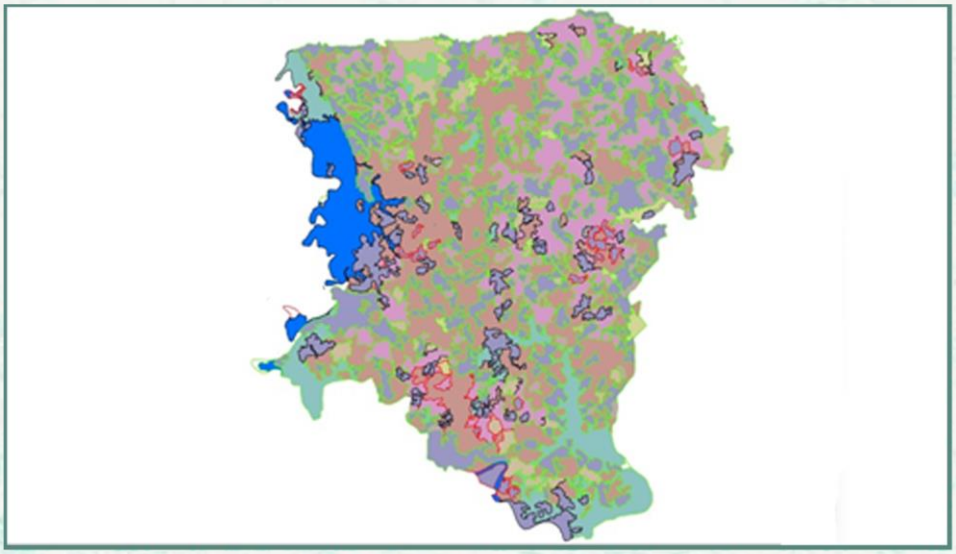
Approach for the historical assessment of forest and land cover change

A case study on Banshtail Range



Bangladesh Forest Department

December 2016

UN-REDD PROGRAMME

Food and Agriculture Organization of the United Nations

UNDP

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The UN-REDD Programme, implemented by FAO, UNDP and UNEP, has two components: (i) assisting in developing countries to prepare and implement national REDD strategies and mechanisms; (ii) supporting the development of normative solutions and standardized approaches based on sound science for a REDD instrument linked with the UNFCCC. The programme helps empower countries to manage their REDD processes and will facilitate access to financial and technical assistance tailored to the specific needs of the countries.

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EXECUTIVE SUMMARY

Ensuring sustainable management of natural resources, environmental protection, biodiversity conservation and development of sustainable livelihoods requires assessment and monitoring of forest and land cover transitions over time. In this context, FAO in collaboration with other partner organizations is supporting to several activities under UNREDD program. This report outlines methodological approaches for assessment of historical changes of land cover and forests in pilot basis.

Two approaches are identified to assess the land cover changes and implemented for Banshtali range as a case study. One of the approaches was NDVI (Normalized Difference Vegetation Index) trend analysis. MODIS 16-day composite NDVI (MOD13Q1) data for the period of 2000-2016 were collected through Google Earth Engine (GEE). Seasonal decomposition was performed using R commands to determine the trend, seasonal component and residuals during data processing. Forest and land cover changes were assessed by regression analysis.

In another approach Phenology based synthesis (PBS) classification was tested. In this approach, single date classification (SDC) was conducted using Landsat images and processed multispectral images into a discrete thematic layer of 13 classes. The PBS algorithm combined SDCs into a land cover map based on predefined frequency rules.

After successfully conducting both approaches, outcomes were presented to stakeholders for their observations to integrate both approaches into one that would be feasible and replicable at national level. Some issues for each of approaches were identified that needed to be addressed to finalize the methodology for historical assessment of land cover change at national scale.

Contents

1 Introduction

Assessment and monitoring of forest and land cover dynamics are essential for the sustainable management of natural resources, environmental protection, biodiversity conservation and developing sustainable livelihoods particularly for a populated country like Bangladesh. National forest monitoring systems, in this regard, is intended to contribute to forest and natural resource management programs through monitoring forest changes, and forest services, over time (FAO, 2013). The diminishing pattern of forest resources has put forward questions concerning the dynamics of the forest:

- Where have they changed?
- How have they changed?
- Why have they changed?
- How will they change in the future?

To account for forest variability within forest types or strata, recent works have relied on remote sensing signals to model in a continuous way the spatial and temporal variation of forest cover or forest carbon stocks (Achard et al., 2014; Asner et al., 2010; Baccini et al., 2012; Hansen et al., 2013; Saatchi et al., 2011). However, huge discrepancies have been shown both between these different maps (Mitchard et al., 2013) and between these maps and the national estimates (Achard et al., 2014). Considering such inconsistencies, a clear challenge to improve estimates of forest cover, carbon stocks and dynamics is thus to effectively combine different top-down and ground-up approaches, a recommendation made by the United Nations Framework on Climate Change Convention in the context of reducing emissions from deforestation and forest degradation (REDD+) (UNFCCC, 2009). However, the combination of field and remote sensing information requires an appropriate use of definitions and descriptors at all levels. Using the FAO Land Cover Classification System, LCCS (Di Gregorio & Jansen, 2005) to label the various identified land cover classes is suggested by Global Forest Observation Initiatives (GFOI, 2014) as a promising option ensuring homogeneity between different country-specific legends and maps.

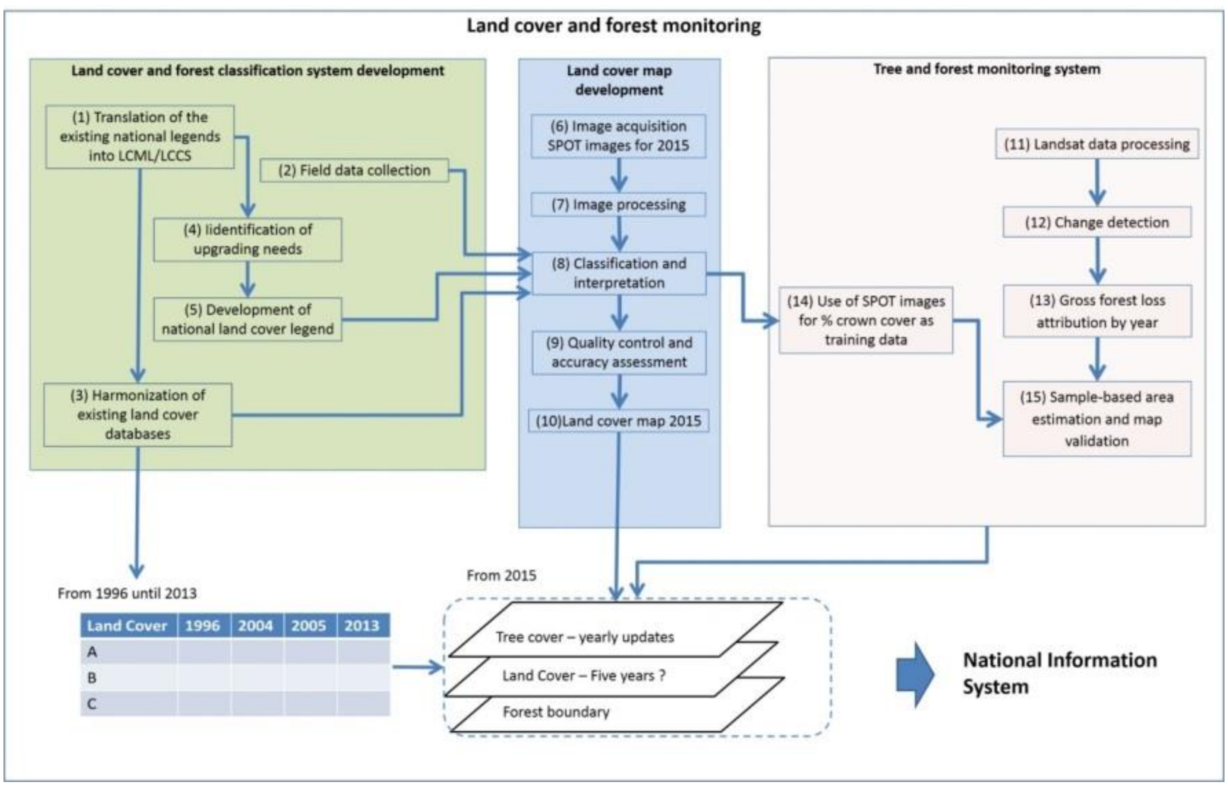
The data available on forest cover change are limited in Bangladesh. The national forest monitoring system (NFMS) of the Bangladesh Forest Department (BFD) aims at providing information about the status of forest and tree in an integrated way with land/use cover mapping activities. In response to the need for information on land cover/use and forest changes in Bangladesh, FAO in collaboration with other partner organizations, is supporting several activities, including training on LCCS (Costello & Franceschi, 2015), translation of national legends (Hadi, 2016), field data collection (Hadi & Kamal, 2016), radar data integration for land cover mapping (Vollrath, Costello, & Akhter, 2016), training on national land cover monitoring using optical satellite data (Costello, Potapov, & Dannunzio, 2016), forest boundary delineation (Chakma, Udita, & Akhter, 2016), development of national land representation system (Gregorio et al., 2016), development of national land cover legend and map (Udita, Franceschini, Jalal, & Akhter, 2016), etc.

2 Context and Objective

In February 2016, a training/workshop was held at Forest Department with the aim of transferring knowledge on tree and forest cover monitoring to national experts (in remote sensing and GIS) involved in supporting the national forest monitoring system of the Forest Department and exploring harmonization possibilities with Land Use maps produced at national level (Costello et al., 2016). At that training a national-scale mapping tool developed by University of Maryland (UMD) was presented as a leapfrog technology whereby implementing partners can rapidly map national-scale tree cover and tree cover change over a set study interval. Currently, UMD employs Landsat data from 2000 to present as the baseline input data and period of analysis. At that training/workshop a conceptual diagram of an integrated framework for land cover and forest monitoring was initiated and gradually developed later (see Figure 1). The framework shows how the different activities can be integrated and how this can contribute to the implementation of national information system. Some of the activities presented in Figure 1 are completed (e.g. field data collection for LCCS), several are ongoing (e.g. land cover map development).

Within this context, this report is a part of the process to support developing an operational methodology for the part related to the assessment of historical changes of land cover and forests in Bangladesh. The objective of this report is to present the methodology for the historical assessment and implementation of the same on a case study basis. Another objective is to identify the issues to be addressed to operationalize the methodology in a national context for Bangladesh.

Figure 1: Integrated framework for land cover and forest monitoring



3 Tentative methodology

Two approaches to assess the land cover change have been identified and implemented for Banshtail range as a cases study. These two approaches are described in below sections, followed by next steps to develop and implement an operational methodology at national scale.

3.1 Approach 1: NDVI trend analysis

For each area of interest (i.e. polygons of different land cover classes obtained from Land cover map 2015), 250 m multi-temporal MODIS Normalized Difference Vegetation Index (NDVI) 16-day composite data are used to assess the trends. Suitable protocols have to be developed to first filter the MODIS NDVI data to remove poor data values and then estimate the missing data values using an appropriate technique to provide high quality uninterrupted data to support the change detection analysis.

Linear regression relationships are generated for each AoI between time (x variable) and the vegetation index value (y variable). As a general rule, regression models with low slope values tend not to be statistically significant (i.e. no apparent trend), whereas regression models with high positive or negative slope values are more likely to be statistically significant. Maps depicting regression line slopes with associated t-values and statistical significance is derived to help visualize the significant trends spatially and facilitate the interpretation of changes. The following subsections describe the different steps of NDVI trend analysis (Approach 1).

3.1.1 Downloading data

The MODIS 16-day composite NDVI (MOD13Q1) data for the period of 2000-2016 was used. A google earth engine (GEE) script was used to download the time series data (mean value of the pixels within an AoI) for each AoI.

```
// Get the feature
var fc = ee.FeatureCollection('ft:1a2gWU17CBqROZX-Et0rA45CmgedgtEX_bWhM8kSA');

// Get the NDVI image collection
var NDVI_T = ee.ImageCollection('MODIS/MOD13Q1').filterDate('2010-09-01', '2010-12-31')
.select('NDVI');

//Map.centerObject(fc);
//Map.addLayer(fc);

// Create a time series chart.
var tempTimeSeries = ui.Chart.image.seriesByRegion(
    NDVI_T, fc, ee.Reducer.mean(), 'NDVI', 1, 'system:time_start', 'system:index')
        .setChartType('ScatterChart');

// Display.
print(tempTimeSeries);
```

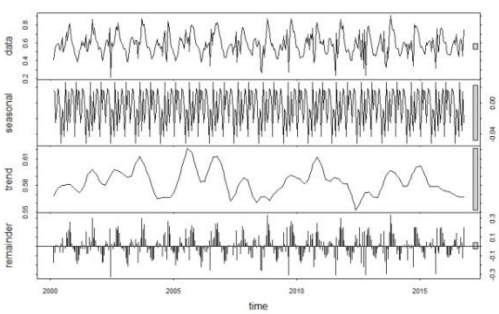
3.1.2 Data processing

There are several methods to process the data before doing time series analysis. For the case of Banshtail, seasonal decomposition is performed using R commands to determine the trend, seasonal component and residuals.

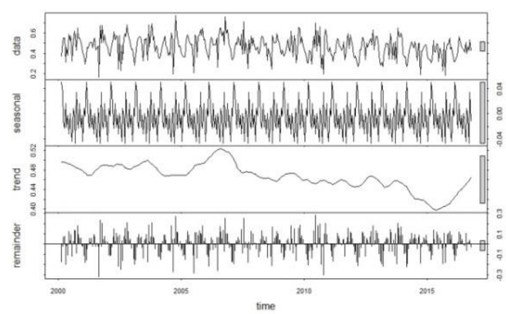
```
f = 365/16

ts_dd <- lapply(dd[1:nrow(dd),2:ncol(dd)], ts, start = 2000.13388, frequency = f)

# Seasonal decomposition
sd_dd <- lapply(ts_dd, stl, s.window="periodic")

# plot(sd_dd$X107)
```

The results for different land cover types are shown below –

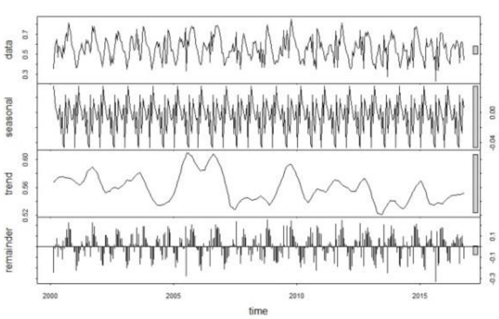
Seasonal decomposition of NDVI time series (2000-16) for different land cover class



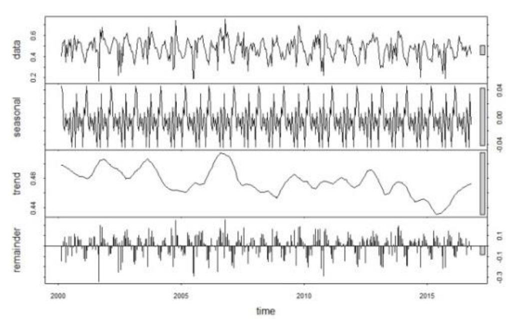
Plain Land Forest (Sal Forest) - FDp



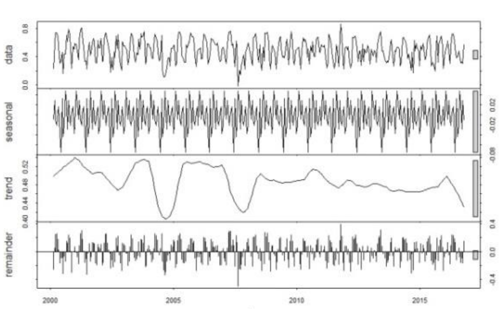
Rural Settlement - RS



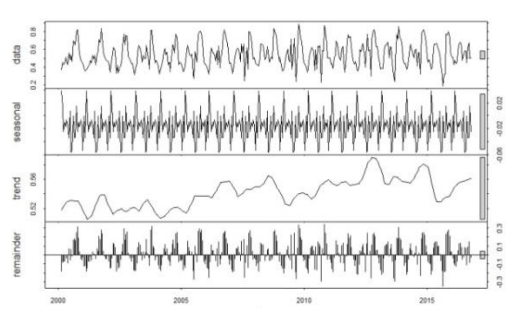
Forest Plantations - FP



Orchards and Other Plantations (Trees) - OT



Single Crop - PCs



Multiple Crop - PCm

3.1.3 Data analysis

For the assessment of change linear regression analysis is performed and significant changes (at 5% level of significance) are identified. The trend component resulted from the seasonal decomposition is used as the dependent variable and time as predictor in the linear regression analysis. The slope and p values are used to prepare the spatial distribution of change over the period of 2000-2016 (Map below).

```
# Linear model
var_list <- list()
for(i in 1:length(sd_dd)){
  var_list[i] <- paste("sd_dd$X",i, "$time.series[,2]",sep = "")
}

p_val = list()
slope = list()
for(i in 1:length(var_list)){
  var = eval(parse(text = var_list[i]))
  fit <- lm(var ~ dd$Date[1:381])
  p_val[i] = summary(fit)[[4]][[8]]
  slope[i] <- summary(fit)[[4]][[2]]
}
```

3.1.4 Results illustration

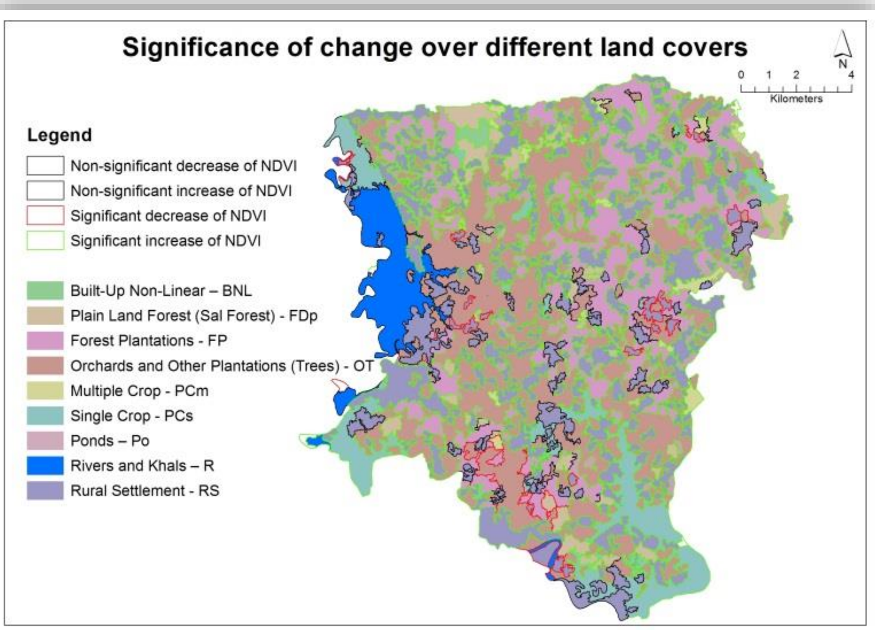


Figure 2: Significance of change over different land covers

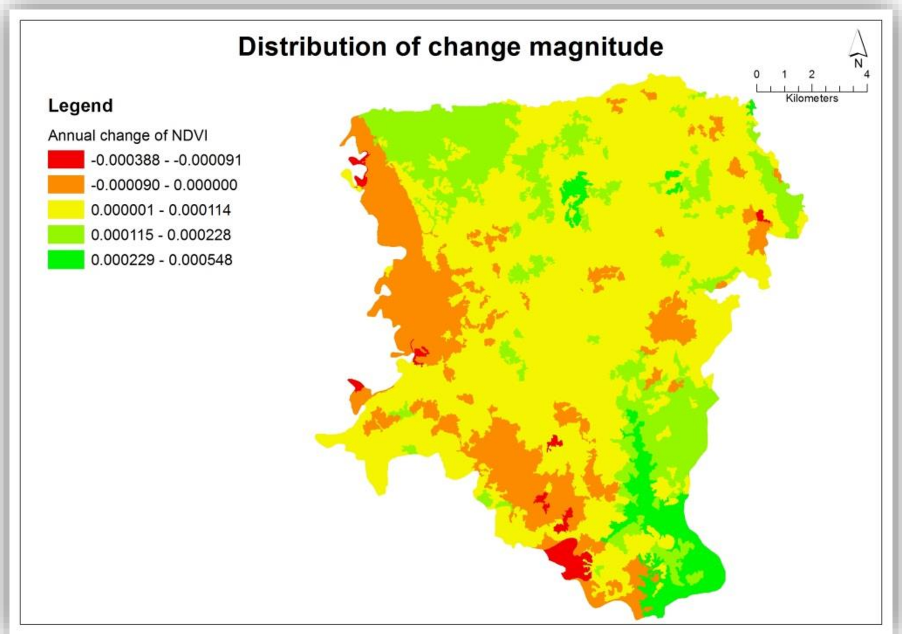


Figure 3: Distribution of change magnitude

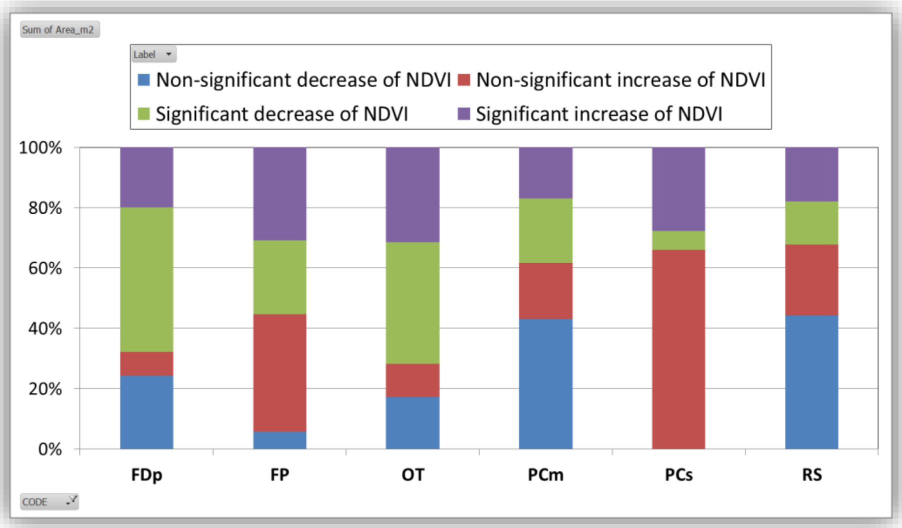


Figure 4: Change dynamics within land cover classes

3.2 Approach 2: Phenology based synthesis (PBS) classification

This approach is based on phenology based synthesis (PBS) classification (Simonetti, Simonetti, Szantoi, Lupi, & Eva, 2015).

3.2.1 Single date classification (SDC)

Landsat images are used for single date classification. The proposed pixel-based SDC algorithm (see Table 1), driven by predefined knowledge-based rules built upon spectral signature collected at global scale, processes the input multispectral image into a discrete thematic layer of 13 classes (see Table 2).

Table 1: Pseudo code of the SDC algorithm as implemented in GEE (Values are in TOA reflectance)

1st step categorization based on **NDVI**	**2nd step**
[-1,0] CAT1	if Snowshape = 1 then **SI** else if Watershape and B >= 0.078 and 0.04 <=G <=0.12 and max(SWIR1,SWIR2) <= 0.04 then **DWAT** else if R >= max(NIR,SWIR1,SWIR2) and 0.04 <=R <= 0.19 and B > 0.078 and max(SWIR1,SWIR2) < 0.04 then **SWAT** else if B > 0.94 and G > 0.94 and R > 0.94 and NIR > 0.94 then **CL** else if Wetness > 5 then **DWAT** else **SS**

[0,0.45]
CAT2
	if Snowshape = 1 then **SI** else
	if B > 0.94 and G > 0.94 and R > 0.94 and NIR > 0.94 then **CL** else
	if Other_watershape and B > 0.078 and max(SWIR1 , SWIR2) < 0.058 then **SWAT** else
	if Cloudshape or Cloudshape1 or Cloudshape2 then **CL** else
	if B > G > R and NIR > 0.254 and B > 0.165 and NDVI < 0.40) then **CL** else
	if (B > G) and B > 0.27 and G > 0.21 and ABS(R-G) <= 0.1 and NIR > 0.35 then **CL** else
	if 0.13 > B > G > R < 0.05 and (B-NIR) < -0.04 then **SV** else
	if Wetness > 5 then **DWAT** else
	if 0.13 > B > G > R < 0.05 and B-NIR < 0.04 then **SV** else
	if (ABS(NIR-G) < 0.01 or (B-NIR) < 0.01) and B>G >R and NIR>0.06 then **SS** else
	if NDVI <= 0.09 and NIR < 0.4 and G <= R <= NIR then **OLD2** else
	if NDVI <= 0.20 and NIR > 0.3 and B <= G <= R <= NIR then **OLD1** else
	if NDVI >= 0.35and B >= G and ABS(R-G) < 0.04 then **SPV** else
	if NDVI >= 0.20 and ABS(R-G) < 0.05 then **OLD** else **OLL**

[0.45,1] CAT3	if NDVI < 0.5 and NIR >= 0.15 then **SPV** else if NDVI < 0.5 and NIR < 0.15 then **SV** else if NDVI < 0.55 and B <= NIR <= 0.15 then **SV** else if NDVI < 0.55 and B <= NIR then **GRS** else if NDVI < 0.55 and B > NIR then **SV** else if NDVI < 0.65 and NIR >= 0.22 then **TCL** else if NDVI < 0.65 and NIR >= 0.165 then **TCD2** else if NDVI < 0.65 and NIR < 0.165 then **TCD1** else if NDVI < 0.78 and NIR < 0.30 then **TCD** else if NDVI >= 0.78 **SHR** else **TCL**
Where: B: blue, G: green, R: red, NIR: band 4, SWIR1: band 5; SWIR2: band 7; Watershape: ((B-G) > -0.2) >= G >= R >= NIR >= SWIR1) Other_watershape: B >= G >= R <= NIR < R*1.3 < 0.12 > SWIR1 > SWIR2 and 0.039 < NIR < G NDSI: (G - SWIR1) / (G + SWIR1) Wetness: 66.96*B + 53.55*G + 23.61*R + 16.72*NIR – 194.53*SWIR1 – 137.19*SWIR2 Brightsoil: (B < 0.27 and Growing15) or (B < 0.27 and Growing14 and SWIR1-SWIR2 > 0.038) Saturation: max(G,R,NIR)-min(G,R,NIR)/max(G,R,NIR) Snowshape: min(B,G,R,NIR) > 0.30 and NDSI > 0.65 Cloudshape: min(B,G,R)> 0.17 and max(G,B,R,NIR) > 0.30 and (NIR/R) >= 1.3) and (NIR/G) >= 1.3 and (NIR/SWIR1) >= 0.95 and SWIR1 > min(B,G.R) and NDSI < 0.65 Cloudshape1: max(B,G,R,NIR,SWIR1,SWIR2) > 0.47 and min(B,G,R,NIR) > 0.37 Cloudshape2: min(B,G,R) > 0.21 and SWIR1 > min(B,G,R) and 0.2 <= Saturation <= 0.4 and max(G,R,NIR) >= 0.35 and NDSI > -0. Growing14: B<G<R<NIR Growing15: B<G<R<NIR<SWIR1	

Table 2: Thematic classes ID, description, and the associated land cover as observed at the date of the image acquisition

Class ID	**Thematic Classes**	**Associated Land Cover**
ND	No Data	-
WAT	Water	Deep water bodies/Rivers
CL	Clouds	Clouds
SI	Snow	Snow / Ice
TCD	Tree Cover Dark	Dense Forest/Dense Shrub
TCL	Tree Cover Light	Open Forest/Shrub

SHR	Shrub	Dense Shrub
GRS	Grassland	Dense Grassland/Open Shrub
SPV	Sparse vegetation	Sparse Grassland/Sparse Shrub
OLL	Other Land Light	Light soil/rocks/sand
OLD	Other Land Dark	Dark soil/rocks/sand
SV	Shadowed Vegetation	Shadowed / Low Illuminated Vegetation
SS	Shadowed Soil	Shadowed Soil / Built Areas

3.2.2 Phenology based synthesis (PBS) classification

The PBS algorithm combines SDCs into a reliable land cover map based on predefined frequency rules determined on the basis of

1) basic assumptions for “stable” classes such as permanent water or evergreen vegetation and
2) empirical thresholds based on observations (for the Banshtail case these thresholds are at the global scale).

These rules have been coded (see Table 3) in the algorithm, avoiding any user interaction/training collection while executing the PBS.

Table 3: Frequency rules table with the percentage of observations per class

Classes	ND	CL	SI	WAT	SV	TCD	TCL	SHR	GRS	SPV	OLL	OLD	SS
No data	100	0											
Cloud + No data		100											
Permanent Water			100										
Seasonal Water				100									
Evergreen Closed Forest			>=0	>60	>=0	>=0	>=0	>=0	>=0	>=0	>=0	>=0	>=0
Evergreen Open Forest					>=0	>80	>=0	>=0					
Evergreen Shrub					>=0	>40	>=0	>=0					
Closed Deciduous Forest						>=0	>=0	>60	<10				
Open Deciduous Forest					>=0	>60			>=0	>=0	>=0	>=0	<20
Grassland						>=0	>=20	>35		>=0	<30		
Dark Rocks / Urban											>=0	>=0	>80
Dark Soil											>=0	>80	>=0
Light Soil / Sand										<20	>80	>=0	>=0

Thematic map products (SDC) reduce the data dimensionality and thus help to develop a simple and robust classification model that can perform relatively fast. The “frequency rule” analyses the thematic class of each pixel in the same geo-location from all available SDC maps looking for a defined pattern during the observed period (see Table 3). Observations such as “No data” (ND), as detected by the SDC, are excluded from the analysis, except when no other valid observations are available; in this latter case, PBS output will inherit the “ND” label accordingly.

3.2.3 Results illustration

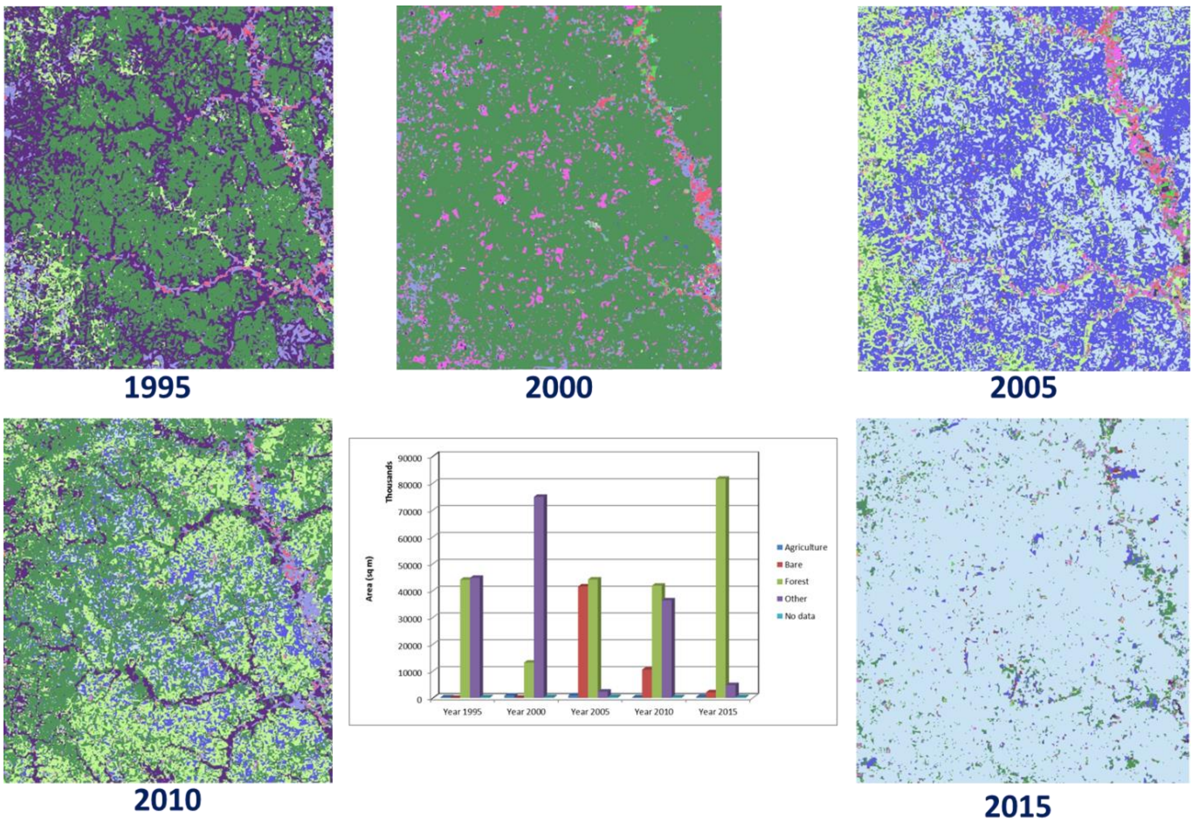


Figure 5: PBS classifications of part of Banshtai range for different years

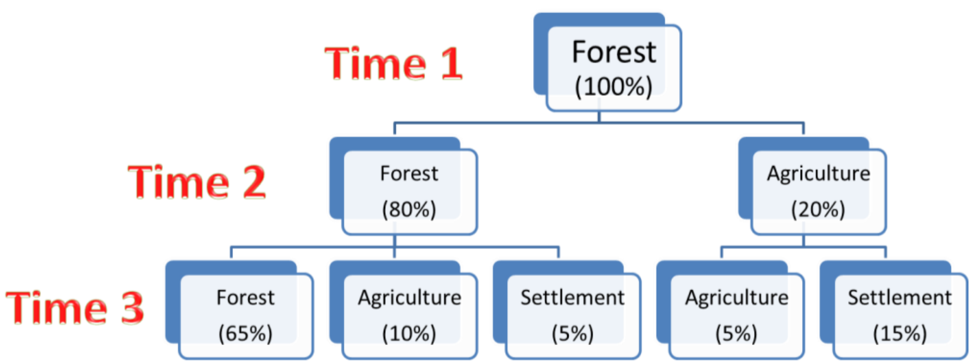


Figure 6: Sample illustration of land cover change dynamics based time series PBS classification

4 Next steps

The two approaches have been presented to stakeholders. Comments are received to integrate the two approaches and come up with a one that will be feasible to implement at national scale. Apart from the integration efforts, there are several issues (for each approach) to be addressed to finalize the methodology for historical assessment of land cover change (Table 4). In response, a letter of agreement (LoA) between FAO and CEGIS is signed and currently under implementation.

Table 4: Issues to be addressed

	Issues to be addressed
Approach 1	- Size limitation to upload kml for fusion table (upto 250 MB) - Processing time is very high - Processing volume limitation (upto 5000 elements) - Possibility to use other data (e.g., MYD13Q1, Landsat, EVI) - Possibility to use other method to download and analysis
	- Use of other filtering method (e.g., moving average, etc.)
	- Use of different time-steps (e.g., 5, 10, 15 years, etc.)
Approach 2	- Identification of national land cover classes for change detection
	- Rule set development for SDC classification
	- Development of frequency rules for PBS classification

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