poorly studied. As the selective felling is the adopted silvicultural practice of the Indonesian Forest Management System, only land cover change does not fully support the detection of spatial extent and intensity of such logging. In addition, Illegal loggers, who are only interested with timber quality and easy accessibility, generally carry out the selective logging. Though, it is clear that the selectively logged points become similar to other area in short period of time due to the fast growing nature of tropical forest it should be quite different for some period as felling of single tree creates an average of about 400 m^2 of opening in such forest. Therefore, there is a possibility of detecting such newly logged points using medium resolution image data. In addition, integration of some geographic information system (GIS) operation with remote sensing data can strengthen the analysis. For example, the location of road is quite important for planned as well as unplanned, legal or illegal logging. Whatever be the methods, there is no doubt that if such selectively logged points can be identified with known level of error, it will be quite useful to support SFM certification, to monitor illegal logging and to take rehabilitation measures.

The objective of this research was to compare the ability of Sub-pixel Classifier and the traditional Maximum Likelihood Classifier in detecting tropical deforestation in form of selective illegal logging in Labanan Forest, East Kalimantan, Indonesia.

2. Study Area

The Labanan forest concession area is found in East Kalimantan, which is an Indonesian province, located in the eastern part of the Island of Borneo (Figure 1). The entire concession area covers 83,240 ha of which 54,567 ha is under fixed production, 26,997 ha under limited production and 1,676 ha has been used for other purpose such as transmigration, camping for logging and cruising crews, settlement and agriculture (Fakul tas kehutanan, 2000) cited from Dahal (2002). The area receives 1500-3000 mm rainfall per year. The forest of the Labanan area is known as lowland mixed *Dipterocarp* forest, because the family *Dipterocarpaceae* is dominant.

PT. Inhutani I, a state owned forest concession company manages this concession area. The adopted silvicultural system for the management of the forest in the area is known selective cutting and planting (TPTI). According to the national guidelines, an average of 8 trees per hectare are logged at 35 years interval (Charls, 1996; Sist *et al.*, 2003). Based on this management system, the Labanan concession area has been divided in to seven compartments (known as RKL: Recana Karya Limathahum locally). Each RKL has been further subdivided in to five annual coups and logging has been taking place progressively since 1976. At present, the logging has been going on in RKL six. According to the plan available in concession office, RKL seven is still in un-logged condition and the end of the first felling cycle will be reached in 2011, when logging will be carried out in the last i.e. 35th coup of RKL seven. Figure 2 shows the five-year working plan (RKL) map of the study area.

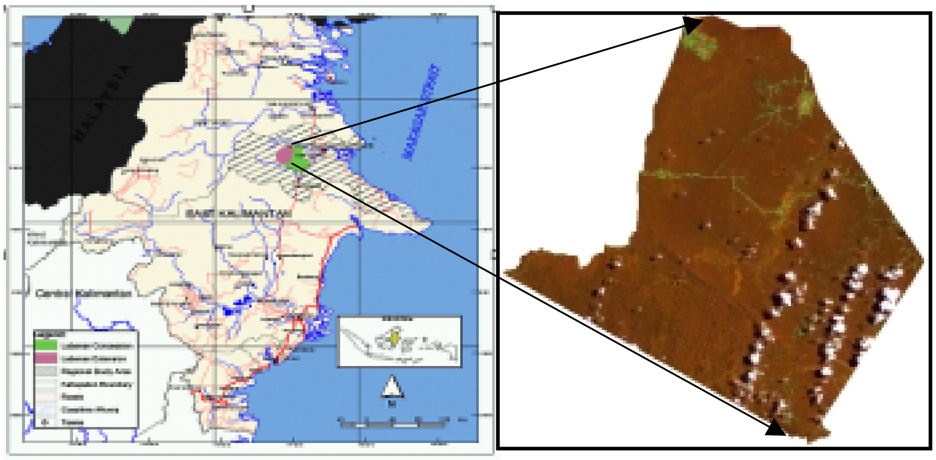


Figure 1. Location of the study area

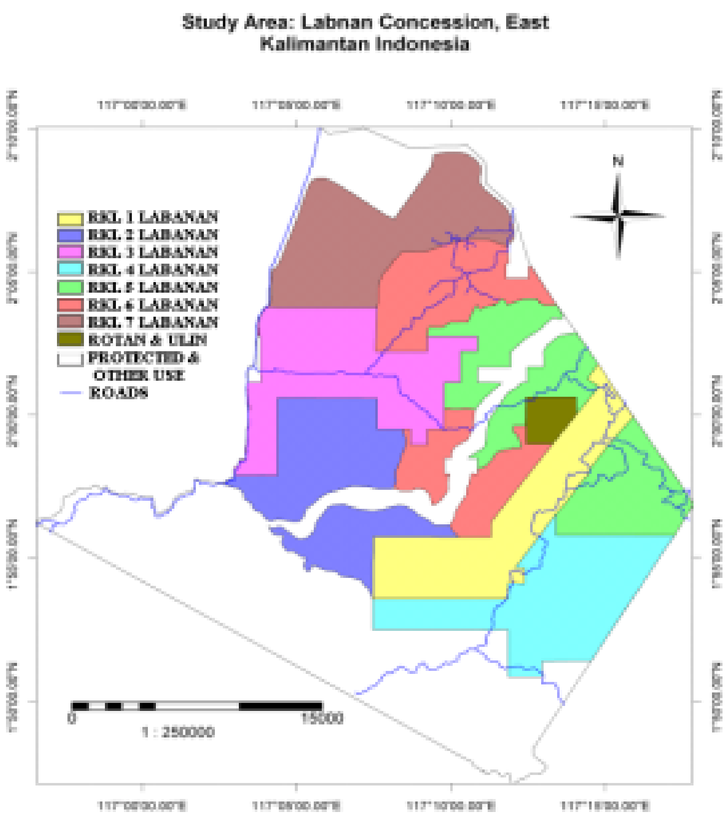


Figure 2. Map of study area's five-year working plan (RKL)

3. Methodology

Research methodology was done in three stages namely: pre-fieldwork stage, fieldwork stage and post-fieldwork stage. Figure 3 shows the detailed methodology of this research.

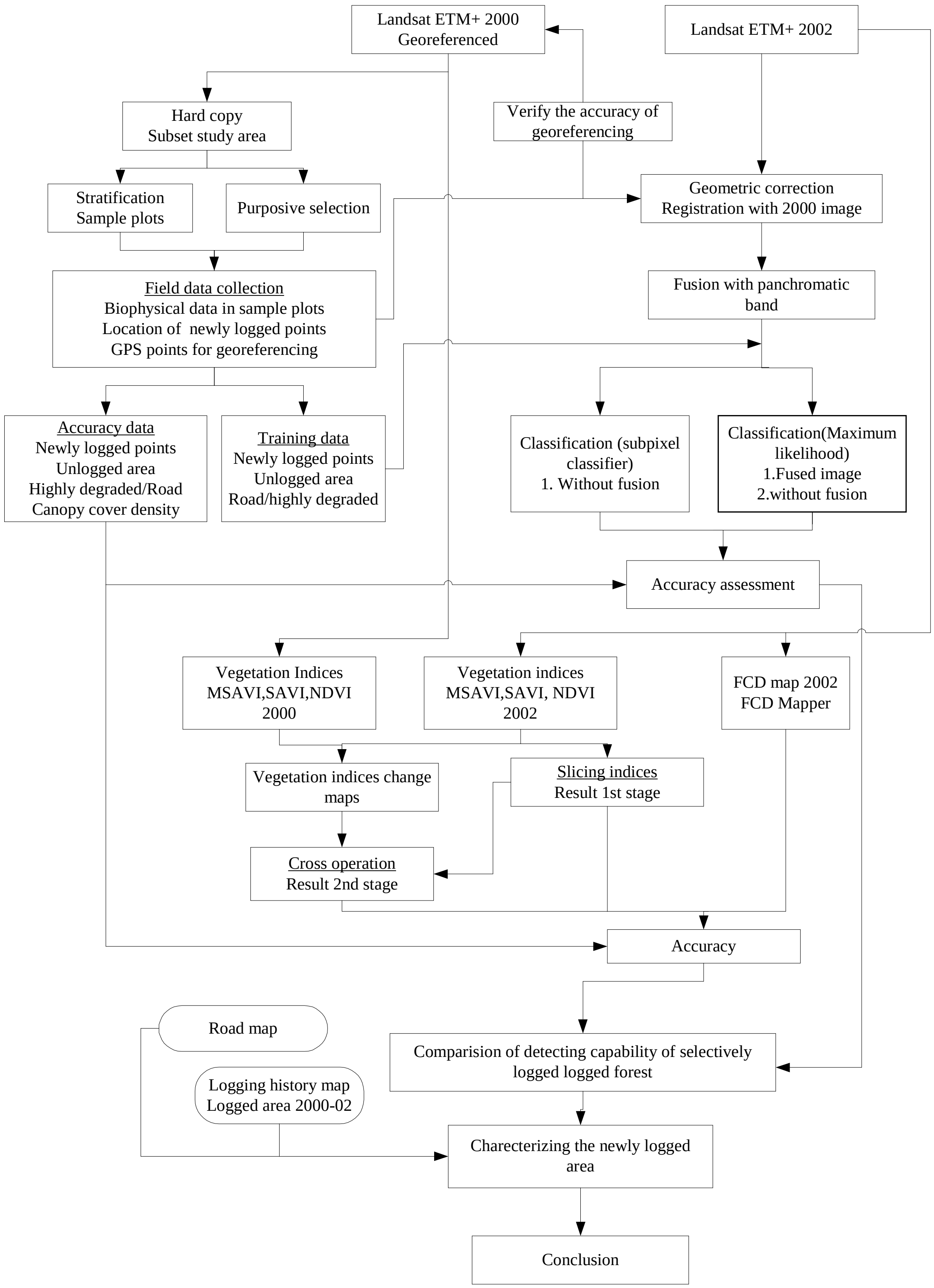


Figure 3. Flowchart showing research procedure.

4. Results and Discussions

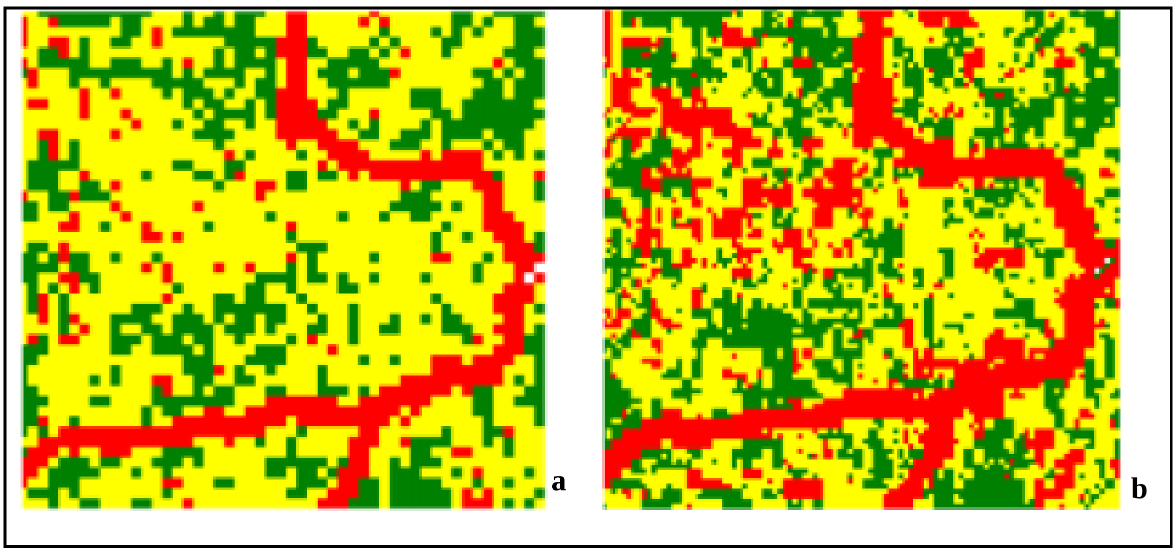
4.1 Maximum Likelihood Classification

The classification of Landsat-7 ETM+ 2002 image using maximum likelihood classifier showed that the method is not able to well differentiate the selectively logged points from un-logged area. However, the fused data set of panchromatic band with multispectral showed that the differentiation becomes better. Both The qualitative and quantitative assessment of the classified maps shows that the result of the fused image is much better than its un-fused counterpart.

It can be noted from Figure 5 that the transmigration area of the upper left corner of the map has been clearly classified as the highly degraded category from the fused image but it has been mixed with newly logged points in case of un-fused image. Similarly, the superiority of the result from fused image can also be seen in Figure 4. The figure shows a part of RKL 6 where the official logging is presently going on. It can be seen that most of the area in the case of un-fused image has been classified as NLP whereas the result from fused image differentiate three different classes more clearly. The latter situation can be considered more natural because some area can become more degraded due to log skidding etc and some area can remain intact, as the selective logging is not always evenly distributed.

Figure 6 shows the result of quantitative evaluation. The overall accuracy as well as kappa was found much higher in case of fused image. The overall accuracy of un-fused image was 72% and kappa 0.56 whereas it was 84% and 0.75 in the case of fused image. As the main objective was to assess the capability of detecting newly logged areas, the class mapping accuracy of NLP was also calculated. The class mapping accuracy of NLP was found 74% in case of fused image but it was only 47% without fusion. It shows that the relatively higher overall accuracy of un-fused image was due to its comparatively better performance in other class i.e. un-logged and road/ highly degraded. Moreover, the much higher kappa shows the benefit of fused image to detect selective logging as the kappa is the better tool for comparing two methods of map preparation (Skidmore, 1999). The z test for kappa confirmed that difference in result of these two techniques is highly significant (z =20.5, p =0.00).

Figure 4. Part of RKL6 showing the classification result of un-fused (a) and fused (b).



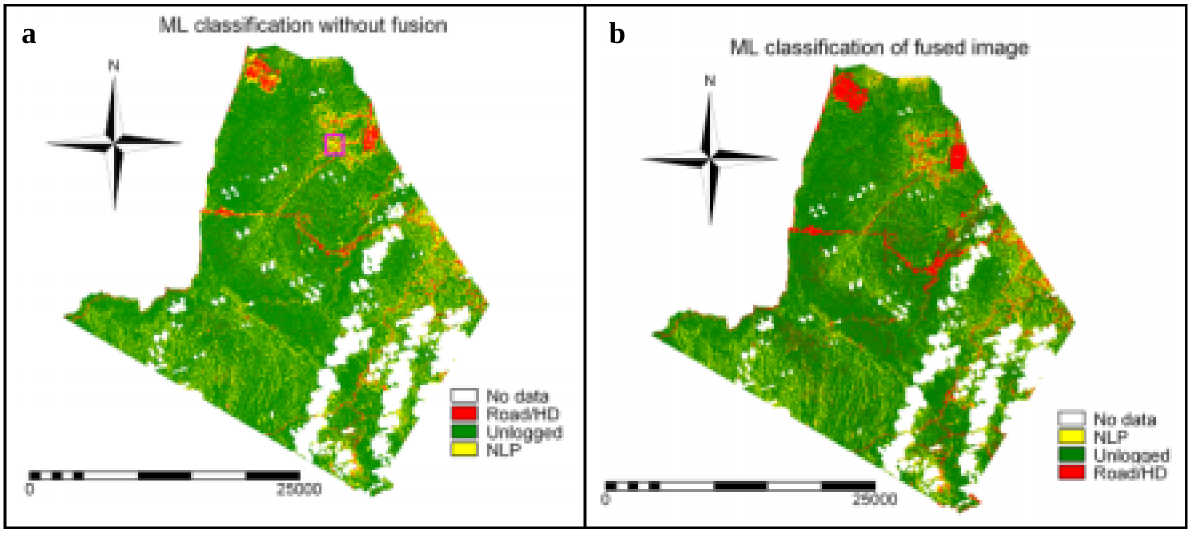


Figure 5. Classified maps using maximum likelihood classifier from unfused (a) and from fused image (b).

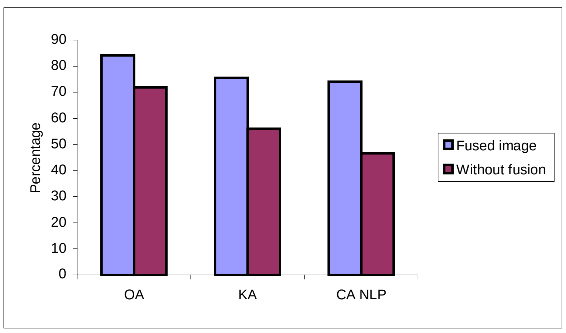


Figure 6. Comparison of accuracies between maps produced from fused image and without fusion. OA= Overall accuracy, KA= Kappa and CA NLP= Class accuracy of Newly logged points.

4.2 Sub-pixel Classification

Figure 7.a shows the typical result of the sub-pixel classification. Eight different MOI, which is the Materials Of Interest, (MOI here is newly logged points) fractions that can be seen ranging from 0.2 to 1. As discussed in methods earlier, the mean MOI fraction for signature was selected 0.21 that means the disturbance due to logging (opening etc) was considered 21% of the area of a pixel. Therefore, the lower class of MOI fraction could be natural opening and simple other disturbances but not logged points. That's why, only the area classified as 0.8 or higher MOI fraction was considered as newly logged points. Figure 7.b shows the result of newly logged area after considering that criterion.

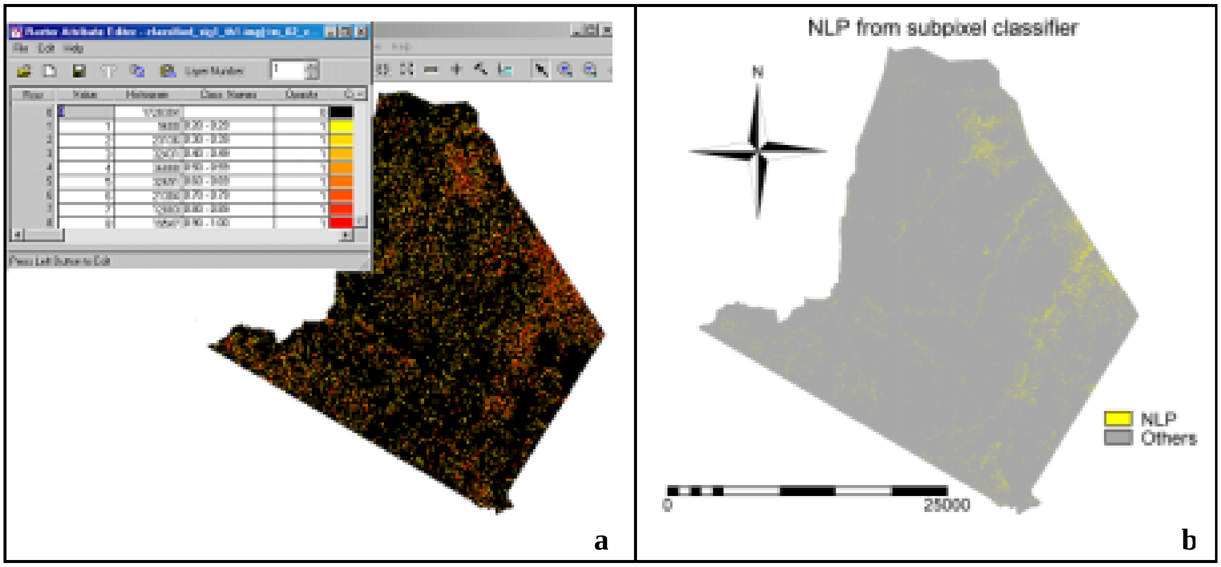


Figure 7. The result of sub-pixel classification with different fraction of MOI (a) and NLP after considering area with 0.8 or more as NLP (b).

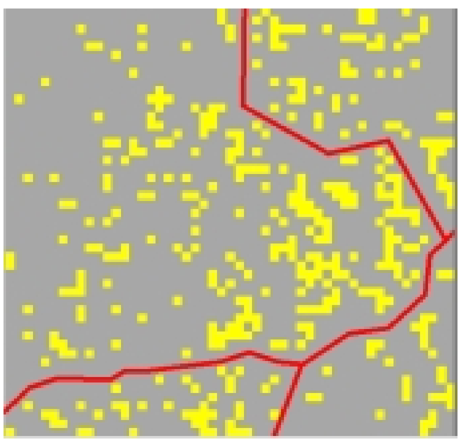


Figure 8 shows the result of sub-pixel classifier of the same area as shown in Figure 4 overlaying road on it. It is not an easy comparison with previous figure as it has only two classes i.e. the road/highly degraded and un-logged have been merged as others. But, careful observation can conclude that relatively less area was classified as NLP than in case of ML classifiers.

Figure 8. Part of RKL6 showing NLP

Although it is not directly comparable, the overall accuracy of this procedure was 86% a bit higher than ML with fused image. The average user's and producer's accuracy of this procedure was found 87% and 84% respectively. But, the kappa and class mapping accuracy of NLP was found 0.71 and 0.69 a bit lower that the ML method. The significance of the differences could not be tested, as they don't have similar classes.

4.3 Performance of Fused Image and Maximum Likelihood Classification

As anticipated, the ML classification result from fused image was found better than classification of un-fused ETM bands. The significantly better result in terms of overall accuracy kappa and class mapping accuracy of NLP shows the usefulness of fusion of ETM+ panchromatic bands with multispectral bands. It is obvious that the main reason of better accuracy is the high spatial resolution of panchromatic image. In this particular case of selective logging, a felling of a single tree can create the canopy disturbance of whole pixel area (225 m^2) of ETM+ pan image. Certainly, it is not the case in multispectral bands of same image where it is expected as mixed pixel in most of the cases. Due to the mixed effect, the reflectance in multispectral bands will not be much different than the surrounding un-logged forest. Therefore, the merging of the panchromatic band will create more variation between those two classes and ultimately can give the good classification result.

Many authors have successfully used different data type and various fusion techniques for different purpose such as image sharpening, feature enhancement, improve classification result etc (Pohl & Van Genderen, 1998). Hussin and Shaker(1996) used radar image to fuse with TM image and get better visual interpretation as well as classification result. Munechika *et al*. (1993) have also reported the improvement in classification accuracy after merging TM multispectral and SPOT PAN image. Those finding supports the better classification accuracy of fused image though the data type and merging techniques were different in either case. But few researchers also reported some disagreement about the superiority of fused image over original dataset for the classification purpose. Shaban & Dikshit (2002) have reported significantly lower classification accuracy from merged data of SPOT XS and PAN as compared to original data in an urban area. They have pointed the high heterogeneity of urban area as a reason of poor result of merged data as an agreement with van der Meer (1997). Talking mainly about visual interpretation, however van der Meer (1997) has suggested that image fusion will be more successful with spatially homogeneous data means where there is no spatial dependence.

It can be noted from the view of different authors (Zhang, 1999; Zhou *et al.*, 1998) that the result of fused data depend on various factors such as data type, merging techniques and purpose of using. As the ETM panchromatic data is relatively new, very few work have been reported about merging of these data. Therefore, to find the reference of similar data type and merging method for similar purpose is not easier. However, Hung *et al*. (2002) used fused ETM+ PAN and multispectral data and found better classification result in some geological study. One obvious benefit of merging ETM+ PAN and multispectral data is temporal consistency as both images are acquired at simultaneously, which is hardly the case of multisensor data fusion.

The logging points can be considered as objects with no spatial dependence though there might be little affect of road. So we can consider the findings of this study is in agreement with the observation of van der Meer (1997) in that sense.

4.4 Performance of Sub-pixel Classification

The qualitative and quantitative analysis of classification result of sub-pixel classifier showed that the method is useful to detect the recent selective logging. The almost similar value of kappa and class mapping accuracy of NLP ≈ 0.7 proved that the method can be considered fairly good for this purpose. In qualitative terms also the more NLP has been detected in reasonable area such as near to road and the official logging area. However, the concept and software both are relatively new and very little reference could be found to compare the result as well as method used in this study.

The sub-pixel classifier has been reported as a specialized tool suitable to get greater precision from medium resolution data as Landsat-7 TM than generally provided by whole pixel approach (Flanagan & Civco, 2001). As the canopy disturbance in case of selective logging is generally in sub-pixel level, this approach was considered suitable for the purpose. But it was realized during the study that the process is not straightforward and many issues such as MOI, its fraction and signature etc. should be considered seriously to use and interpret the result.

Conceptually, sub-pixel classifier considers each pixel of the image as linearly additive combination of optically thick materials and the signature spectrum as the spectrum from a pixel entirely covered by the MOI (Huguenin *et al*., 1997). Therefore, the reflectance of the logged pixel is the combination of reflectance of remaining trees and the materials beneath the gap. Though our MOI is canopy gap, which is in itself not responsible for the reflectance. So, the whole pixel MOI situation could be fully bare soil or almost full ground vegetation or a combination of different materials, which certainly don't have similar reflectance. It means that the whole pixel MOI situation in this case is more abstract and we cannot use whole pixel situation to train the classifier, though it could be a better option in case of other MOI. In this case, therefore, signature was generated through automatic option using the mixed pixel situation. The signature should represent the pixel with no tree but similar ground situation as it was in case of those logged points used as training set. Therefore, the possibility of misclassifying the logged points with very much different ground situation than the average situation of training pixels cannot be ignored.

The realization of MOI fraction during signature evaluation is also important issue. MOI fraction is the only factors we can realize except SEP value calculated by classifier to select the final signature from suggested five signatures. Considering the similar ground situation the canopy gap was considered as MOI as mentioned above. The best signature suggested by classifier with lowest SEP with 0.21 MOI mean fraction was accepted as realistic assuming logging of a tree per pixel. It means that our MOI cover only 21% of the area of pixels in average. So the signature will not represent the situation of removal of many trees in one pixel.

Huguenin *et al*. (1997) used only the presence and absence of MOI in the pixel for accuracy assessment of the classification of Bald Cypress and Tupelo Gum trees. But in this case, it wouldn't be logical to consider the presence and absence of MOI as we cannot consider very small canopy gap as a logged points. Therefore, to decide on the actual logging points only the pixels with MOI fraction greater than 0.8 were considered. The threshold 0.8 was selected in the iterative way checking the accuracy including different level of MOI fraction.

In spite of few mentioned difficulties, the method provides a useful way of detecting logged points. This process also supports creating family of signature to classify the MOI. If it would be possible to make separate signature from the pixels where more trees were logged, the result could have been better. Due to the lack of sufficient knowledge on this procedure prior to the fieldwork, the collected data were not supportive to create such signature. In short, it can be said that there are still more probabilities of improving the result.

5. Conclusions

- The poor accuracy of the ML classification of Landsat-7 ETM+ image shows that the method is not useful to detect selective logging.
- The fusion of panchromatic band with multispectral bands produces much better result to detect the selective logging. Different methods of fusion could be useful but forward reverse principle component substitution is one of the methods that can be used to fuse the image for this purpose.
- The sub-pixel classifier gives better result than ML classifier in the case of un-fused image. But the result of fused image from ML classifier showed almost similar accuracy with sub-pixel result. However the qualitative evaluation of results and possibilities of improvement suggest sub-pixel classifier may perform better.

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