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MAPPING DEFORESTATION PATTERNS WITH TIME SERIES MODIS DATA AND BFAST ALGORITHM

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ABSTRACT

Mapping deforestation is a common feature of Remote Sensing and Geographical Information System. However, understanding deforestation pattern (time of occurrence, with dates and sometimes precise time) is a paradigm shift from the usual deforestation mapping. This study uses a web based Earth Observation Monitoring system developed at Friedrich Schiller University, Germany to determine the deforestation pattern. The web-based EOM incorporated the 250 m multi-temporal MODIS NDVI 16-day composite data for temporal analysis using the Breaks For Additive Season and Trend (BFAST) algorithm for the detection of temporal changes (events, trends and phenology metrics). The results of the phenology matrix from MODIS time series reveal significant forest degradation through anthropogenic activities from 2000 to 2014.The spatial and temporal patterns of forest loss detected by MODIS EVI phenelogical metrics (phenometrics) showed acceptable matching with OBIA derived map with accuracies disturbance mapping of 93% and 74% for logging and deforestation through fire respectively.

Keywords: Afromontane forest; Landsat; MODIS; OBIA; BFAST.

INTRODUCTION

The Afromontane forests of Nigeria belong to the ecoregion referred to as the Biafran forests and highlands (BFH) which is part of the West African forest biodiversity hotspot. The ecoregion is recognised for its unique biological and ecological diversity (Bergl *et al* 2007; Cronin *et al* 2014), thus act as a reservoir of genetic diversities. The BFH ecoregion has the highest mean annual rainfall and is known to contain the largest block of contiguous forest in West Africa. The Afromontane ecosystems in Nigeria are situated on a chain of volcanic highlands extending from the North West of Cameroon to the Gulf of Guinea (Bergl *et al*., 2007) with altitude ranging from 600 m to 2430 meters above sea level.

These ecosystems are referred to as cloud montane forest because of their characteristic cloud and mist almost all year round. The ecosystem exhibits a high level of species richness and endemism that transverse many taxa such as vascular Plants, Primates, Amphibian, and Birds. Examples of Afromontane plant endemics within the aforementioned ecosystem include; *Entandrophragma angolense, Lovoa trichilioides, Millettia conraui, Prunus africana* and *Pouteria altissimo* (Chapman *et al* 2004; Chapman and Chapman, 2001), all of which are on the *International Union for Conservation of Nature* (IUCN) red data list. The forests are also rich in mammal species, especially primates, including the Nigerian-Cameroon chimpanzee *Pan troglodytes ellioti,* noted as the most endangered subspecies of chimpanzee in Africa (John, Richard and Joshua, 2004). Several Afro-Palaearctic bird species and IUCN listed endemic bird species have been sighted in the study areas, making it to be designated as important bird areas (IBA) by the World Wildlife Fund. This highly rich ecosystem has been undergoing severe anthropogenic deforestation (Chapman *et al*., 2004; Chapman. and Chapman., 2001) and requires urgent mitigations.

Mitigating the effects of deforestation requires an understanding of the causes of deforestation and its location. Satellite remote sensing provide efficient and cost effective source of conducting, evaluating and monitoring deforestations through change detection studies (Foody, 2002)**.**

It has been suggested that no single change detection technique can be applied with equal success across different ecosystem (Lu *et al*, 2014). Successful land cover change analysis is dependent on the objectives the study and the nature of the landscape chosen for change detection analysis. The Afromontane forest is a heterogeneous ecosystem with rugged and complicated biophysical landscape. This paper therefore presents an integrated change detection assessment of the Afromontane forest ecosystem with the Object based image Analysis (OBIA) and the Breaks For Additive Seasonal and Trend (BFAST) algorithm. The study aimed to quantify the rate of forest changes between the year 1988 and 2014 using decadal Landsat images and also to determine trend of forest changes using MODIS Enhanced Vegetation indices (EVI).

METHODOLOGY

Study area

The study was conducted in the highlands of North East of Nigeria, along the Nigerian-Cameroon border (Longitude 07^{o} 20$^{'}$ N and Latitude 11^{o} 43$^{'}$ E). These highlands are part of the Cameroon volcanic chain of mountains ranging from mount Oku in the north of Cameroon to Bioko in the south. The study area encompasses three contiguous montane forest areas with altitude ranging from 700 m to 2400 m above sea level (asl). The montane forest areas are as follows: the Mambilla Plateau, the Gotel mountains) and the Kurmi Baissa forest (figure 1). These forests are representatives of the sub montane moist broadleaf ecosystem and are highly diverse in both fauna and flora.

There are two distinct seasons, a dry season when there is little or no rain of approximately 6 months and a wet season when it can rain almost every day. The rainy season usually commences from early April until late October with mean annual rainfall of 1780 mm in the Mambilla Plateau but higher in the Gotel mountains. The temperature of the study area rarely exceeds 30°C in the dry season but lower temperature of 9-12 °C in late November to early January.

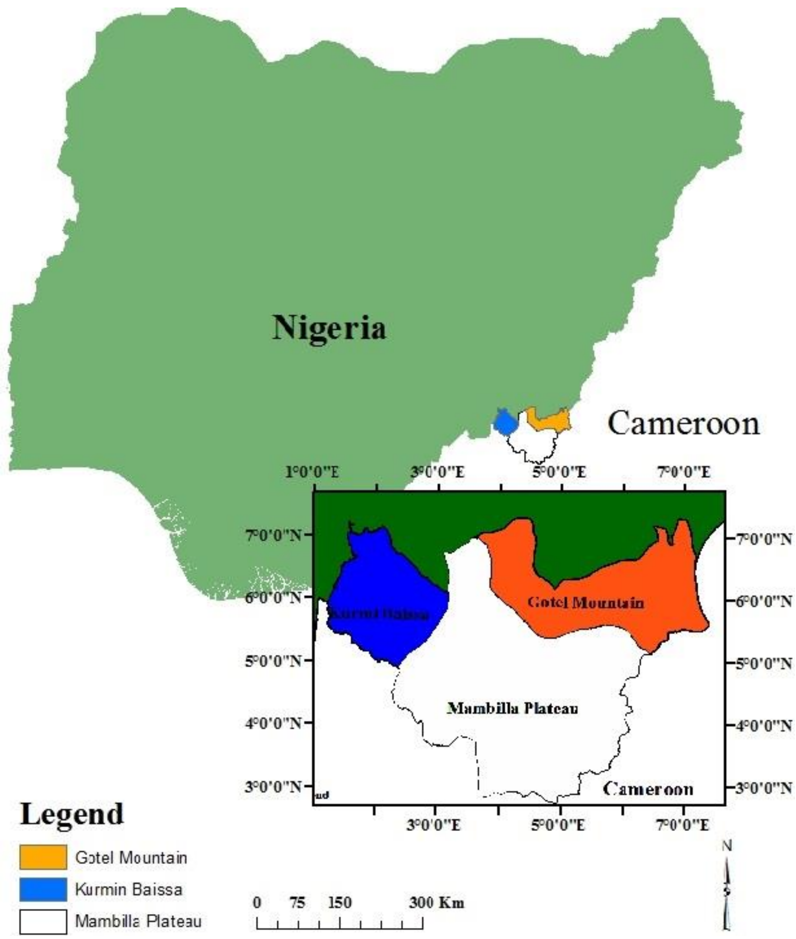

Figure 1. Map of Nigeria showing the study area.

Fig 1: Temporal change detection with MODIS EVI in Earth Observation Monitor tool set

Phenology change detection using time series MODIS data from 2000 to 2014 was carried with Earth Observation Monitor tool set. The Earth Observation Monitor (http://www.earth-observation-monitor.net/map.php) is a web-based service for vegetation monitoring using spatial time series data based on TERRA/AQUA MODIS imagery. The web-based software in an integration of Breaks for Additive Seasonal and Trend (BFAST) algorithm. The BFAST package provides analytical tools for breakpoint detection and derivation of phenology metrics (phenometrics) for vegetation characterization and classification through satellite time-series. The algorithm integrates the decomposition of time-series into trend, season and provides the time and number of changes in the time-series. Thus, it enables the detection of land cover changes through the detection of phenology changes in inter annual time series using the Enhanced Vegetation Index (Jonas *et al*., 2015). The procedure uses an automated processing workflow described below in figure 2.

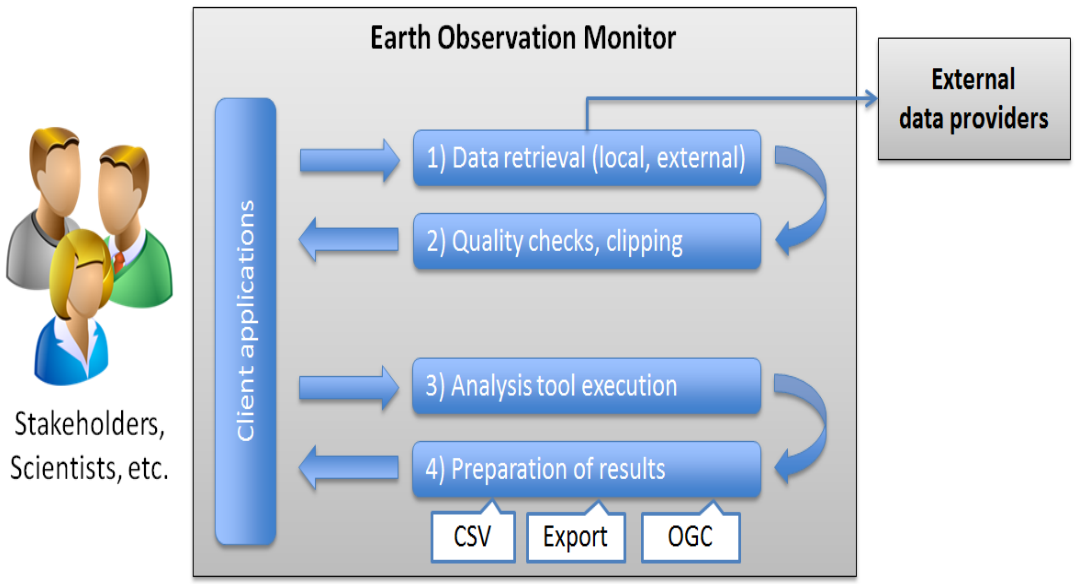

Figure 2: Concept of the Earth Observation Monitor.

Fig 2: Extraction of time series data with a selected polygon

The area of interest (AO) to be analysed for change detection was selected by drawing polygon on the AO (figure 3). Thereafter, MODIS data from 2nd of July 2000 to 31st of March 2014 were retrieved for quality check and analysis.

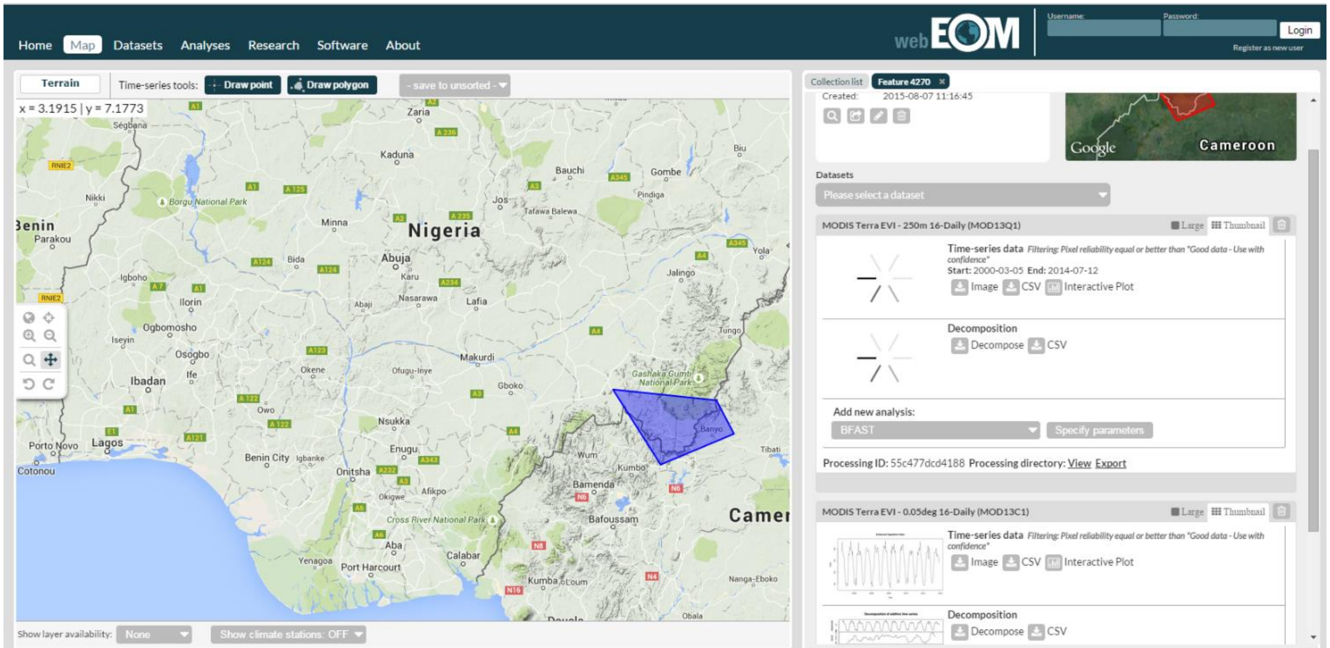

Figure 3: Screenshot of drawn polygon of the study area in the EOM tool set

Data post-processing for quality checks and interpolation

Products from MODIS sensor are always delivered with quality flags so that users can decide which data are good enough for their specific application. For this study, the MODIS Terra EVI 16-daily (MOD13Q1) data were chosen with the quality flag set at good data use with confidence. All selected MODIS Terra EVI data were automatically clipped to the drawn polygon and extracted for analysis.

Data preparation for the individual analysis tool

Before the commencement of the analysis, the BFAST parameter in the EOM tool set was set to harmonic with minimum segment size of 0.15, breaks of 0, maximum iteration and maximum p value of 1.0 each. The minimum segment size is the potential detected breaks in the trend model and is given as the fraction of relative sample size (i.e. the minimum number of observations in each segment divided by the total number of time series). The breaks threshold determines the minimum numbers of breaks phenelogical or phenometrics expected from each analysis. The maximum iteration is the amount of the breakpoints in the seasonal and trend components.

Execution of the analysis tool

The resulting data from the analysis is then exported as a GeoTIff. The GeoTIF output was imported into ArcGIS 9.2 and overlaid with the Landsat change detection maps. Comparative analysis of change and no change carried out on the derived maps from MODIS EVI derived GeoTIF and Landsat change map of c 2011-2014. The classification results were evaluated with independent verification data and were compared in order to examine the contribution of the EVI data to image classification using object-based method with MODIS multi-spectral data.

Temporal pattern change detection with MODIS data

Temporal pattern change detection was conducted using the BFAST phenology matrix derived land-cover changes implemented in the EOM tool set. The areas observed as forest change had breakpoints within the time series components of 2000 to 2014. The phenology matrix breakpoints are indications of inter-annual forest disturbances. Examples of the break points (Figure 4) showing phenological disturbances through forest logging.

For the study area, it was observed that the major causes of deforestation were forest fires arising from illegal grazing and logging. Two spots observed for logging and forest fire were further analyzed with the EOM tool set to determine the dates and pattern of deforestations.

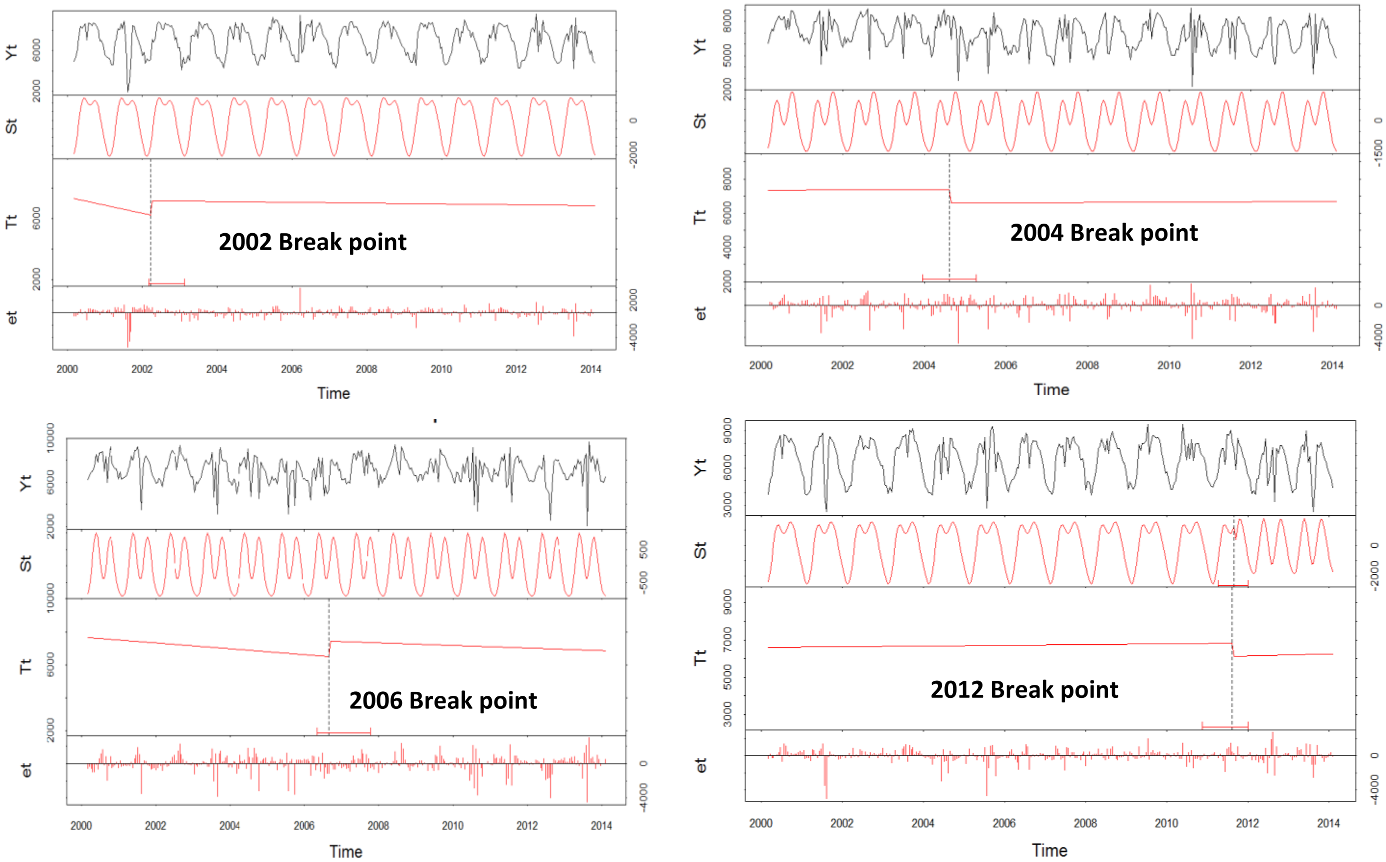

Figure 4: Detected Phenology breakpoint for 2002, 2004, 2006 and 2012

The breakpoints detected by EOM were cross-compared with the Landsat map of 2014 and the High Resolution Global Maps of the 21st Century Forest Cover Change (Hansen *et al.*, 2013). Validation of selected test sites for logging and forest fires (figure 5 and figure 6) was performed by selecting 120 reference points for two test sites. Figure 5 shows that there was good agreement between MODIS and reference local-scale forest disturbances. The legend in figure 5 (left) showed the commencement of deforestation in the test site in the year 2000 but peaked as large contiguous part of the forest was clear felled in 2011 and 2012. Figure 6 also showing the deforestation pattern by forest fires in and around the Gashaka Gumpti National Park. The spatial and temporal patterns of forest loss detected by MODIS time series-based breakpoint detection showed acceptable matching with locally derived reference data. The overall accuracy of disturbance mapping was 93% and 74% for clear cut deforestation and deforestation through fire.

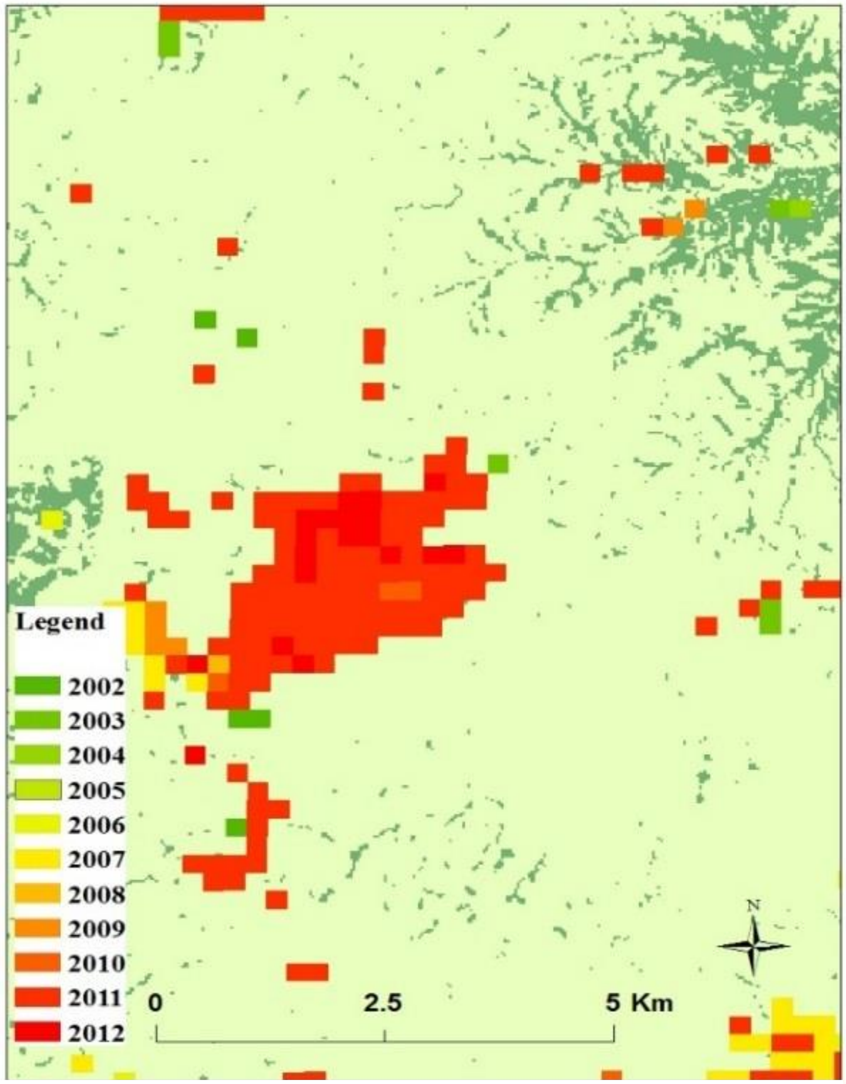

Figure 5: Phenology break points detection for logging near Ngel Nyaki Forest from 2002 to 2012.

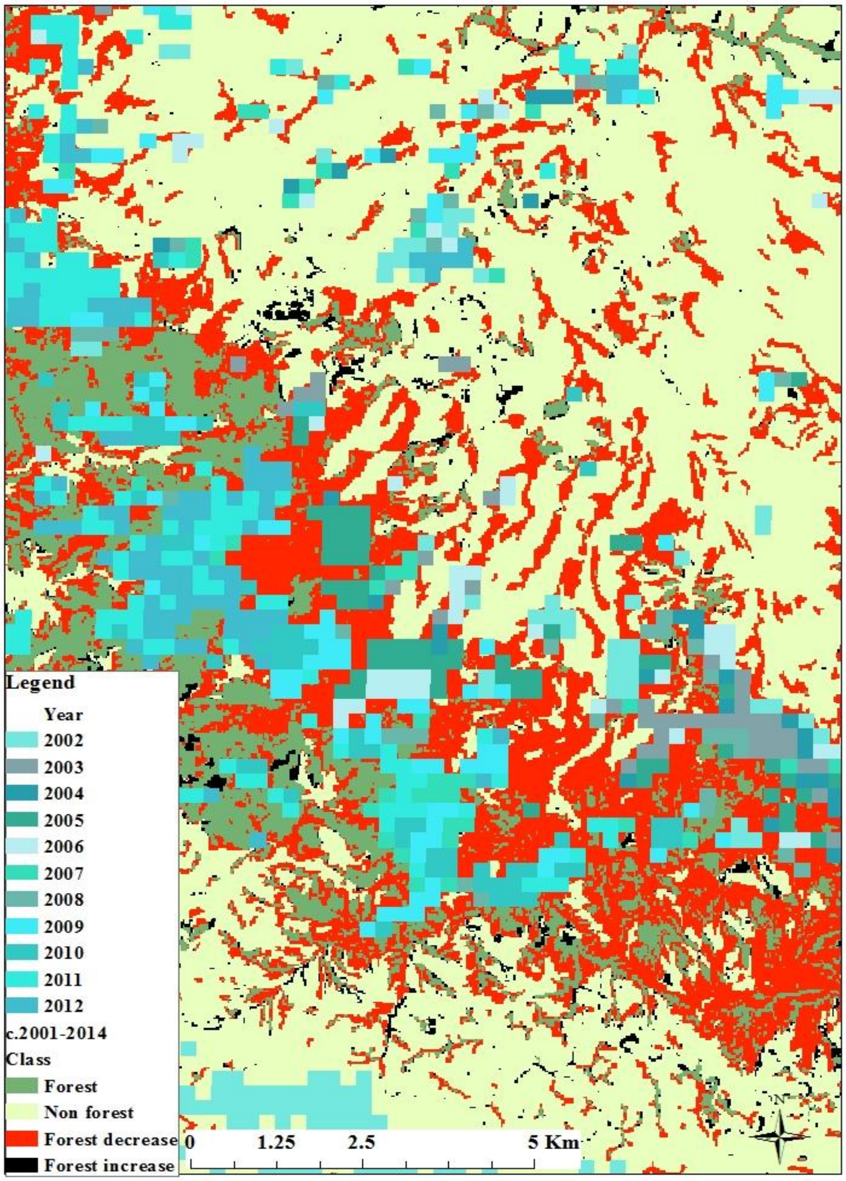

Figure 6: Result of MODIS based BFAST phenometrics overlaid on Landsat change map of 2011-2014 showing the pattern and years of deforestation through seasonal fire.

DISCUSSION

Monitoring heterogeneous ecosystem in the tropics requires a synergy or integration change detection methods to achieve the best possible results. The use of the hybrid technique was critical to the improvement of the derived forest cover change maps, estimated areas of deforestation and also the derivation of deforestation types. The object-based change detection method was fully implemented for the change detection of the study area using decadal Landsat time series for trajectory study. Results from this study were compared with contemporary study by Achard *et al*., (2014); FAO, (2010) and Hansen *et al.*, (2013). Results of the deforestation map was partly consistent with 'the High Resolution Global Maps of the 21st Century Forest Cover Change (Hansen *et al*., 2013). For example, the areas shown as deforested in figure 6 and 7 was found to be same in the "High Resolution Global Maps of 21st Century Forest Cover Change". The only exception to Hansen *et al.*, (2013) map is that the Landsat-8 data used has not been validated, hence biased in capturing forest gain and forest loses in small areas . This biasness can also be attributed to mapping regional or country wide forest cover changes without adequate in situ data for validating the change map.

The change detection mapping revealed evidence of decreasing trend of the forest cover in the study area. Deforestation rates increased from 18% (c. 1988 to 2001) to 26% (2001 – 2014). The increased in the deforestation rate from 18% or (1.3% per annum) between 1988 and 2001 change map and 26% or (2.0% per annum) in the 2001 and 2014 change map can be attributed to the influx of nomadic heard men and farmers from conflicts areas in the north East and north central Nigeria to this study area. The estimated deforestation rate of 2.0 % per annum is lower than the FAO (FAO, 2010) estimates of 3.7% per annum for Nigeria. The FAO data sources are from the statistic of national inventory which are non- existence for the country and may be unreliable. The "High Resolution Global Maps of 21st Century Forest Cover Change" more reliable for validating results from locally produced forest cover map than the FAO forest cover estimates.

Efforts at reducing deforestation rates require understanding the drivers and the pattern of deforestation. The Earth observation monitoring software was integrated to detect the deforestation sequence through the phenology studies of the forest ecosystem. Analysis of the web-based MODIS EVI revealed patterns and drivers of deforestation through the phenometrics generated from the studies. MODIS satellite became operational from the year 2000, therefore limited the applications of the EOM tool between 2000 and 2014. The phenometrics revealed the spatio-temporal pattern of the Afromontane ecosystem dynamics with the medium scale MODIS EVI. Temporal change in the time series of the monitoring period included integration of the time series components into the trend and seasonal components.

The phenology matrix derived from the web-based EOM complemented the change detection maps from the Landsat data. While the Landsat data were used for change detection analysis, the phenometrics from 2001 to 2014 clearly revealed the temporal pattern of deforestation (Gumnior and Sommer, 2012). Thus, it clearly indicated and subdivided the pattern of deforestations into years (Figure 5 and 6).

Results from this study was consistent with the object-based change map of 2001/2014 and the published high resolution digital maps by Hansen *el al* (2013). However, the nature and types of change were inferred from the Landsat based map and field observations. The accuracies of phenometrics prediction of disturbances within the study sites in an indication ofthe efficiency of the web-based EOM.

CONCLUSION

The consequences of deforestations at the local level include the loss of biological diversity (both flora and fauna), erosion, siltation, drying off of streams etc. The Afromontane forests of north eastern Nigeria is on gradual decline, with large patches of fragmented “forest islands” found in the study area. These fragmented “forest islands” lack corridors for genetic flow or interaction between species especially wild animals. Reducing the rate of biodiversity losses and averting dangerous biodiversity changes are the international goals of the United Nations Convention on Biological Diversities (UN-BD) and the Aichi Targets for 2020. The Global Earth Observation Network (GEO BON), a partner to the Aichi targets has proposed the Essential Biodiversity Variables (EBV) as a framework for achieving the Aichi 2020 goals. One of the key mandate of

EBV is the inclusion of Remote Sensing (RS)/ Earth Observation platforms for monitoring habitat loss and fragmentation.

Reference

Achard, F., Beuchle, R., Mayaux, P., Stibig, H.-J., Bodart, C., Brink, A., Simonetti, D. (2014). Determination of tropical deforestation rates and related carbon losses from 1990 to 2010. *Global Change Biology, 20*(8), 2540-2554. doi:10.1111/gcb.12605

Bergl, R. A., Oates, J. F., & Fotso, R. (2007). Distribution and protected area coverage of endemic taxa in West Africa's Biafran forests and highlands. *Biological Conservation, 134*(2), 195-208. doi:http://dx.doi.org/10.1016/j.biocon.2006.08.013

Chapman, H. M., Olson, S. M., and Trumm, D. (2004). An assessment of changes in the montane forests of Taraba State, Nigeria, over the past 30 years. *Oryx, 38*(03), 282-290.

Chapman. J. D, and Chapman.H.M. (2001). *The Forests of Taraba and Adamawa States, Nigeria-An Ecological Accounts and Species Checklist*. Christchurch, New Zealand: University of Canterbury.

Cronin, D. T., Libalah, M. B., Bergl, R. A., and Hearn, G. W. (2014). Biodiversity and Conservation of Tropical Montane Ecosystems in the Gulf of Guinea, West Africa. *Arctic, Antarctic, and Alpine Research, 46*(4), 891-904. doi:10.1657/1938-4246-46.4.891

FAO. (2010). *Global Forest Resources Assessment 2010 - Main report. FAO Forestry Paper.* Retrieved from Rome, Italy:

Foody, G. M. (2002). Status of land cover classification accuracy assessment. *Remote Sensing of Environment*, *80*(1), 185-201. doi:http://dx.doi.org/10.1016/S0034-4257(01)00295-4

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A and Townshend, J. R. G. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science, 342* (6160), 850-853. doi:10.1126/science.1244693

John, F. O., Richard, A. B., and Joshua, M. L. (2004). *Africa's Gulf of Guinea Forests: Biodiversity Patterns and Conservation Priorities*: Conservation International.

Jonas Eberle, Ralph Adewoye, C. H., and Christiane Schmullius (2015). From global observations to local information: The Earth Observation Monitor. *In Press*.

Lu, D., Li, G., and Moran, E. (2014). Current situation and needs of change detection techniques. *International Journal of Image and Data Fusion, 5*(1), 13-38. doi:10.1080/19479832.2013.868372

M. Gumnior, and Sommer., V. (2012). Multi-Scale, Multi-Temporal Vegetation Mapping and Assessment of Ecosystem Degradation at Gashaka Gumti National Park (Nigeria). *Research Journal of Environmental and Earth Sciences, 4*(4), 397-412.