MAPPING NATURAL FOREST BY LANDSAT MULTITEMPORAL IMAGE DATA – CASE STUDY IN KON TUM PROVINCE OF VIETNAM

Nguyen Dinh Duong

Institute of Geography, Vietnam Academy of Science and Technology, 18 Hoang Quoc Viet, Cau Giay, Hanoi, Vietnam
Email: duong.nguyen2007@gmail.com

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ABSTRACT: Natural forest is a basic component of earth ecology and essential for biodiversity and environmental protection. Globally, natural forest is gradually reduced due to timber logging, conversion to cropland, production forest, commodity trees, and infrastructure development. Monitoring natural forest cover change, therefore, is an urgent need for sustainable development, watershed management, and climate change study, particularly, estimation of carbon emissions. Inventory of natural forest, however, still contains considerable uncertainty. At regional levels, forest cover estimates derived by aggregation of national forest data are often affected by incompatibilities of the individual inventory methodologies, definitions and inventory dates. There is notable variability between forest change estimates also at national levels. In this study, a new method for mapping of natural forest by Landsat multitemporal image data is presented. Landsat image data covering province Kon Tum of Vietnam since 1989 to 2018 were used to map natural forest cover. Natural forest is assumed as forest cover which is not disturbed during the course of 30 years. More than 2000 Landsat scenes of sensors TM, ETM+ and OLI were used for automated classification with land cover categories: Cloud, cloud shadow, water, wetland, closed forest, open forest, and area of intense human activities. The study showed that natural forest reduces from 848,307 ha in 1989 to 424,388 ha in 2018. On average, deforestation rate is about 1.7 % annually. The proposed method for mapping natural forest is stable, independent and uniform for natural forest inventory in large areas. The advantage of the newly proposed method is that it provides not only statistic data, but also spatiotemporal patterns on how the natural forest was reduced across time.

1. INTRODUCTION

Natural forest is important for biodiversity and environmental protection as well as for socio-economy and the living conditions of forest-dependent populations (Stibig et al., 2014). Tropical forest of Southeast Asia consists of about 15 % of the world's tropical forest (FAO, 1995). The United Nations Food and Agriculture Organization (FAO) reported a net annual forest area loss in Southeast Asia of 2.4 Mha in the 1990s, and then of 0.4 Mha and 1.0 Mha for the periods 2000–2005 and 2005–2010, respectively (FAO, 2010). The estimates of forest provided by FAO includes both natural forests and man-made forests. At regional levels, forest cover estimates derived by aggregation of national forest data are often affected by incompatibilities of the individual inventory methodologies, definitions and inventory dates. There is notable variability between forest change estimates also at national levels (FAO, 2010).

Remote sensing data was used for forest mapping since the beginning. Many classifiers from statistical-based algorithms - e.g., cluster analysis, maximum likelihood classifier (MLC) - to machine learning algorithms - e.g., decision tree (DT), artificial neural networks (ANN), vector-support machine (SVM), expert rules-based approach, and random forest (RF) - have been used for land-cover classification based on high spatial resolution imagery. Previous research implies that the choice of the best classifiers depends mainly on the specific study area, data, and land-cover classification system (Xie et al., 2019). However, none of them reports on ability to separate natural forests from man-made ones. Forest cover estimations reported by FAO once every 5 years are

based on national reports where natural forests are mixed up with man-made ones.

Due to high values of natural forests versus man-made forests from environment protection and biodiversity points of view, there is an urgent need to develop methods for uniform and independent mapping natural forests. In this study, a new method for mapping of natural forest by Landsat multitemporal image data is presented. Landsat image data covering province Kon Tum of Vietnam since 1989 to 2018 were used to map natural forest cover. Natural forest is assumed as forest cover, which is not disturbed during the course of 30 years. More than 2000 Landsat scenes of sensors TM, ETM+ and OLI were used for automated classification with land cover categories: Cloud, cloud shadow, water, wetland, closed forest, open forest, and area of intense human activities. The study showed that natural forest reduces from 848,307 ha in 1989 to 424,388 ha in 2018. On average, deforestation rate is about 1.7 % annually. The proposed method for mapping natural forest is stable, independent and uniform for natural forest inventory in large areas. The advantage of the newly proposed method is that it provides not only statistic data, but also spatiotemporal patterns on how the natural forest was reduced across time.

2. MATERIALS AND METHOD

2.1 Study Site

Kon Tum province is one of provinces of Vietnam belonging to the famous geographical area: Tay Nguyen highland plateau of Vietnam near the border of Laos and Cambodia. Kon Tum has two distinct seasons: dry and rainy. The rainy season starts in May and ends in October. The dry season lasts from November to April annually. The Kon Tum province is covered by three Landsat scenes with paths number 124 and 125 and rows number 49 and 50 (Figure 1). Due to influences of monsoon climate there is low opportunity to obtain cloud free image, especially during rainy season. Prevalent vegetation cover of Kon Tum is evergreen. However, there are also deciduous broad-leaved forests that lose their leaves during dry season.

2.2 Landsat Image Data

To classify natural forest we collected all available Landsat image data for Kon Tum. Natural forest can be differentiated from man-made vegetation by some techniques. In this study, nevertheless, we develop a new method based on an assumtion that natural forest is contiguous forests, which remain undisturbed in long period exceeding life cycle of planted vegetation (perennial trees or planted forest). For application of Landsat image data, we set undisturbed period to 30 years.

Total number of collected Landsat scenes covering Kon Tum from 1988 to 2018 is estimated about 3000. However, after elimination of scenes with high cloud contamination, errors in geolocation and signal noises, number of scenes used for this study is reduced to about 300. Level processing of image data was Landsat Collection 1 level-1.

2.3 Methods

The goal of our proposed procedure for natural forest mapping is to detect contiguous forest, which is undisturbed during period from 1985 to 2018. Long time undisturbed forest could be considered as natural one. This concept requires classification of study area to at least two classes: natural forest and non-natural forest areas. The procedure, therefore, is broken down to two major steps: classification of land cover and accumulation of bare land areas across time. We assume that natural forest changes are, in general, caused by human activities in form of timber logging or conversion to agricultural cultivation or developed land. Selective timber logging convers closed to open forest while clear cutting or conversion of forest land to other land use forms always experiencing a moments when forest land changed to bare land. Hence, detection of bare land is one of steps for classification of non-natural forest areas.

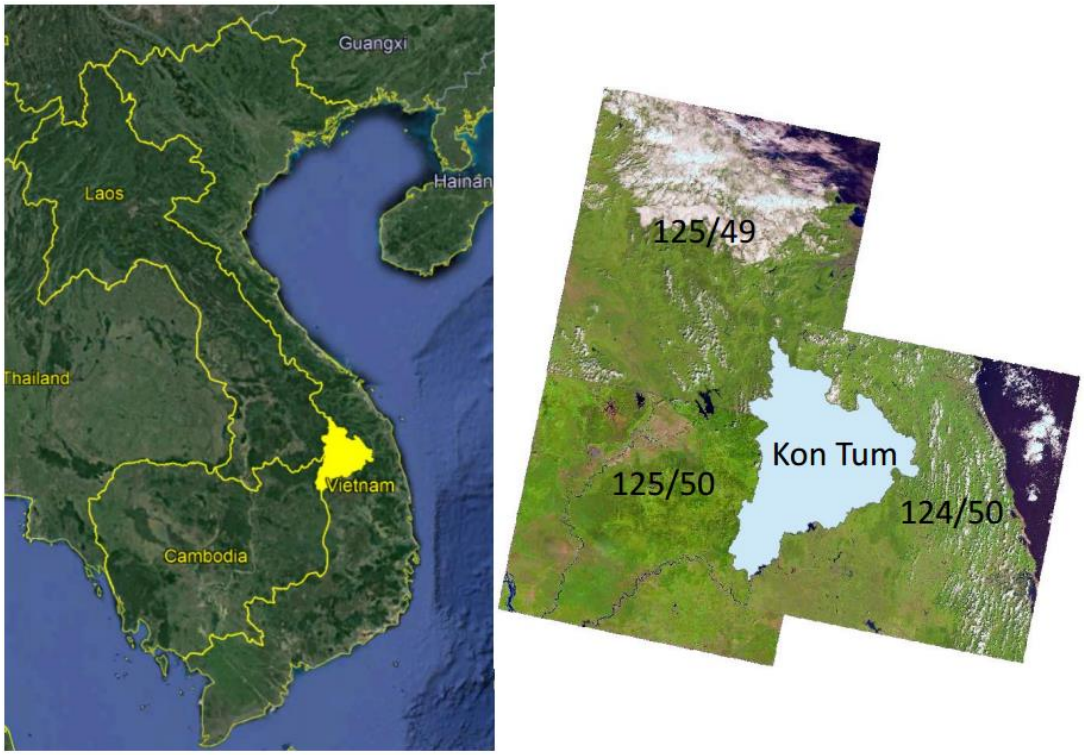

Figure 1. Location of the study area

2.3.1 Automated classification of land cover

We applied algorithm for automated classification of land cover for classification of all Landsat image data from 1985 to 2018. The algorithm for automated classification of land cover is based on application of simplified spectral pattern (SSP) concept. Every land cover type is characterized by spectral patterns that are constructed by using the six values of reflective spectral bands of Landsat image data. An SSP is a transformation of the full spectral pattern into a simplified digital form, which allows direct incorporation of the spectral pattern into the classification. The SSP is constructed by non-repetitive pairwise comparison of reflectance values between two bands. The construction of SSPs for a given image is performed for pixels that have valid digital numbers without saturated values (Duong, 2016; Duong et al., 2017). To perform an automated classification of land cover using Landsat TOA reflectance, we first developed an SSP database for various land cover types. Development of the SSP database was realized by interactive visual inspection using a special software tool. A pixel of water area was selected for SSP construction and the remaining pixels in the image with similar SSPs were rendered by a given color. If the SSP being assessed accurately depicts a land cover, it is added to the SSP database.

2.3.2 Detection of area of intense human activities

We define area of intense human activities as a forested area, which was converted one time to bare land. Bare land is a signal of human activities in forested area where forest is cut and the land is converted to agricultural cultivation or forest plantation. To record the change of forest to bare land we accumulate occurrence of bare land in any time and mark the pixel as bare land. Any change of bare land pixel back to forest pixel (forest plantation) is ignored because planted forest is actually an area of intense human activities. Figure 2 shows flow chart of algorithm for automated classification land cover and mapping natural forest.

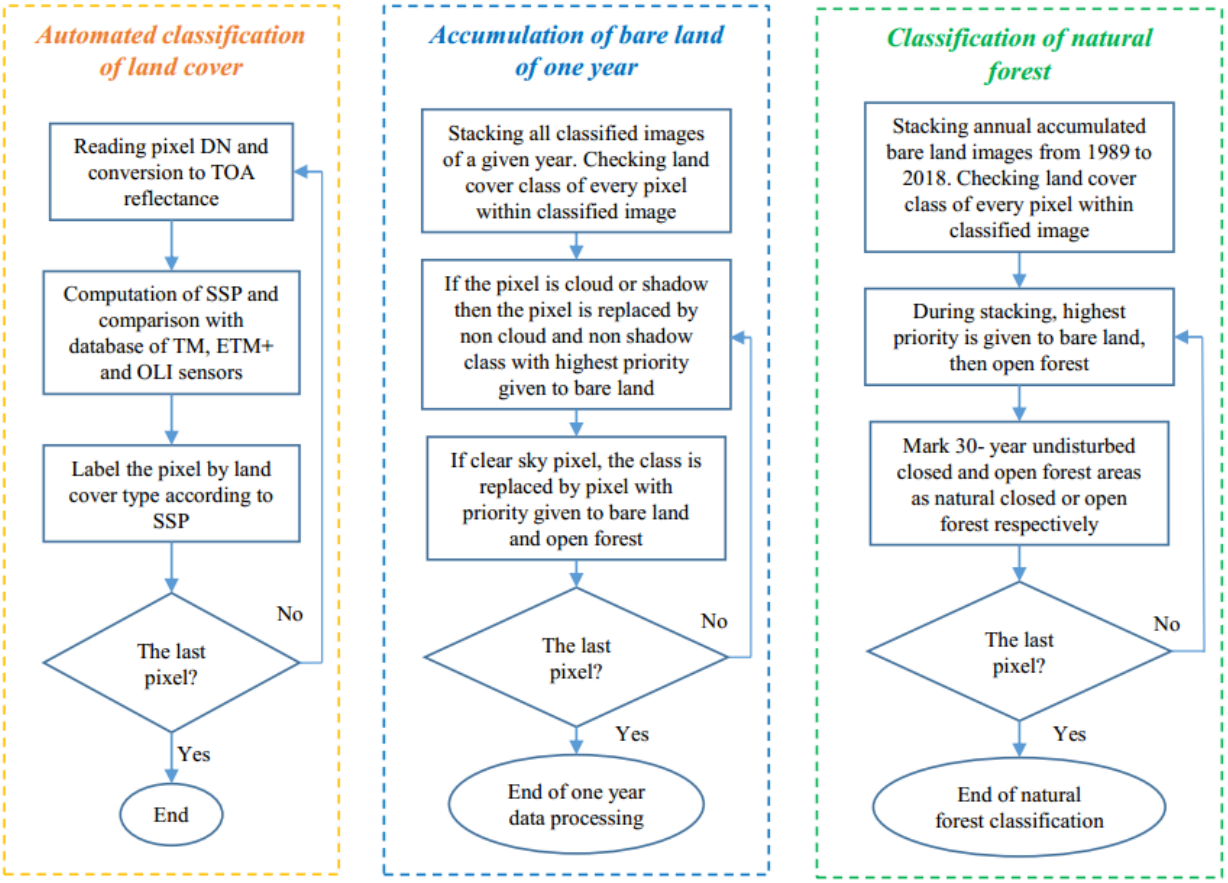

Figure 2. Flow chart of algorithm for automated classification of land cover and natural forest mapping.

3. RESULTS AND DISCUSSION

To map natural forest we used all Landsat image data available on USGS website https://earthexplorer.usgs.gov/ since 1989. By using algorithm described in the previous session, we completed classification of land cover of Kon Tum province and mapped changes of natural forest across time. Figure 3 shows 30-year land cover changes in Kon Tum province. Dark green area is forest, which is undisturbed by human activities. Light green indicates change of natural closed forest to open and orange color stands for area of intensive human activities.

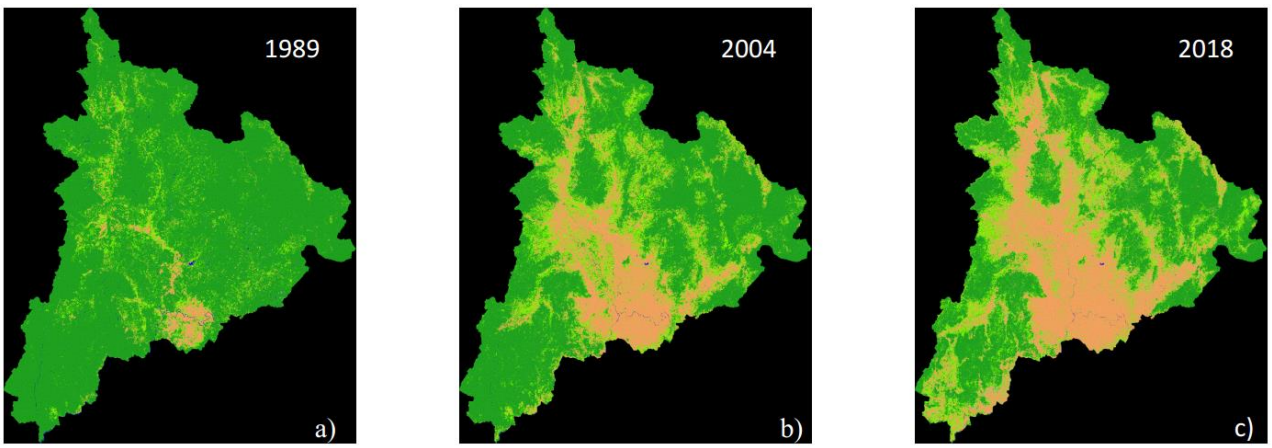

Figure 3. 30-year land cover changes in Kon Tum. Distribution of natural forest and areas of intense human activities of Kon Tum in 1989 a), 2004 b) and 2018 c). Dark green color shows closed natural forest, light green open forest and orange areas of intense human activities.

Figure 4 displays graphical presentation of statistical data derived from classified image and shown in detail in Table 1. After 30 years of development, natural forest was decreased from 848,307 ha in 1989 to 424,388 ha in 2018, equivalent to 50% of loss and 1.7 % annually. Closed forests were changed to either open forest or agricultural cultivation. Figure 4 presents steadily declining trend of closed forests and constantly rising trends of open forests and areas of intense human activities.

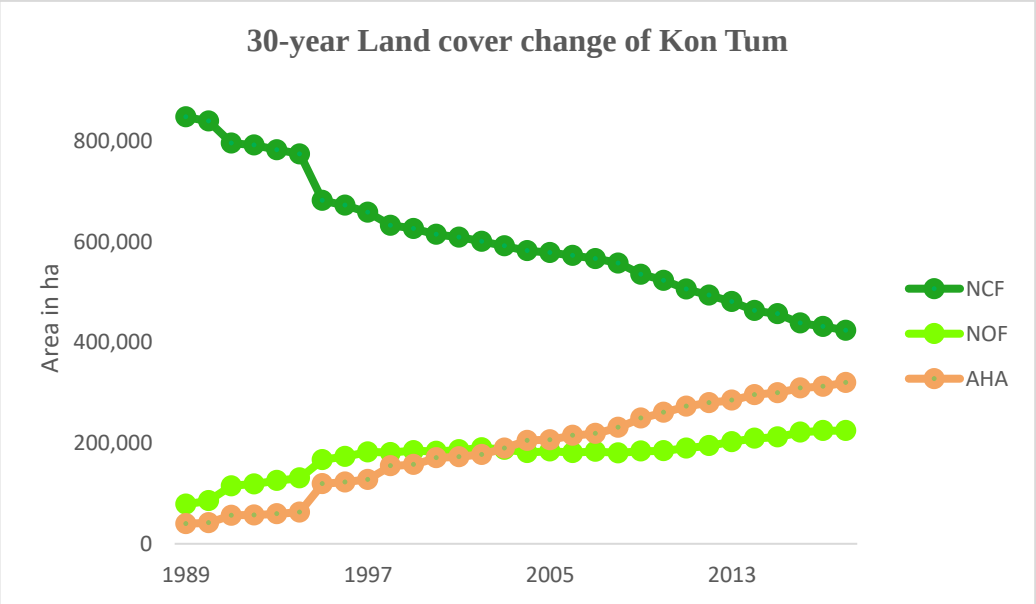

Figure 4. Graphical visualization of changing trends of natural closed forest (NCF), natural open forest (NOF), and areas of intense human activities for years from 1989 to 2018 for Kon Tum province.

Spatiotemporal patterns of closed forest changes reveal a continuity of illegal timber logging that results changes of closed forest to open forests. In 1989 open forests distributed in low land and valleys only (Figure 3a). However, in 2004 and 2018, open forests expanded its presents to all hilly land and low mountain areas. Natural forest remains in 2018 only in high mountains and protected areas (national parks) (Figure 3b and 3c).

Table 1. Areas of natural closed forest (NCF), natural open forest (NOF), and areas of intense human activities for years from 1989 to 2018

Year	*NCF*	*NOF*	*AHA*
1989	848,307	78,629	40,098
1990	840,261	85,397	41,543
1991	796,535	115,044	56,576
1992	792,246	118,874	57,127
1993	783,221	125,635	59,520
1994	774,854	130,697	62,837
1995	682,290	167,152	119,383
1996	672,880	173,361	122,682
1997	658,660	182,531	127,833
1998	633,160	181,256	154,884
1999	626,719	185,245	157,410
2000	615,000	183,459	170,936
2001	609,403	186,827	173,140
2002	601,240	190,531	177,626
2003	591,913	187,528	189,982
2004	582,577	181,383	205,484

2005	578,790	184,001	206,662
2006	572,784	181,281	215,445
2007	566,943	183,479	219,098
2008	557,863	180,554	231,118
2009	535,762	184,081	249,743
2010	523,721	184,883	261,008
2011	506,041	190,279	273,298
2012	494,024	195,118	280,489
2013	481,426	202,790	285,380
2014	463,389	209,729	296,542
2015	457,110	212,241	300,319
2016	438,528	221,778	309,381
2017	431,989	224,829	312,881
2018	424,388	224,963	320,354

4. CONCLUSIONS

Mapping natural forest is very challenge for optical remote sensing if using single date data. This study presents preliminary results on using 30-year Landsat image data to map natural forest. The author selected Kon Tum province of Vietnam for case study. After 30 years of development, Kon Tum lost 50% of natural forest with rate of 1.7% annually. Natural forests were converted to open natural forests due to illegal timber logging, forest plantation, perennial trees, and cropland. Spatial patterns of open natural forests indicate continuous illegal timber logging even in protected areas such as national park. The algorithm presented in this paper requires analysis of large amount of Landsat image data, which can be considered as weakness of the proposed method. Thanks to policy of NASA and USGS on public access to archived Landsat image data, this will not be a problem in coming years. The proposed algorithm formulates a stable, independent and uniform method for natural forest inventory in large areas. The advantage of the newly proposed method is that it provides not only statistical data, but also spatiotemporal patterns showing how the natural forest was being lost across time.

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